Economic and environmental impacts of the energy sector in Portugal

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Abstract

In this work an hybrid input-output model is built (monetary and energy units) and the environment, economic and social impacts are calculated for the energy sector and the rest of the economy. Although some studies have provided answers towards similar problems, this specific work intends to disaggregate the energy sector into technologies and carriers to assess the mentioned impacts to the Portuguese reality from 2000 to 2010. Three different effects are studied: operational, capital investment towards capacity power installation and subsidies to technologies/tariff deficit. The Portuguese energy policy impacts are obtained combining these different effects. The overall result shows a positive impact towards economic growth, employment and GHG emissions reduction. However, in 2010 the energy policy begins to have a negative impact on employment and on gross value added (GVA), possibly forecasting an increasing negative impact on the following years.

Keywords: Input-output, hybrid model, green jobs, energy sector, subsidies

1. Introduction

1.1. Context

Energy produced from renewable sources is becoming a significant fraction of the energy mix in many countries, as the result of policies that aim to reduce the emission of green house gas (GHG) and mitigate climate change. International policies applied, as Kyoto protocol, and also at the European Union (EU) level, renewable energy and carbon mitigation policies have been guided by the European Renewable Energy Council and the European Comission, among other directives and road maps. At the national level, Portuguese policies on these matters have been guided by Roteiro Nacional do Baixo Carbono, for example. In the Portuguese case, the promotion of electricity generation from the renewable sources, RES-E, has been a priority not only due to the environmental concerns but also to increase energy security and diversify our energy supply. Of course, social and economical considerations play a fundamental role in energy policy (Philbert 2011).

In the last decade Portugal witnessed a substantial increase in the penetration rate of renewable energies, fueled by high feed-in tarrifs (FIT). As a result, over a short period of time Portugal became a leader in renewable energy use (IEA 2009). Feed-in tariffs are a part of an energy policy which includes other financial incentives (National Renewable Energy Action Plan from 2009) and ambitious targets for the development of hydro power, wind and solar and other technologies. According to the National Energy Strategy, in 2020 Portugal should reduce the energy dependency on imports to 74%, the RES-E production share should increase to 60%, and the final energy consumption should decrease by 20%, among others goals such as the creation of 100,000 new green jobs.

Although a number of challenges still remain, the renewable energy technologies development has been undisputed. This is also because in a country with natural conditions such as Portugal, rainfall (for hydropower) and wind play a main role. As a result, if measured by penetration rate of several renewables sources, the contemporary Portuguese renewable energy policy has been a great success. But at what cost?

Besides environmental impacts such as the reduction in carbon emissions, the Portuguese RES policy has also had social impacts such as the creation or destruction of employment and the increase or decrease in GDP. Although it is often claimed that the promotion of renewable energy increases energy security, mitigates climate change and promotes job creation, the latter result is still disputed (Lamberti & Silva 2012).

1.2. Literature review

Due to his work, Leontief (1936) and Leontief (1941), he was later credited with the development of this framework which granted him the Nobel Prize in Economics in 1973. The Leontief demand-driven quantity input-output model allows the quantification of the final demand stimulus in primary production factors (**?**). This model allows to identify the impacts that arise from changes in the intermediary flows between industries (and products) as a result to a variation in the final demand. It is a widely used model for its numerous applications and input-output may be used recurring to units other than monetary. In fact, Leontief continued to explore his framework regarding physical units (Leontief 1989), and many researchers such as Duchin (1992) and Cleveland (1999) have extended the original framework in the direction of areas such as industrial ecology and economics ecologic.

Energy was and still is a crucial factor on production for many industries over the world. The focus on the role of energy in the economy became a priority, specially during fossil fuel crisis and climate change in recent years (Miller & Blair 2009, pag. 400-401). The early developments were achieved by several authors and their work such as Strout (1967), Cumberland (1966), Bullard & Herendeen (1975), among others. Also, the concern and technology changes worldwide has boosted several works. Although it seems to be only a recent issue, it is not. Such studies have been guided also in the past years by authors such as Just (1974), Gowdy & Miller (1968) and Herendeen & Plant (1981). In this work, it is proposed to built and hybrid units model (both monetary and energy units). The so-called 'hybrid units" approach was first introduced by Bullard & Herendeen (1975) to address the limitations about the simplest approaches.

The development and growth of new energy technologies has encouraged several studies. Some recent studies are directed to impacts caused by the renewable energy sources sectors, mostly on employment or sometimes referred as clean jobs such as NCAER (2013), Winter & Moore (2013) and even for Portuguese case Oliveira, D.Coelho, Silva & C.H.Antunes (2013). Other works recurring to IO analysis include Markaki, Roboli, Michaelides, S.Mirasgedis & D.P.Lalas (2013), Lehr, Nitsch, Kratzat, Lutz & Edler (2007), Liang, Wang & Zhang (2010), Tarancon & Ro (2007) and lvarez (2013). Also, other studies have been published accounting the Portuguese reality. These include works such as Silva, Henriques & Coelho (2012), Proena & Aubyn (2013), Proena & Aubyn (2009), Dias & Domingos (2012) and Amorim, Martins & Silva (2010).

2. Background

2.1. Leontief model

Leontief model is defined by the following objects: $\mathbf{Z}$, $\mathbf{y}$ and $\mathbf{x}$. The $\mathbf{Z}$ matrix is known as the interindustry inputs or intermediate inputs matrix, with z_{ij} in each entry . These are the designation for the monetary values of the transaction between sectors i to each other sector j. The tecnical coefficient matrix $\mathbf{A}$ is obtain from the interindustry matrix: $\mathbf{A} = \mathbf{Z}\mathbf{x}^{-1}$. Each a_{ij} entry is viewed as a relationship between a sector's output and it's input, meaning how much of good or services from sector i do i need to produce one unit of output in sector j. The final demand $\mathbf{y}$ is the exogenous stimulus and $\mathbf{x}$ is the total output of production. The main equation for this demand-driven model is:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{L}\mathbf{y} \quad (1)$$

In this, $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is known as the Leontief inverse or total requirements matrix, in which each matrix component l_{ij} represents the total amount directly and indirectly needed of good or service i to deliver one unit of final demand of good or service j. These assumption allows us to establish a way to compute the output of each sector, as for example, the economy response to changes in the final demand stimulus $\mathbf{y}$. Therefore, this model provides the possibility to assess impacts on primary factors such as employment, GHG emissions, value added, among others.

3. Method

3.1. Impact analysis

It is intended to present more than one scenario for the historical analysis, hence every year from 2000 to 2010 will have an alternative scenario in addition to the reference one (the so-called "real case scenario"). The operational, capital investment and subsidies related the tariff deficit effects on the economic, social and environment impacts are obtained from alternative scenarios. Furthermore, each effect has different methods of obtaining the appropriate alternative scenario. The net values comparing reference to alternative scenario is obtained from the following expression:

$$\Delta\mathbf{x} = \mathbf{x}^R - \mathbf{x}^A \quad (2)$$

The way that $\mathbf{x}^A$ is obtained depends on the effect desired. These methods are explained further for each case in the section 4. Obtaining $\Delta\mathbf{x}$ from expression 6, the difference between reference and alternative scenario impacts are calculated as follows:

$$\Delta\mathbf{b} = \text{diag}(\mathbf{r})\Delta\mathbf{x} \quad (3)$$

In this case, calculating $\Delta\mathbf{b}$ allows a relative interpretation about impact $\mathbf{r}$ on both reference and alternative scenario (as a comparison result).

4. Hybrid IO model

4.1. Operational (O&M) effects

It is provided in table 1 the first extenstion of the hybrid model do assess these operational effects.

In this table figure two extra blocks are inserted where interaction between energy and economy is provided. The block $\mathbf{A}^{CA}$ contains the use of energy carriers by all of the 49 economy activities considered. The block $\mathbf{A}^{PT}$ reefers to the use of economy products by each of the 18 technologies. The first block mentioned is in energy units (toe) while the second is in monetary units (M€).

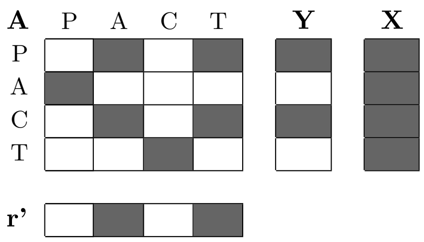

Table 1: Energy and economy interaction hybrid model.

In this, to calculate the impacts including only the basic energy and economy blocks with O&M costs, the technical coefficient matrix A is divided in two blocks: $\mathbf{A}^{R}_{ROE}$ and $\mathbf{A}^{R}_{E}$.

To assess the operational effects, O&M, each alternative scenario considers that the energy sector remains constant from the previous year to the present one, i.e., there is no technology evolution (technical coefficient matrix $\mathbf{A}_{E}$ does not change). As a result, the output variables for the reference scenario "R" and alternative "A" are given by:

$$\mathbf{x}^{R} = \mathbf{L}\mathbf{y}^{R} \tag{4}$$

$$\mathbf{x}^{A} = \mathbf{L}^{*}\mathbf{y}^{R} \tag{5}$$

In which $\mathbf{L}^{*} = (\mathbf{I} - \mathbf{A}^{*})^{-1}$ and $\mathbf{A}^{*} = [\mathbf{A}^{R}_{ROE}|\mathbf{A}^{A}_{E}]$. This technical coefficient matrix is therefore built with both the reference year t economy block, $\mathbf{A}^{R}_{ROE}$, and the $t-1$ energy block, $\mathbf{A}^{A}_{E}$ (as an alternative). Naturally, from this, the $\mathbf{A}^{R}_{ROE}$ block includes the products and industry/activities columns and $\mathbf{A}^{R}_{E}$ the carriers and technologies respective columns. It may be useful to analyze the results as differences:

$$\Delta\mathbf{x} = \mathbf{x}^{R} - \mathbf{x}^{A} = (\mathbf{L} - \mathbf{L}^{*})\mathbf{y}^{R} \tag{6}$$

The resulting $\Delta\mathbf{x}$ can be used in the expression 3 to obtain the economic, social and environmental impacts due to the energy technology mix development over the years.

4.2. Electricity cost and price difference effects

The following extension includes the households endogenous and the energy subsidies spent on electricity producing technologies. As a result, a couple of selected modifications were processed to obtain the extended hybrid model shown in table 2.

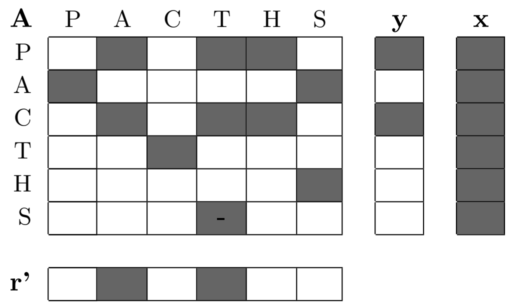

Table 2: Hybrid model extension with subsidies and endogenous households

The $\mathbf{A}^{ST}$ block considers the subsidies received by the energy technologies (electricity producers). The $\mathbf{A}^{AS}$ and $\mathbf{A}^{HS}$ blocks are the amount that is paid for subsidies either by ROE activities, A, or by households, H. Note that these 2 group of blocks must have different signs in the technological matrix to represent the different flow direction either by receiving or paying processes. Hence, to simplify, the $\mathbf{A}^{ST}$ is negative as the $\mathbf{A}^{AS}$ and $\mathbf{A}^{HS}$ remain positive elements of the full $\mathbf{A}$ matrix.

The blocks $\mathbf{A}^{PH}$ and $\mathbf{A}^{CH}$ describe the use of products and carriers by the households. These are estimated considering the fraction spent by households in subsidies. To assess the effects on subsidies and the tariff deficit the alternative scenario considers endogenous modifications. The main question here is: what would happen if the subsidies were fully reproduced in the electricity bill and no tariff deficit would occur? In other words, the cost/price difference of electricity producing is considered zero in alternative scenario. Therefore, these effects are captured on the resulting impacts.

Therefore, with the presented hybrid model, this question can be answered by stating that alternative scenario considers the blocks $\mathbf{A}^{AS}$ and $\mathbf{A}^{HS}$ to be consistent with the block $\mathbf{A}^{ST}$ (every subsidy received is really supported by consumers). Naturally $\mathbf{A}^{PH}$ and $\mathbf{A}^{CH}$ are recalculated for the alternative scenario.

To summarize, the $\Delta\mathbf{x}$ is obtained just as for the operational effects. The difference is in the alternative scenario considerations.

4.3. Capital investments effects

The following procedure considers the capital investments in the hybrid model with the block structure presented in table 3. The implemented blocks are $\mathbf{A}^{PK}$, $\mathbf{A}^{KA}$ and $\mathbf{A}^{KT}$.

A	P	A	C	T	H	S	K	**y**	**x**
P		■		■	■		■	■	■
A	■					■			■
C		■		■	■			■	■
T			■						■
H						■			■
S				-					■
K		■		■					■
r'		■		■					

Table 3: Full integrated hybrid model.

First of all the investment, K, has 5 different categories: construction, transport equipment, other machinery and equipment, cultivated assets and intangible fixed assets. Hence the block $\mathbf{A}^{PK}$ is a 49×5 matrix obtained from the gross fixed capital formation (included in the final demand as exogenous). Those values had to become endogenous according to a conversion key to disaggregate the 49 goods in those 5 categories. Obviously, just as the previous case with the endogenous households, the gross fixed capital formation is removed from the final the demand as it is already considered inside the $\mathbf{A}$ matrix. The $\mathbf{A}^{KA}$ block is simply the consumption of fixed capital distributed across the 49 activities (without counting the energy sectors: electricity and oil refining). However, the $\mathbf{A}^{KT}$ block is more subtle. It has to consider the investment expenditures related to the maintenance according to the consumption of fixed capital. The investment portion related to the installation of new capacity power has to be exogenous in order to contribute to the alternative scenario. The data manipulation to obtain this blocks in detail is explained in the following chapter.

To sum, the reference scenario is obtained simply by $\mathbf{x}^R = \mathbf{L}^R\mathbf{y}^R$ while the alternative scenario includes a different approach:

$$\mathbf{x}^A = \mathbf{L}^R\mathbf{y}^A \tag{7}$$

In this case the alternative scenario does not use the reference year final demand but a different exogenous stimulus instead, $\mathbf{y}^A$. This alternative final demand vector does not include the investment estimated to contribute to the installation of new capacity power (as it is considered only in the reference final demand). Therefore, this analysis is possible for all of the 10 years, once the variable in this alternative scenario is related to the exogenous stimulus and no previous year data is necessary. The investment effects are thus isolated from every other effects.

5. Data and assumptions

The data gathering process is usually an intense and demanding step, because obviously it is intended to find the most detailed and accurate data available. In table 4 it is possible to see the main electricity producing technologies considered for the further analysis.

Energy Technologies	
Biomass	Dedicated CHP
MUW	Incineration
Biogas	
Wind	On-shore
Hydro	Small Large
Geothermal	Binary Cycle
Solar	Photovoltaic
Thermoelectric	Fuel Oil (CCOT) Coal (PCC) Natural Gas (CCGT)

Table 4: Electricity generation technologies. Combined Heat and Power (CHP) allows heat supply as well.

Several type of data was gathered and processed: installed capacities; investment and operation and maintenence costs; direct employment; electricity bill decomposition; subsidies paid by households and activities by type of consumer (voltage level); SR and OR subsidies received; carbon emission factors for CO_2, CH_4 and N_2O (and carbon emission trading prices).

These were the technologies characterized in detail. However the total technologies considered are 18. The others are: oil refining; coal refining; petrochemical, biodiesel, electric grid and natural gas distributed. Therefore, the model characteristics are: 49 activities and products, 18 technologies and 42 carriers. In addition, processes of manipulation such as aggregations/disaggregation and other assumptions are described with detail.

6. Results

In this section the total impacts are presented. First, the overall results are displayed for each type of impact. Afterwards, the total separated impacts disaggregated only by effect, i.e, operational, capital investment and electricity cost/price differences (associated with tariff deficit) are shown.

6.1. Scenarios and structure

The most general and fundamental question that motivated this thesis work is related the evaluation of the impacts of Portuguese energy policy. Combining the considered effects, the results (in the most aggregated way possible) that provide an answer to this formulated question are presented in table 5.

Year	**GVA**[M€$_{2002}$]	**Employment** [10^3]	$\mathbf{CO_2}_{eq}$ [Mton]
2000	125.45	12.76	0.18
2001	579.04	26.06	-0.36
2002	81.80	2.37	1.85
2003	123.08	10.00	-2.76
2004	223.66	10.37	1.05
2005	395.77	19.31	0.77
2006	320.36	22.62	-1.63
2007	973.96	42.90	-1.26
2008	599.33	28.52	-0.07
2009	39.15	13.35	0.12
2010	-278.02	-0.82	-4.60

Table 5: Total impacts of the Portuguese energy policy.

The economic impacts studied are related to the GVA which is proportional to the GDP and this is a key indicator of the country whole economy condition. From observing the table, the national energy policy generated economic output until 2009. Afterwards, these policies costed 278.02 M€$_{2002}$. The social impacts follow the same behavior, generating employment mainly due to investments associated with capacity installations (as it will be clarified in the following subsections). In 2010 the total result accounts for the loss of 820 jobs. Although in 2010 the impacts start to be negative for economy and employment, the environmental impacts show that the future seems to be "greener'. In fact 6 out of 10 analyzed years show a cleaner environment, culminating in 4.60 Mton of GHG avoided emissions into the atmosphere.

6.2. Economic impacts

In table 6 the net contribution of each effect regarding the economic impacts is shown. Note that in the operational analysis (model with O&M costs) there are no results for the year 2000. This is because naturally the alternative scenario requires data from the year preceding the year to be analyzed. Therefore, 1999 data for the energy sector would be necessary, and the timeline of this study ranges from 2000 to 2010, thus truncating the results for 2010 in this case.

	Operational		**Capital**		**Cost/Price dif.**	
Year	Energy	ROE	Energy	ROE	Energy	ROE
2000	-	-	10.7	400.9	-19.8	-266.3
2001	16.9	59.5	14.9	963.8	-20.3	-455.8
2002	25.9	1.8	8.3	549.6	-21.6	-482.2
2003	-64.9	67.0	9.6	564.0	-21.1	-431.5
2004	73.7	7.2	11.6	649.4	-24.0	-494.3
2005	59.9	51.9	15.1	902.1	-28.7	-604.6
2006	-56.7	31.5	16.0	877.1	-27.7	-519.9
2007	4.2	375.0	21.1	1176.7	-27.6	-575.4
2008	108.0	-128.1	27.2	1291.4	-34.1	-665.0
2009	72.8	-59.6	17.2	938.5	-30.9	-898.8
2010	20.0	-149.4	15.4	807.0	-35.9	-935.0

Table 6: Total economic impacts, GVA, by type of effect. Monetary units in M€$_{2002}$.

Observing the table, operational results have positive or negative values depending on the energy sector technology mix development. On the other hand, capital investment impacts are, as expected, always positive, adding up the GVA. However, the fact that the subsidies payed to the electricity (and heat) producers are not fully supported by activities and households generate debt that have a negative impact on GVA.

6.3. Social impacts

In table 7 the net contribution of each effect regarding the social impacts is shown. Just as the previous subsection, operational net impacts for 2000 are not available.

	Operational		**Capital**		**Cost/Price dif.**	
Year	Energy	ROE	Energy	ROE	Energy	ROE
2000	-	-	0.07	34.79	-0.12	-21.98
2001	-0.20	2.26	0.09	45.66	-0.14	-21.61
2002	-0.40	-0.11	0.04	25.83	-0.13	-22.87
2003	-0.43	2.43	0.05	28.35	-0.11	-20.28
2004	-0.85	1.87	0.05	32.31	-0.12	-22.89
2005	-1.51	2.57	0.06	46.12	-0.14	-27.80
2006	0.51	0.65	0.06	45.41	-0.12	-23.88
2007	-1.42	14.44	0.08	54.63	-0.11	-24.72
2008	-0.60	-4.87	0.09	60.73	-0.12	-26.70
2009	0.66	-1.50	0.06	42.60	-0.12	-28.35
2010	-2.11	-6.05	0.05	36.04	-0.12	-28.63

Table 7: Total employment impacts (10^3 jobs) by type of effect

The positive or negative contributions is maintained by the same type of effects. In other words, capital investment towards capacity installation tends to generate more jobs in the ROE activities (which is comprehensive, e.g., construction, manufacture, etc). In addition, the tariff deficit contributes to a future job destruction, growing year by year representing the higher difference in what is received by the producers (subsidies) and what is really paid by the costumers.

6.4. Environment impacts

In table 8 the net contribution of each effect regarding the environmental impacts is shown.

	Operational		**Capital**		**Cost/Price dif.**	
Year	Energy	ROE	Energy	ROE	Energy	ROE
2000	-	-	0.08	0.35	-0.18	-0.08
2001	-0.73	0.05	0.11	0.48	-0.18	-0.09
2002	1.81	0.01	0.07	0.26	-0.21	-0.10
2003	-2.87	0.01	0.06	0.30	-0.16	-0.09
2004	0.89	0.03	0.08	0.35	-0.19	-0.11
2005	0.48	0.00	0.12	0.52	-0.27	-0.09
2006	-1.94	0.02	0.10	0.48	-0.22	-0.07
2007	-1.84	0.18	0.12	0.54	-0.18	-0.07
2008	-0.47	-0.04	0.14	0.57	-0.20	-0.07
2009	-0.01	-0.03	0.10	0.37	-0.21	-0.10
2010	-4.69	-0.05	0.06	0.33	-0.16	-0.09

Table 8: Total environmental impacts. Emissions of CO_{2eq} in Mton by type of effect.

For CO_{2eq} emissions, the behavior of these effects is similar as in the previous impacts discussed. For example, the operational effect shows that the energy sector has developed towards a cleaner sector and from 2008 further the reductions are even visible on the ROE. Capital investment obviously contributes to additional emissions while subsidies/tariff deficit avoids emissions (much smaller contribution).

Note that the row sum (for each year) for economic, social and environmental impacts in tables 6, 7 and 8 respectively produce the total impacts in table 5.

6.5. Disaggregation by effect

Operational (O&M) effects show that the increasing mix of renewable sources in the energy sector is not always positive regarding social and economic concerns. In fact, renewable energies do create jobs, however other jobs are destructed elsewhere (mainly fossil fuel - conventional source plants). From 2008 to 2010, the net results show job destruction on technologies and on ROE activities. Isolating the capital investment effects, the impacts are positive. This means that, investing towards the installation of new capacity power (building or upgrading plants) creates employment, enhances economic growth and generates additional CO_{2eq} emissions. The activities related to construction reveals the highest impact on job creation, as naturally expected. Industry and trade activities however show the highest impacts towards environmental concerns. When the subsidies and the tariff deficit effects are isolated, these show clearly negative impacts on the whole economy, i.e., the fact that debt is being generated prevents economic growth and destructs jobs in the future. Government and real estate related activities are the ones that reveal the most notorious negative economic impacts.

7. Conclusions

The disaggregation of the energy sector and thus the characterization of the several technologies was one of the main milestones of the work. Achieving the technological description regarding issues such as subsidies and tariffs to electricity producers, both O&M and investment costs as well their decomposition, gases emission factors and to try to able to replicate the Portuguese energy reality between 2000 and 2010 was indeed a major portion of this work (although with a lot of assumptions). Therefore, the data manipulating step associated with the gathering process revealed to be quite extensive and it is clearly worth mentioning.

Although the results obtained, as seen in the previous chapter, can provide a significant level of detail the main question is related to the general impacts of the Portuguese energy policy. Hence, the major result provides information on how this policy and the several modifications and implementations that occurred during these 10 years affected the whole economy (energy sector included). The environmental impacts are without a doubt positive, meaning that the energy policy allowed the development towards a greener future (GHG emissions are indeed reduced, specially observed in 2010). Economic and social impacts have also been positive, until 2009. From that year further, the impacts switch signs, thus having negative impacts both on employment (job destruction) and economic growth (GVA). However, note that these overall net impacts originated by the energy sector are not even on the 1% of the whole economy.

When comparing the reference to the alternative scenario where the available technology mix in the system (technology characterization in the energy sector, O&M effects) is considered the same from one year to the following, it is necessary to take in consideration the importance of several factors, such as the natural sources availability. Therefore, factors as rain Hydroelectric Index (which translates into the Productibility HydroelectricIndex, PHI) may distort the results obtained for these technologies (small and large hydro).

The national energy policy was conceived considering three different type of effects: operational, capital investment and subsidies related to the tariff deficit. The increasingly negative impacts related to the tariff deficit seem to explain the impacts sign switch in 2010, possibly forecasting a future with total negative impacts regarding employment and economic growth.

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