Title: 3Es assessment of energy efficiency scenarios: A MULTI2C application

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1. Introduction

Energy efficiency is at the heart of the European Union (EU) 2020 Strategy for smart, sustainable and inclusive growth (COM/2010/2020). The initial purpose of this work is to build an input-output (IO) model for the Centro region (C), Portugal. This model uses 2010 data and analyses the interactions between the Centro region (a NUT II located in mainland Portugal, occupying the central part of its territory) and the rest of Portugal, hereafter designated as “Rest of the Country” (RC). Next, the bi-regional Centro-Rest of the Country (C-RC) IO model is explored to assess the impacts, in both regions, resulting from energy efficiency scenarios. For this it is critical to extend the modelling framework, in order to account for energy-economy-environment interactions. Indeed, the ultimate aim of this research is to extend the assessment of the impacts resulting from energy efficiency gains to the environmental dimension.

The rest of this paper is structured as follows. Section 2 starts by presenting the structure of the multi-sector bi-regional C-RC IO model, followed by a discussion on the core aspects of its extension for the consideration of energy and environmental
issues. This section presents both the methodological choices and the data sets used for the bi-regional Portuguese empirical model. The main results of the scenarios considered are presented and discussed in Section 3. Section 4 concludes.

2. Methodology and data

The bi-regional IO model proposed in this work is an application of the MULTI2C (multi-sectoral multi-regional Coimbra model) framework. MULTI2C is a general flexible approach, developed by a group of researchers, mainly from the University of Coimbra (Portugal) that allows for the construction of multi-regional IO models for different geographic configurations and empirical applications\(^1\). The MULTI2C approach has a great level of detail concerning both the products (or groups of products) included and the industries that produce them. The bi-regional Centro-Rest of the Country IO model uses 2010 data and is focused on the Portuguese NUT II Centro region.

2.1 The structure of the bi-regional Centro-Rest of the Country IO model

The structure of the multi-sector bi-regional C-RC IO model is schematically represented in Table 1.

**Table 1 - Structure of the multi-sector bi-regional C-RC IO model**

\(^1\) As a rule, MULTI2C models are of the bi-regional kind, as the one used here, although multi-regional structures are also being considered in a experimental way. Sargento *et al.* (2013) have already adopted a similar framework, dividing Portugal in the “interior” and the “coast” parts of the country. The interior-coast dichotomy is again considered in Ramos *et al.* (2014). For an example of a tri-regional application please see Ferreira *et al.* (2014).
### Legend:

- **C** - Centro
- **RC** - Rest of the Country
- **IC\(_i,j\), i, j = C, RC** - Intermediate consumption of i’s regional products, used by j’s industries
- **HC\(_i,j\)(Lab), i, j = C, RC** - Final consumption of i’s regional products, consumed by households mainly dependent from labor income living in region j
- **OFD\(_i,j\), i, j = C, RC** - Other final demand for i’s regional products, used in region j
- **R\(_i,j\), i, j = C, RC** – Residues on the demand of products in region i
- **HI\(_i\)(Lab), i = C, RC** - Region i’s households income distributed to the households that live mainly from their labor compensations (it includes the mixed income distributed to the self-employed workers)
TPO\(i, i = C, RC\) - Total output of products produced in region i, at basic prices

\(P^{ii}, i = C, RC\) - i’s regional products, according to their production industry (generic element of the i’s supply table)

\(TIO\(i, i = C, RC\) - Region i’s total industry output, at basic prices

\(T(g)^i, i = C, RC; g = IC, HC, OFD\) - Taxes less subsidies on products, falling upon g, in region i

\(TT\) - Total taxes less subsidies on products

\(M(g)^i, i = C, RC; g = IC, HC, OFD\) - International imports destined to use g, in region i

\(TM\) - Total International Imports

\(TIC\(i, i = C, RC\) -Total intermediate consumption by industries, in region i, at purchaser’s prices

\(THC(Lab)^i, i = C, RC\) - Total region i’s consumption by households mainly dependent on labor income, at purchaser’s prices

\(THI(Lab)^i, i = C, RC\) - Total region i’s households income distributed to the households that live mainly from their labor earnings

\(OFD\(i, i = C, RC\) - Other final demand in region i, at purchaser’s process

\(TIC + TFD\) - Total intermediate and final demand, at purchaser’s prices

\(NHVA\(i, i = C, RC\) - Gross Value Added which is not directly distributed to households, in region i

\(TNHVA\) - Total Gross Value Added which is not directly distributed to households

\(S\(i, i = C, RC\) - Savings and net transfers to other institutional sectors of the households that live mainly from their labor income, in region i

\(TS\) - Total savings and net transfers to other institutional sectors of the households that live mainly from their labor income

The structure of the model in Table 1 is based on a set of characteristics and hypotheses, which leads to the classification of this modelling approach as a “closed rectangular bi-regional IO model”, using domestic flows at basic prices.

Rows corresponding to products (431 products \(\times\) 2 regions) describe their different destinations, which include: the intermediate consumption (IC) in each region (naturally, a product produced in C can be inter-regionally exported and used as
intermediate consumption in \( RC \); the final consumption of the different types of households in both regions; and other destinations in the “Other Final Demand”.

Columns corresponding to industries describe their technologies in absolute values, i.e., each product intermediate consumption in each industry, according to the origin’s region (\( C \) or \( RC \)); the intermediate inputs internationally imported (although in this case, the total inputs are not disaggregated by products); the (non-deductible) taxes less subsidies falling upon the purchased inputs (in order to assure that each industry IC is expressed at purchaser prices); the income generated in each industry and in each region, i.e., the gross value added (GVA), whether it is directly distributed to households living mainly from their labor income, or distributed to some other institutional sector (NHVA).

(i) Closed model

The model considers, both in \( C \) and \( RC \), different household’s types, according with their main source of income, namely: labor earnings, capital income, real estate income, pensions and other social transfers\(^2\).

The model is “closed” regarding only the consumption of households that live mainly from labor income (employees or self-employed workers). The income generated in each region contributes only for the consumption of households living in the same region; commuting and other periodical or seasonal migrations between \( C \) and \( RC \) (that are negligible between these regions) were not considered. Consumption of other household’s types (the non-labor income dependent ones) is considered exogenous, and therefore considered as part of the Other Final Demand.

The Other Final Demand includes the consumption of other household’s types (the non-labor income dependent ones), the consumption expenditures of general government and non-profit institutions; the investment, the consumption of non-residents in Portugal that visit both regions and, finally, other international exports of goods and services.

(ii) Regional production technologies and the electric power industry specificities

\(^2\) The technical details on the procedures used to derive the consumption structure for different household types, according to their main source of income, as well as the main methodological procedures and hypotheses used to estimate inter-regional trade, are presented in Ramos et al. (2015).
This rectangular bi-regional IO model admits that each industry has its own technology, identically to the production of all its primary or secondary products (as explained above secondary products represent only a residual value in total industry production). Moreover, in general, it is assumed that each industry has the same production technology in both regions, i.e. each input has the same weight in the intermediate consumption regardless the production place.

At the high disaggregated level we conducted our work the equal production technology assumption in both regions leads to negligible errors. But this is not the most accurate for all the cases, because it does not take into account the disparities of activities within some industries and/or regional differences. E.g., the original information provided by the Portuguese National Accounts Supply and Use Tables (INE, 2012a) considers one column vector of technologies for the electricity industry. However, the electricity power industry is composed by different activities such as production and distribution. Further, for the purposes of this research, it is particularly relevant to highlight that electricity can be generated by a wide variety of sources (renewable and non-renewable), encompassing a set of activities with different production technologies. Thus, as the regions possess different structures of electricity production and distribution, first and higher-order effects of a shock spread-out differently. The technical details on the procedures used to derive the electricity production structure for the different regions, in the Portuguese case, are briefly mentioned ahead.

We consider a division of the original electricity industry into 10 different industries. The electricity industry vector of production and intermediate consumption, for the 431 products, provided by the Portuguese National Accounts Supply and Use Tables (INE, 2012a), was taken as the primary data. Then, to disaggregate this vector by the different activities and regions, we proceed to the estimation of each activity’s total production and intermediate consumption. The data sources used to estimate such values (for 2010) were: the Portuguese National Statistical Institute (INE, 2015a, 2015b), which supplies information on total electricity production, as well as on total electricity produced by cogeneration plants; the database Quadros de Pessoal, from the Statistical Department of the Ministry of Labor and Social Solidarity (GEP-MTSS, 2011), which provides

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3 See Sargent et al. (2011) for a discussion on the (dis)advantages of rectangular input-output models. Deeper descriptions of this kind of structure can be seen in the pioneering contribution of Oosterhaven (1984) and in Miller and Blair (2009: Chapter 5).
information on the number of workers in each activity; and the reports published by companies that manage the thermoelectric power plants (EDP Produção, 2011, 2012, 2013; Turbogás/Portugen, 2011; TejoEnergia/Pegop, 2011; EEM, 2008, 2011) to estimate the electricity produced by conventional sources, as well as the energy inputs used in such production; lastly, additional data on the power plants in operation throughout the country was gathered from Pinto and Faria (2015).

The disaggregation of the electricity industry considers one industry of electricity distribution and 9 industries of electricity production according to the following sources: 1) wind; 2) geothermal; 3) hydro; 4) photovoltaic; 5) coal; 6) fuel oil; 7) natural gas; 8) diesel; 9) cogeneration. Each of these sub-industries has its own production technology. The total electricity sector, that merges the 10 sub-industries, produces two distinct products (in each region): produced electricity and distributed electricity.

A second exception we looked at was the case of the refined petroleum industry, where a single column technical vector would hide the regional disparity of its input structure. Accordingly, we assume diverse production technologies for the different regions, based on Regional Accounts’ information (INE, 2012b), and taking into account our knowledge of the actual location of the refineries in Portugal.

Summing up, this model considers that the 431 products included in the MULT12C approach are produced by the 134 industries in the two different regions or are being internationally imported, i.e., part of these products are produced outside the Portuguese territory. It is important to mention that the portion of Table 1 inside the bold border - a square matrix of dimension 1134 (431 products, 134 industries and 2 extra rows relating to household income, for each one of the two regions) - is the core of the IO framework implemented. Indeed, one departs from this core to compute the inverse matrix, which comprises a set of multipliers that measure impacts of exogenous final demand changes on products and industries production. Also, this inverse matrix includes the impacts on the income of the households that live mainly from their labor earnings, caused by those shocks. Noteworthy, it is also possible to assume exogenous shocks on such income and compute their effects on products/industries outputs. Further, exogenous final demand shocks can be formulated either in terms of products, or by redirecting them to industries.
2.2 The extension of the IO modelling framework to account for energy-economy-environment interactions

Extensions of the application of I-O models to the examination of interactions between economic activity and environmental issues date back to the late 1960s and early 1970s\(^4\). These studies can be considered as benchmarks of an approach that would be further developed by some energy analysts during the 1970s and the 1980s, extending the use of I-O analysis to consider energy-economy interactions\(^5\). But, over time, the modelling approaches have become more and more complex, to allow, for example, the consideration of global environmental issues such as the greenhouse effect and the ‘resulting’ climate change problem. This has led to the development of numerous theoretical models and empirical studies that combine both perspectives, making it hard to distinguish between environment and energy models, and therefore it become usual to talk about ‘energy-economy-environment’ models (Faucheaux and Levarlet, 1999).

Thus, it is not surprising that also our I-O models have been extended to deal with both environmental and energy issues. Therefore, we apply the I-O technique to the structural analysis of energy requirements and CO\(_2\) emissions by economies, relating this pollution with the use of fossil fuels. For this, it is used a satellite account approach regarding the primary energy consumption by industry, from which the changes in oil, natural gas and coal consumption are evaluated in terms of tons of oil equivalent (toe) and then estimated the corresponding CO\(_2\) emissions. The methodology used follows Cruz (2009) and Cruz and Barata (2012).

Generally, the data required for the estimation of primary energy consumption is not directly available in the appropriate, or consistent, form. This subsection shortly presents the assumptions and estimations required in order to correlate the different data sources, with the final aim of obtaining suitable estimations of the physical quantities of the three primary fuels (natural gas, crude and waste oil and coal) used by each sector in the the Portuguese regions.

The estimation of primary fuels consumption (in physical terms) by each of the 134 industries considered in the IO tables made available in INE (2012a), takes advantage of

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\(^4\) Detailed surveys of environmental I-O models, with many references, including theoretical extensions and applications are provided, for example, by: Barata (2009), Cruz et al. (2005), Hawdon and Pearson (1995), Miller and Blair (2009).

\(^5\) A detailed survey of energy I-O analysis is presented, e.g., by Miller and Blair (2009).
the 2010 “Energy Balance” statistics (DGEG, 2013). According to the “Energy Balance”, the Portuguese economy total consumption of coal, (crude) oil and natural gas was of 1654580, 11920903 and 4506817 tons of oil equivalent (toe), respectively. These values were considered as credible totals of domestic energy use (by type of fuel) and it was from these that was derived the (physical) quantity of each primary fuel used by each of the 134 sectors.

Then, from these national figures, several procedures where applied to estimate the regional consumption of the primary fuels (in physical terms). As a rule, the regionalization process was developed considering the structure of intermediate consumption for each sector that consumes each of the primary fuels in each of the NUTIII regions. But some additional steps and further information was required to accomplish the task.

Firstly, the estimation of coal consumption per region, for “351011 - electricity produced by coal” takes into account information on the quantities of coal consumption by the thermoelectric power plants located in the different regions. This information is available on the reports published by the companies that manage these power plants (EDP Produção, 2011; TejoEnergia/Pegop, 2011).

Secondly, the crude and waste oil consumption was regionalized assuming the production technologies of the refined petroleum industry. The Portuguese National Accounts (INE, 2012a) original information contained a single column vector of technologies for the refined petroleum industry. But this would hide the regional disparity of its input structure because, e.g., while some regions (Lisbon) require more goods and services related to the management activities, others consume mainly inputs directly related to the production process of refined products. Accordingly, we assume diverse production technologies for the different regions, based on Regional Accounts’ information (regarding compensations, gross value added and production of the different regions) (INE, 2012b), and taking into account our knowledge of the actual location of the refineries in Portugal. These new production technologies give us information on the crude consumption regional structure.

Finally, it was considered more specific information regarding natural gas consumption by two particular sectors: “351017 - Electricity produced by natural gas” and “2303 – Manufacture of cement, lime and plaster”. The natural gas regional consumption by the electricity sector was estimated taking into account the information on the quantity of
this fuel consumption by the thermoelectric power plants (available on the reports published by companies that manage these power plants: EDP Produção, 2013; Turbogás/Portugen, 2011; TejoEnergia/Pegop, 2011). On the other hand, the natural gas regional consumption by the cement sector was estimated taking into account the reports published by the companies that manage the cement plants (Secil, 2010a, 2010b, 2010c).

3. Results and Discussion

The bi-regional C-RC IO model is here considered to assess the socio-economic and environmental impacts resulting from energy efficiency gains for the Centro and the Rest of the Country regions. More specifically, we assume a hypothetical 1% reduction in electricity consumption by all industries and household types, in both regions. Additionally, we analyze two possibilities:

- **i)** this energy efficiency gain originates a proportional output decrease in all types of electricity production (*Scenario A*), or
- **ii)** total electricity generation from renewables and co-generation remains the same as before the energy efficiency gain, i.e., the decrease in electricity generation caused by the 1% reduction in electricity (intermediate and final) consumption is fully accommodated through a reduction in electricity generation by thermal power plants (*Scenario B*).

The amounts saved by all industries are assumed to be “redistributed” with the following destinations: i) 1/3 is reallocated to GFCF; ii) 1/3 is distributed as a salary increase to the households living mainly from labor earnings; and iii) 1/3 is retained by the companies or distributed to other institutional sectors (e.g., general government, financial institutions), whose expenditure is not assumed as endogenous to the model, not generating an automatic increase on final demand. Further, the amounts retained by the different household types are assumed to be reallocated in the consumption of all the remaining products, according to their specific (regional) structures of consumption, in both scenarios.

Table 2 summarizes the estimated impacts (in C and RC) associated with the two energy efficiency scenarios in terms of the environmental dimension, namely the fossil fuel (coal, crude oil and natural gas) requirements, as well as the corresponding CO₂ emissions embodied, to satisfy the total industries output.
Table 2 – Environmental Impacts of the Energy Efficiency Scenarios

<table>
<thead>
<tr>
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<th>Scenario A</th>
<th></th>
<th>Scenario B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Centro Region</td>
<td>Rest of the Country</td>
<td>Centro Region</td>
<td>Rest of the Country</td>
</tr>
<tr>
<td>Absolute (%</td>
<td>Absolute</td>
<td>Absolute (%)</td>
<td>Absolute</td>
<td>Absolute (%)</td>
</tr>
<tr>
<td>Coal (toe)</td>
<td>-3895</td>
<td>-1.06</td>
<td>-14351</td>
<td>-1.11</td>
</tr>
<tr>
<td>Crude oil (toe)</td>
<td>0</td>
<td>0.00</td>
<td>-189</td>
<td>0.00</td>
</tr>
<tr>
<td>Natural Gas (toe)</td>
<td>-9584</td>
<td>-0.83</td>
<td>-20011</td>
<td>-0.60</td>
</tr>
<tr>
<td>CO₂ emissions</td>
<td>-37107</td>
<td>-0.91</td>
<td>-101464</td>
<td>-0.23</td>
</tr>
<tr>
<td>(tons of CO₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>equivalents)</td>
<td></td>
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</tbody>
</table>

Considering primary energy requirements, Table 2 shows the estimated decrease of coal, crude oil and natural gas required to satisfy the total industries output, for both regions. Further, the savings in fossil fuels’ needs is higher in the Scenario B case, as the electricity production reduction is concentrated in the non-renewable sources.

Extending the assessment of the energy requirements to the estimation of CO₂ emissions embodied in the industries production, the estimates reveal that there is a reduction of 0.91% in Centro region and 0.23% in the Rest of the Country, in the Scenario A case. Again, as happens in the case of primary requirements, the reduction of CO₂ emissions is ‘naturally’ greater in the Scenario B case.

Next, Table 3 presents the total effects in the main socio-economic aggregates (inC and RC) associated with the two energy efficiency scenarios considered.
Table 3 – Socio-Economic Impacts of the Energy Efficiency Scenarios

<table>
<thead>
<tr>
<th></th>
<th>Scenario A</th>
<th></th>
<th>Scenario B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Centro Region</td>
<td>Rest of the Country</td>
<td>Centro Region</td>
<td>Rest of the Country</td>
</tr>
<tr>
<td></td>
<td>Absolute</td>
<td>Relative (%)</td>
<td>Absolute</td>
<td>Relative (%)</td>
</tr>
<tr>
<td>GDP (10^6 €)</td>
<td>-6.5</td>
<td>-0.020</td>
<td>-8.5</td>
<td>-0.006</td>
</tr>
<tr>
<td>Imports (10^6 €)</td>
<td>-0.4</td>
<td>-0.003</td>
<td>-5.8</td>
<td>-0.011</td>
</tr>
<tr>
<td>Household’s income (10^6 €)</td>
<td>1.0</td>
<td>0.005</td>
<td>7.0</td>
<td>0.008</td>
</tr>
<tr>
<td>Employment (FTE)</td>
<td>189</td>
<td>0.018</td>
<td>637</td>
<td>0.017</td>
</tr>
</tbody>
</table>

The results of this modelling exercise indicate that energy efficiency gains would generate a net contractionary effect both on the Portuguese economy and in the Centro region main economic indicators, following the electricity production decrease, which is not fully compensated by the second-order expansionary effects. Indeed, e.g. for Scenario A, concerning Centro region’s GDP, the model foresees a reduction of approximately 6.5 million €, which is deepened by a decrease of approximately 8.5 million € in the Rest of the Country’s GDP; in relative terms, this small overall negative impact is more important in C than in RC (−0.020% against −0.006%). Further, the results indicate that the net contractionary effect is lower (both in C and RC) in Scenario B than in Scenario A. The reason is that the global GDP decrease in Scenario B is mitigated by the imports effect, as the electricity produced by thermal sources requires mainly imported inputs. Accordingly, in Scenario A the effect is mainly felt in the national economy, while in Scenario B it leaks into a large extent to the rest of the world.

Table 3 results also reveal a decrease in total (fuels and other products) imports, more expressive in RC than in C, and clearly better in the Scenario B case, as would be expectable taking into account the nonexistence of fossil fuel resources in Portugal. The estimated reductions in imports corresponds to the net effect of a reduction in the
consumption/imports of fossil fuels (as a consequence of the energy efficiency gain considered), together with increasing imports of some other products (mainly as a consequence of the increase in the intermediate and final consumption/imports of other products resulting from the assumed energy expenditure’s savings).

The estimations also show that this energy efficiency gain would increase employment and the income of households living mainly from labor earnings. This happens mainly because the total amount saved in electricity expenditures is to be applied in the consumption and other uses of products produced by relatively high labor-intensive industries, comparing with the electrical sector.

Overall, Scenario B reveals better effects than Scenario A, for both regions, mainly as a result of the circumstance that it implies the (relative) changeover from products imported (fossil fuels) to others domestically produced (renewables) in electricity generation. This is true, as expected, for the energy and environmental indicators, but also in the form of a small contractionary effect on GDP. However, as for household’s income and employment Scenario B yields slightly not as good results. This happens mainly because electricity production activities by renewable sources are less labor-intensive than those corresponding to electricity production activities by thermal sources.

4. Conclusions

This work proposes a closed rectangular bi-regional IO model, at domestic flows and basic prices, comprising beyond the Centro region also the Rest of Portugal. Recognizing that electricity production and distribution encompasses a set of activities with different technologies, either by main energy source or by region, we consider the division of the original electricity industry into one industry of “electricity distribution” and 9 industries of “electricity production” according to the following sources: 1) wind; 2) geothermal; 3) hydro; 4) photovoltaic; 5) coal; 6) fuel oil; 7) natural gas; 8) diesel; and 9) cogeneration. Summing up, this modelling framework has a great level of detail concerning both the products and the industries that produce them, namely 431 products, produced by the 134 industries in the two different regions or being internationally imported.

Next, we use this modelling approach to assess the socio-economic and environmental impacts, in the Centro region and nationwide, resulting from energy efficiency gains.
More specifically, we assume a hypothetical 1% reduction in electricity consumption by all industries and household types, in both regions. Additionally we analyze two possibilities/scenarios, i.e., the corresponding electricity production reduction is (a) proportionally accommodated among all sources of electricity generation or (b) concentrated in the non-renewable sources. The amounts saved by industries are partially “reallocated” in gross fixed capital formation (GFCF) and distributed as a salary increase to the households living mainly from labor earnings, and the households’ savings are distributed by increasing consumption of the remaining products, in both scenarios.

Our results reveal that the energy efficiency gains considered in both scenarios are expected to generate a negative impact in terms of GDP, but positive effects in terms of the reduction of imports and increasing employment and household’s income. Regarding primary energy consumption and CO₂ emissions, it is estimated a positive impact of the energy efficiency gains in the environment. Thus, this modeling exercise illustrates that the economic negative effects are being counterweighed by social and environmental improvements.

Finally, it is possible to claim that it was shown that the definition of the economic structure in terms of sectors, and the relative simplicity of (multi-regional) IO systematic connection of a set of economic variables, adequately combined with satellite accounts on energy and CO₂ flows, provides a modelling framework that clearly illustrates the interdependencies not only between sectors, but also between socio-economic, energy and environmental issues. Therefore, it becomes clear that energy-economy-environment IO analysis can be crucially helpful in supporting policy making within a perspective of sustainable development, and particularly relevant in the discussion, supported by ex-ante assessments, on the possible trade-offs among several 2020 EU targets.

Acknowledgments

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Energy for Sustainability Initiative
Since 2006

University of Coimbra
Since 1290
Summary

University of Coimbra

EfS Initiative
   Purpose and objectives
   Areas
   Activities

To come

www.uc.pt/envefs/
The University of Coimbra

The oldest and one of the most prestigious universities of the Portuguese speaking world (in the UNESCO World Heritage List)

Around 25 000 students 
(3500 foreign) 
1500 faculty and 
1000 workers 
10 schools

Graduation and post-graduation in a broad spectrum of areas
Engineering, Arts and Humanities, Law, Medicine, Basic Sciences, Earth and Life Sciences, Psychology and Education, Economics, Management, Sports, Pharmaceutical Studies

One doctoral school - Interdisciplinary Research Institute

www.uc.pt/en/efs/
Purpose

of the Energy for Sustainability (EfS) Initiative:

Promote cross-fertilization in research, knowledge transfer and educational activities within the broad area of

energy resources for sustainable development
EfS Initiative started in 2007[6]

Objective:

Provide interdisciplinary answers to challenges in the study, design, operation and regulation of systems for:

- Production,
- Distribution and
- Use of energy

In four vectors:

- Research and development
- Education and training
- Knowledge and technology transfer
- Institutional activities ("sustainable campus")
EfS broad areas of activity and competence

Energy Systems and Policies

Sustainable Built Environment

Sustainable Mobility

www.uc.pt/envfs/
Energy Systems and Policies

- Study of energy-environment-economy interactions
- Electricity markets and regulation
- Energy planning and market transformation
- Multi-objective optimization and multi-criteria analysis
- Renewable energy production, Geothermal electricity, Bioenergy
Sustainable Built Environment

- Modeling of physical systems, such as buildings and equipment, or urban areas, for energy efficiency and comfort assessment
- Experimental analysis of comfort and physical features of buildings
- Spatial Decision Support Systems development, namely for urban planning
Sustainable mobility

- Transport network planning models and methods
- New urban transportation modes and services planning
- Traffic engineering design
Overview

A multidisciplinary set of units

- Researchers affiliations:

  **14 R&D Units**
  - All the Engineering Departments (5)
  - Departments of Architecture, Life Sciences and Earth Sciences
  - Faculty of Economics (economics, management, sociology)
  - Faculty of Psychology and Educational Sciences
  - Faculty of Law
Educational activities and plans

3 levels of educational, multidisciplinary programs, a common approach

- **PhD** (Sustainable Energy Systems - UC, UP, UL, MIT) under MIT-Portugal,
- **MSc** (Energy for Sustainability)
- Specialisation Studies, Life Long Learning

Two main areas

- Energy Systems and Policy (ESP)
- Buildings and Urban Environment (BUE)

.(plus “Indoor Climate and Comfort” at Msc and LLL level)

Currently, 45 PhD and MSc students (around 30 grants annually provided to students to attend international conferences)
Institutional relation with industry

External [companies] Advisory Board
- 26 companies (energy, construction, equipment)
- 2 associations of companies
- 1 environmentalist NGO
- The national energy agency
- The energy regulator

One annual meeting
With the students, one poster contest
With the faculty (assessment, counselling, discussing the future)
Fostering interdisciplinary R&D
What is EfS?

A group of 14 R&D Units
An agora for more than PhD 100 researchers of many scientific fields
A framework for interdisciplinary R&D projects
A PhD programme on Sustainable Energy Systems (MIT-P)
A MSc programme on Energy for Sustainability
A platform for university-industry relations
A framework for scientific international cooperation
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A suggestion...


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The use of assessment methodologies is becoming increasingly important in the decision making process under very different environments. There are increasing concerns about making the best possible use of the limited available resources. There is also an increasing will of justifying the decisions in a sound way. This is even more important when considering public spending, public scrutiny and governance accountability. The use of recognized assessment techniques is actually mandatory in many situations, considering environmental, social, economic and sustainability concerns.

This book gathers contributions from several authors, advancing the state-of-the-art and presenting examples of applications of assessment methodologies in energy, mobility and other real world applications.

www.uc.pt/erfes/
Energy-Economy-Environment assessment of energy efficiency scenarios:

a MULTI2C application

Luís CRUZ, Pedro RAMOS, Eduardo BARATA, André PARREIRAL, João FERREIRA
Outline

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2 – METHODOLOGY AND DATA
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   2.4. THE EXTENSION OF THE IO MODELLING FRAMEWORK TO ACCOUNT FOR ENERGY-ECONOMY ENVIRONMENT INTERACTIONS

3 – RESULTS AND DISCUSSION

4 – CONCLUSIONS
1. **Introduction: (General) Motivation**

**Challenge:**
- to fine tune environmental sustainability with economic growth and welfare
  - (by decoupling resources use and environmental degradation from the growth of the economy)

**Threat:**
- the continuous growing demand for energy and resources - to sustain human needs and economic growth
  - and corresponding consequences on climate change
1. (Specific) Motivation and Aims

- EU 2020 Climate and Energy targets
  - Energy Efficiency Plan (COM/2011/0109)
  - Energy Efficiency Directive (2012/27/EU) \[ \{ 20\% \uparrow \text{primary energy use} \]  

- R&D Project (CENTRO-07-0224-FEDER-002004) focused in the Centro region (C), Portugal.
  - EMSURE
    - Energy and Mobility for Sustainable Regions

- Initial purposes:
  - To build an IO model to analyze the interactions between the Centro region (a NUT II located in mainland Portugal, occupying the central part of its territory) and the rest of Portugal (hereafter designated as “Rest of the Country” (RC)).
  - To implement this bi-regional Centro - Rest of the Country (C-R) IO model to assess the impacts, in both regions, resulting from energy efficiency scenarios.
1. Motivation and Aims

- It is assumed a hypothetical 1% in electricity consumption by all industries and household types, in both regions.

- Scenario A: What if this energy efficiency gain originates a proportional output decrease in all types of electricity production.
  - But the EU 2020 Strategy goes beyond and, e.g., seeks to reduce the dependence on imported fossil fuels and to increase the share of renewable endogenous resources.

- Scenario B: What if the decrease in electricity generation caused by the 1% reduction in electricity (intermediate and final) consumption is fully accommodated through a reduction in electricity generation by thermal power plants (i.e., total electricity generation from renewables and co-generation remains the same as before the energy efficiency gain).
1. Motivation and Aims

- The 3rd of the EU 2020 Strategy’s key objectives is the 20% \textbf{U} in EU GHG emissions from 1990 levels.
  - Accordingly, there is the need to account for energy-economy-environment interactions.

- The \textit{ultimate aim} of this research is to extend the IO assessment of the impacts resulting from energy efficiency gains to the environmental dimension (both at the level of energy resources use and related GHG emissions).
  - Thus, contributing to raising the level of general awareness of the complex interactions between energy, economic and environmental issues.
2. Methodology and data

2.1 National Accounts and Input-Output Analysis

The Circular Flow Model of Income and Output

Credits to: J. Guilhaume and C. Azzoni
### Input-Output Matrix (Interregional flows)

#### Considering 2 regions (s and t)

<table>
<thead>
<tr>
<th>Setor i reg s</th>
<th>Setor i reg t</th>
<th>MATRIZES DE FLUXOS INTERSETORIAIS (produtos x setores)</th>
<th>Final Demand s</th>
<th>Final demand t</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRODUÇÃO NACIONAL</td>
<td></td>
<td></td>
<td>Exports, Household Consumption,...</td>
<td>Exports, Household Consumption,...</td>
</tr>
<tr>
<td>IMPORTAÇÕES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IIL - IMPOSTOS INDIRECTOS LÍQUIDOS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONSUMO INTERMEDIÁRIO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REMUNERAÇÕES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EOB - EXCEDENTE OPERACIONAL BRUTO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VA - VALOR ADICIONADO custo de fatores</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outros impostos / subsídios sobre a produção</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VA - VALOR ADICIONADO preços básicos</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PT - PRODUÇÃO TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMPREGO (PESSOAL OCUPADO)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Credits to: J. Guilhoto and C. Azzeni
Final Demand Impact Analysis

It is possible to assess economic, social and environmental impacts of changes in final demand, using techniques based on the I-O Matrix.

Credits to: J. Guilhoto and C. Azzoni
2.2 The MULTI2C Approach

- In Portugal there are no regional IO models provided by official institutions, neither regional models that make use of survey methods regionalizing national tables.

- The MULTI2C is a general flexible approach, developed (since 2010) by a group of researchers, mainly from the University of Coimbra (Portugal), that allows the construction of regional Input-Output (IO) tables for different geographic configurations and empirical applications.

- MULTI2C uses non-survey methods to regionalize national IO tables and takes advantage from a very detailed set of information provided by the Portuguese National and Regional Accounts, combining it with several other detailed statistical sources (e.g.: Population Census, Households Expenditure Survey, Agricultural Census, National Forest Survey).
The MULTI2C Approach: \textit{IO bi-regional models}

- MULTI2C is a database comprising IO frames to all the 30
  Portuguese NUTS III regions, which may be combined and
  merged in several different ways, conferring great geographic
  flexibility ⇒ we are able to build an IO model for any
  Portuguese region or group of regions:

  - Our main approach consists in grouping the NUTS III into two
    regions (that exhaust the country – e.g.: Centro Region-Rest of the
    Country; Coast-Interior), settling a consistent estimation for
    interregional trade for these merged big regions.

  - We are also using the method to build up \textit{tri-regional} models, in two
    steps. Firstly, splitting the country into “region A” (\textit{e.g.} the Great
    Lisbon Metropolitan Area) and the “rest of the country”. Then, region
    A is split into A$_1$ (Great Lisbon) and A$_2$ (Peninsula de Setubal), such
    that A$_1$ and A$_2$ exhaust A.
The MULTI2C Approach: *Different household types*

- The most recent versions (for 2010) **disaggregate households consumption by five types of households, according to their main source of income:**
  - labor (employees and own-account workers),
  - real estate rents (landlords),
  - capital income,
  - pensions,
  - other social transfers.

  - This relies on the assumption that **household types have different marginal propensities to consume and different consumption structures.**

  ⇒ they are in the middle way to become *Social Accounting Matrices.*
The MULTI2C Approach: IO closed models

- **Closed** as for the final consumption of households living mainly from labor income (this household’s consumption is deemed to be endogenous, depending on labor income) - i.e., labor income endogenously influences consumption.

  - The income generated in each region contributes only for the consumption of households living in the same region (commuting and other periodical or seasonal migrations between C and RC that are negligible between these regions) were not considered.

  - Consumption of **other household’s types** is considered exogenous, i.e., their consumption expenditures are independent of the generation of productive income, and therefore considered as part of the Other Final Demand.

- We are developing models (specially those focusing on the commuting flows) that also take as endogenous landlords’ income and final consumption.
The MULTI2C Approach: 
*IO rectangular models, domestic flows at basic prices*

- Of the **rectangular** type (*industry-technology assumption*, with a format inspired in the National Accounts Supply and Use tables).

- Although inspired in the National Accounts Supply and Use tables, our models work at **basic prices** and **domestic flows** (the consumption within the Use matrices comprises only domestically produced products).
  - Only domestic consumption can be regionalized by region of production.
  - Taxes on products are national flows by its nature, therefore not regionalizable.

- Sectorial disaggregation (in each region): 431 **products** that may be produced, as primary or secondary products, *by 134 industries*.
  - We have sound information on the main primary products, by region, produced by each industry.
  - Secondary production is estimated at regional level by *ad-hoc* assumptions.
### Structure of the Centro-Rest of the Country MULTI2C model

<table>
<thead>
<tr>
<th>Products + Endogenous Households living mainly from labor income (EHLab)</th>
<th>134 Industries + Endogenous Households living mainly from labor income (EHLab)</th>
<th>Other Final Demand</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre (C)</td>
<td>Rest of the Country (RC)</td>
<td>Centre (C)</td>
<td>Rest of the Country (RC)</td>
</tr>
<tr>
<td>431 Products + EHLab</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rest of the Country (RC)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>134 Industries + EHLab</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Centre (C)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rest of the Country (RC)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- **Centro (C)**
- **Rest of the Country (RC)**
- **Total**

### Notes
- Taxes less subsidies on products, falling upon intermediate consumption or final demand
- International Imports destined to intermediate consumption or final demand
- Total Intermediate Consumption / Final Demand, at purchasers’ prices
- Gross Value Added which is not directly distributed to households
- Savings and net transfers to other institutional sectors of households living mainly from labor income

### Table Entries
- \( T(C) \) for Centre (C)
- \( T(R) \) for Rest of the Country (RC)
- \( T(O) \) for Other Final Demand
- \( T(T) \) for Total

### Additional Table Information
- \( M(O) \) for Other Final Demand
- \( M(T) \) for Total
- \( T(NHVA) \) for Net Intermediates added which is not directly distributed to households
- \( T(S) \) for Savings and net transfers to other institutional sectors of households living mainly from labor income

### Formulas
- \( T(C) = T(R) = T(O) = T(T) \)
- \( T(NHVA) = T(S) \)
Table's Legend

C - Region C; RC - Rest of the Country
1IC\(i,j = A, RC\) - Intermediate consumption of i's regional products, used by j's industries.
HC\(i,\text{(Lab)}\)\(i,j = C, RC\) - Final consumption of i's regional products, consumed by households mainly dependent from labour income living in j.
OFD\(i,j = C, RC\) - Other final demand for i's regional products, used in region j.
HI\(i,\text{(Lab)}\)\(i,j = C, RC\) - Households income generated by the industries located in region j, distributed to households living mainly from their labour compensations, residing in region i.

TPO\(i = C, RC\) - Total output of products produced in region i, at basic prices.
P\(i = C, RC\) - i's regional products, according to the producing industry (generic element of the supply table).
TIO\(i = C, RC\) - region i's total industry output, at basic prices.
T (g)\(i = C, RC; g = IC, HC, OFD\) - Taxes less subsidies on products, falling upon g, in region i.
TT - Total Taxes less subsidies on products.
M(g)\(i = C, RC; g = IC, HC, OFD\) - International Imports destined to use g, in region i.
TM - Total International Imports.
TIC\(i = C, RC\) - Total intermediate consumption by industries, in region i, at purchasers' prices.
THC\(i = A, RC\) - Region i's consumption by households mainly dependent on labour income, at purchaser's prices.

OFD\(i = C, RC\) - Other final demand in region i, at purchasers' prices.
TIC + TFD - Total Intermediate and Final demand, at purchasers' prices.
NHVA\(i = C, RC\) - Gross Value Added which is not directly distributed to households, in region i.
TNHVA - Total Gross Value Added which is not directly distributed to households.
S\(i,\text{(Lab)}\)\(i = C, RC\) - Savings and net transfers to other institutional sectors of the households that live mainly from their labour income, in region i.

TS - Total savings and net transfers to other institutional sectors of the households that live mainly from their labour income.
2.3 The electric power industry specificities

The Portuguese National Accounts (our primary source) consider only 125 industries. The 134 industries in our model result from an “expansion” of the electrical sector, that was split into:

- one industry of electricity distribution
- nine industries of electricity production, according to the following sources:
  - wind;
  - geothermal;
  - hydro;
  - photovoltaic;
  - coal;
  - fuel oil;
  - natural gas;
  - diesel;
  - cogeneration

The total electricity sector, that merges the 10 sub-industries, produces two distinct products: produced electricity and distributed electricity.

Each of the sub-industries has its own production technology. The ancillary activities, as the management of the whole system and of the main corporations, are imputed to the different technologies.
This split of the electrical sector into 10 sub-industries is a novelty of this version of the IO model (Centro - Rest of the Country).

We could not assume equal production technology, in the two regions, for the electricity industry as a whole, when in fact the production sources are very distinct.
2.4 The extension of the IO modelling framework to account for energy-economy-environment interactions

- The energy efficiency scenario analysis is focused on the impacts of a technological change in production (rather than of a final demand shock) ⇒ it is considered as more appropriate to attribute the energy requirements and the CO₂ emissions generated by an economy to total industry output (TIO) (rather than to total final demand for G&S, as happens more often).
The total (primary) energy requirements to satisfy the production (total output) of a given economy (given by the 3-vector \( \mathbf{f} \)) can be obtained from:

\[ \mathbf{f} = \mathbf{C} \cdot \mathbf{TIO} \]

- where: \( \mathbf{C} \) is a \((3 \times (n+1))\) matrix, whose \( n \) generic element \( (c_{ij}) \) represents the (physical) quantity of fuel \( f \) used by industry \( i \) per unit of total output (in tons of oil equivalent - toe/million EUR) and one additional element \( (c_{ni}) \), representing the (physical) quantity of fuel \( f \) used by households living mainly from labor income per unit of their total income received) (i.e. the 'energy intensities'), in each region, and

- \( \mathbf{TIO} \) the vector of Total Industry Outputs (and \( \mathbf{THI} \) the total income received by (endogenous) households living mainly from labor income), in each region.

\( \mathbf{CO}_2 \) emissions (derived from fuel combustion) are estimated applying conversion factors from primary energy to \( \mathbf{CO}_2 \) (IPCC, 2006), arranged in a vector of \( \mathbf{CO}_2 \) emission per unit (toe) of fuel burnt (vector \( \mathbf{e} \)):

\[ \mathbf{c} = \mathbf{e} \cdot \mathbf{C} \cdot \mathbf{TIO} \]

- where the elements of the row-vector \( (\mathbf{e} \cdot \mathbf{C}) \) represent the quantity of \( \mathbf{CO}_2 \) generated by each industry per unit of total output and by endogenous households per unit of total income, located in each region (in tons of \( \mathbf{CO}_2 \)/million EUR), generally designated as '\( \mathbf{CO}_2 \) intensities'.


### Structure of the (energy-environment) extended C-RC MULTI2C model

<table>
<thead>
<tr>
<th>431 Products</th>
<th>134 Industries</th>
<th>Other Final Demand</th>
<th>GDP Emission</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centro (C)</td>
<td>Centro (C)</td>
<td>Centro (C)</td>
<td>Centro (C)</td>
<td>Centro (C)</td>
</tr>
<tr>
<td>Rest of the Country (RC)</td>
<td>Rest of the Country (RC)</td>
<td>Rest of the Country (RC)</td>
<td>Rest of the Country (RC)</td>
<td>Rest of the Country (RC)</td>
</tr>
<tr>
<td>EC</td>
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<td>EC</td>
<td>EC</td>
<td>EC</td>
</tr>
<tr>
<td>EC (Lab)</td>
<td>EC (Lab)</td>
<td>EC (Lab)</td>
<td>EC (Lab)</td>
<td>EC (Lab)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RC</td>
<td>RC</td>
<td>RC</td>
<td>RC</td>
<td>RC</td>
</tr>
<tr>
<td>OFD</td>
<td>OFD</td>
<td>OFD</td>
<td>OFD</td>
<td>OFD</td>
</tr>
<tr>
<td>OFD (Lab)</td>
<td>OFD (Lab)</td>
<td>OFD (Lab)</td>
<td>OFD (Lab)</td>
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<tr>
<td>TPO</td>
<td>TPO</td>
<td>TPO</td>
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<td>TPO</td>
</tr>
<tr>
<td>TPO (Lab)</td>
<td>TPO (Lab)</td>
<td>TPO (Lab)</td>
<td>TPO (Lab)</td>
<td>TPO (Lab)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Additional Notes
- 431 Products: Endogenous Households living mainly from labor income (EHlab).
- 134 Industries: Endogenous Households living mainly from labor income (EHlab).
- Other Final Demand: GDP Emission.
- Total: GDP Emission.
3. Results and discussion

- The bi-regional Centro - Rest of the Country IO model was used to assess the socio-economic and environmental impacts resulting from energy efficiency gains.

- **Assumption: 1% in electricity consumption** by all industries and household types, in both regions. The amounts saved:
  - by industries are partially "relocated" in gross fixed capital formation and distributed as a salary increase to the households living mainly from labor earnings.
  - by households are distributed by increasing consumption of the remaining products according to their specific (regional) consumption structures.

  - **Scenario A: What if** the corresponding electricity production reduction is proportionally accommodated among all sources of electricity generation.

  - **Scenario B: What if** the corresponding reduction in electricity generation is concentrated in the non-renewable sources.
3. Results and discussion

<table>
<thead>
<tr>
<th></th>
<th>Scenario A</th>
<th></th>
<th>Scenario B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Centro</td>
<td>Rest of the Country</td>
<td>Centro Region</td>
<td>Rest of the Country</td>
</tr>
<tr>
<td></td>
<td>Absolute</td>
<td>Relative (%)</td>
<td>Absolute</td>
<td>Relative (%)</td>
</tr>
<tr>
<td>Coal (toe)</td>
<td>-3895</td>
<td>-1.06</td>
<td>-14351</td>
<td>-1.11</td>
</tr>
<tr>
<td>Crude oil (toe)</td>
<td>0</td>
<td>0.00</td>
<td>-189</td>
<td>0.00</td>
</tr>
<tr>
<td>Natural Gas (toe)</td>
<td>-9584</td>
<td>-0.83</td>
<td>-20011</td>
<td>-0.60</td>
</tr>
<tr>
<td>CO₂ emissions (tons of CO₂ equivalents)</td>
<td>-37107</td>
<td>-0.91</td>
<td>-101464</td>
<td>-0.23</td>
</tr>
</tbody>
</table>

- Primary energy requirements to satisfy the total industries output, for both regions.
- CO₂ emissions embodied in the industries production, considerably more important in C than in RC (Scenario A: 0.91% | 0.23%; Scenario B: 2.3% | 0.61%).
- The savings in fossil fuels’ needs and the emissions reduction are ("naturally") greater in Scenario B, as in this case (is assumed that) the electricity production reduction is concentrated in the non-renewable sources.
3. Results and discussion

<table>
<thead>
<tr>
<th>Scenario</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GDP (10^6 €)</strong></td>
<td>-6.5</td>
<td>-8.5</td>
</tr>
<tr>
<td><strong>Imports (10^6 €)</strong></td>
<td>-0.4</td>
<td>-5.8</td>
</tr>
<tr>
<td><strong>Household’s income (10^4 €)</strong></td>
<td>1.0</td>
<td>7.0</td>
</tr>
<tr>
<td><strong>Employment (FTE)</strong></td>
<td>189</td>
<td>637</td>
</tr>
</tbody>
</table>

- A (very small) net contractionary effect, patent in their GDP (following the reduction on electricity production).
  - Both in scenarios A and B, more important in C than in RC.
  - Both in C and RC, lower in Scenario B than in A.
  - This impact is so mild because:
    - the amounts saved on electricity demand are (re)distributed to other uses (GFCF; other households consumptions)
    - the indirect effects resulting from the decrease in electricity production leak to the rest of the world economy (through the lessen of international imports).
### 3. Results and discussion

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Centro</th>
<th>Rest of the Country</th>
<th>Centro Region</th>
<th>Rest of the Country</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absolute</td>
<td>Relative (%)</td>
<td>Absolute</td>
<td>Relative (%)</td>
</tr>
<tr>
<td>GDP (10^6 €)</td>
<td>-6.5</td>
<td>-0.020</td>
<td>-8.5</td>
<td>-0.006</td>
</tr>
<tr>
<td>Imports (10^6 €)</td>
<td>-0.4</td>
<td>-0.003</td>
<td>-5.8</td>
<td>-0.011</td>
</tr>
<tr>
<td>Household’s income (10^4 €)</td>
<td>1.0</td>
<td>0.005</td>
<td>7.0</td>
<td>0.008</td>
</tr>
<tr>
<td>Employment (FTE)</td>
<td>189</td>
<td>0.018</td>
<td>637</td>
<td>0.017</td>
</tr>
</tbody>
</table>

- A (slight) positive effect on employment and household’s income.
- Overall, Scenario B reveals better effects (for the energy and environmental indicators, as well as for GDP and Imports), for both regions, mainly as a result of the circumstance that it implies the (relative) changeover from imported products (fossil fuels) to others domestically produced (renewables) in electricity generation.
- However, Scenario B yields slightly not as good results regarding household’s income and employment. This happens mainly because electricity production activities by renewable sources are less labor-intensive than those corresponding to electricity production activities by thermal sources.
4. Conclusions

- The energy efficiency gains considered in both scenarios are expected to generate:
  - a (very small) negative impact in terms of GDP, but (also very small) positive effects in terms of imports reduction and increasing employment and household’s income.
  - a positive impact in primary energy consumption and CO₂ emissions.

- Our appraisal is that economic negative impacts are compensated by the social and environmental improvements.

- It is possible to claim that energy-economy-environment IO analysis provides a modelling framework that can be crucially helpful in supporting policy making within a perspective of sustainable development, and particularly relevant in the discussion, supported by ex-ante assessments, on the possible trade-offs among several of the 2020 EU targets (namely in what concerns to: the 20% energy savings, the share of 20% final energy consumption from renewable sources, and the 20% reduction in GHG emissions).
4. Conclusions – Work in progress

- Energy efficiency $\Rightarrow$ The “rebound effect”:
  - Increase in the demand for energy in production and/or consumption, as an unintended side-effect of efficiency improvements – namely because the effective/implicit price of energy (the cost of energy to produce one unit of output) falls.

  In general, three main types of energy rebound effect are recognized:
  - Direct – where increased efficiency of the energy product/service lowers the cost of consumption and, as a result, more consumption of this product/service occurs.
  - Indirect – where savings accrued due to efficiency cost reductions in energy product/service, cause increased demand and/or expenditure for other goods and services.
  - Economy wide – where more efficient energy production and use drives productivity resulting in more growth and energy consumption at a macroeconomic level.

  Further research is required to “decompose” the estimated changes in order to assess the contributes from each specific type of the rebound effect.
Thank you for your attention.

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