Use of a bottom-up technology model for the integration of environment & energy policies – case-study of the Portuguese electricity system

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1 Abstract

This paper suggests a methodology for the assessment of synergies and antagonisms between energy and environment policy instruments based on the use of TIMES, a bottom-up technology model developed by the International Energy Agency. A framework for qualitative assessment of interactions between instruments is presented and illustrated for the current energy and environment instruments in place. The paper then illustrates how technology bottom-up models can be used to support energy and environment policy integration, by drafting how the TIMES_PT model will be used to provide quantitative data on losses in effectiveness and cost-efficiency due to antagonisms between existing policy instruments. This quantitative information can then be a precious help to guide policy makers in re-designing more coordinated and effective energy and environment policy instruments.

2 Introduction

It is widely acknowledged that the disarticulation of energy and environment policy instruments generates costs and inefficiencies that stretch already limited government budgets and hamper the efficiency and effectiveness of all policy instruments in place (Briassoulis, 2004; Greening and Bernow, 2004; RIVM et al., 2001; EU Commission COM(2004) 394 final). Accordingly, policy makers are taking efforts to integrate environment and energy policy goals. The 1998 European Council in Cardiff formulated an initiative aiming to more effectively integrate environmental aspects into sector policy making, following the articles 2 and 6 of the Amsterdam Treaty of the European Union (EU). In 2001 the Council adopted environmental integration strategies in the energy area, among other (EU Commission SEC (2001)502, 2001).

However, the initiatives developed so far reflect an incrementalist attitude which mostly results in the addition of environmental goals to sector policies, without actual integration of the instruments and procedures (Briassoulis, 2004). Therefore, it is not surprising that little has actually been achieved (Coffey & Dom, 2004; EEB, 2003; Constantinescu and Janssen, 2003; EU Commission SEC(2001)502, 2001). It is necessary to move from vague statements on the integration of equally vague broad policy goals, to a more concrete integration at the level of the policy instruments, where the conflicts between different objectives are more acutely felt.

The authors defend that a quantitative bottom-up approach that considers the quantifiable effects of implemented policy instruments is essential to support successful policy integration. Each policy instrument has a certain effectiveness and cost-effectiveness, which is sometimes affected, positively or negatively, by other instruments in place. These interactions between the effects of different instruments can be synergetic or antagonistic. The authors defend that it is very useful to quantify, even if only approximately, such losses or gains on effectiveness and subsequent impact in costs for the society. This information can then be used to better assess antagonisms between policy instruments, to set priorities for their integration, and to test more integrated policy designs.

Nonetheless, to quantify interactions between policy instruments is not a simple task mainly because there lacks of information. Although detailed analysis of individual effects of some energy and environment policies (Menanteau 2003) has been done, as well as efforts to study the collateral effects of environmental policy instruments (RIVM, 2001), there is still lack of systematic evaluation practices of individual policy instruments' effectiveness (EEA, 2001, Vehma, 2003), and of methodologies for integrated policy analysis.

In this paper, the authors present a methodology that instead of analysing one instrument at a time considers groups of instruments and thus, their interactions. For this, TIMES, a bottom-up technology model is used for the quantification of synergies and antagonisms between energy and environment policy instruments. Economy-energy-environment models, such as Markal, RAINS and GEM-E3 have been widely used for the analysis of policy effects and to support decision-making (van Harmelen et al., 2002; Greening, 2004). However, these models have not yet been used to assess the effects of policy instruments in an integrated way, and particularly to quantify the costs and benefits of such interactions.

3 Framework for qualitative assessment of interactions between energy and environmental policy instruments

Presently there is a large number of energy and environmental policy instruments in place which overlap with each other in as much as they share policy targets. The same stakeholders along the electricity systems are targeted by many different policy instruments each aiming to steer their behaviour in a particular direction (Midttun & Koefod, 2003). In most cases the steering effects of the policy instruments are affected by the other instruments in place, i.e. the policy instruments have co-effects. These co-effects or interactions occur not only within the same policy field, but also between instruments of different policy fields.

For example, climate change policies implemented by reducing energy use, or by shifting from coal to gas, contribute to the effectiveness of acidification and air quality policies since they reduce acidifying, tropospheric ozone, chemicals and primary particulate matter emissions. On the other hand, emission limit values to air might conflict with emission limit values to water due to relocation of pollutants from air to water (or waste) following the implementation of end-of-pipe technology in chimneys. CO_2 charges for emissions reduction are counteracted by the on-budget aids to subsidising oil and coal infrastructures, or subsidies to renewable electricity generation are counteracted by the restrictions of hydropower for water conservation purposes.

3.1 Overview of energy and environment policy instruments in place

Naturally, the more policy instruments in place, the more the potential for overlaps, leading to more interactions that might significantly reduce overall cost-effectiveness. Currently a total of 26 different generic types of energy and environmental instruments are or will be in place along electricity systems, creating a quite full picture (Figure 1). The figure presents the electricity system as considered for the purpose of this paper. The supply and demand sides are identified together with some of the energy and environment policy instruments in place or soon to be implemented. Each policy instrument is shown linked to the stakeholder(s) that it directly targets. Therefore, indirect effects over other stakeholders are not represented as this would make the picture even more complex.

For the characterisation of the instruments, as presented in Figure 1 the following aspects are considered relevant, since they give information on different levels of interaction between the instruments:

1. **Objective** of the instrument, which refers to the explicit objective of the instrument as stated in the documents that formulate it. This is usually not the same as the broader policy goal that led to the development of the instrument.
2. **Mechanism** of instrument used to steer behaviour (Command-and-control (CAC); economic/market-based and moral suasion and voluntary initiatives[1]).
3. **Target stakeholder(s)**, i.e. those whose behaviour the policy instruments primarily aims to steer, such as primary energy suppliers; electricity generators; transmitters; distributors & retail suppliers; appliances manufacturers and distributors; several types of consumers (household, services, industry), among other.
4. **Action according to the DPSIR framework**, as developed by the European Environmental Agency from the OECD Pressure-State-Response model. According to the adaptation made by RIVM et al. (2001), policy instruments can be part of macro-economic policy or sector specific when designed to reduce or eliminate the underlying causes of the problems, such as market failures[2] (acting at the level of the Driving forces); or be source-oriented (act at the level of the Pressures), effect-oriented (act at the level of the State of the environment) or curative (acting at the level of the Impacts).

Besides these aspects, the characterisation of instruments also considers the instrument's **place of intervention in the electricity system** (extraction of primary energy sources; electricity generation; electricity transmission; electricity distribution and end-use consumption, or at a more broad scale, supply or demand of electricity).

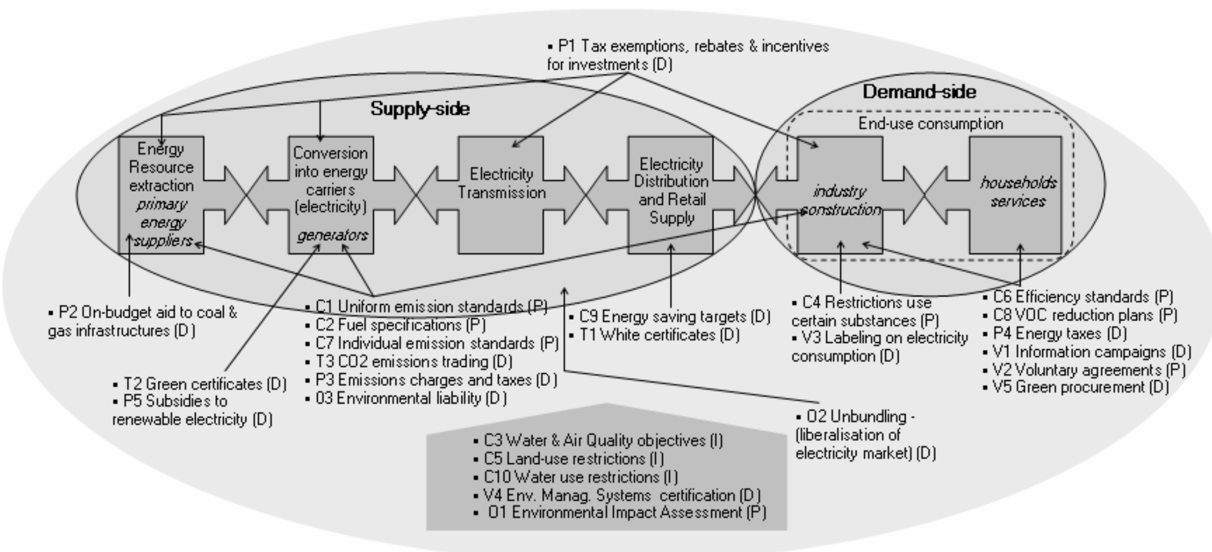

Figure 1 – Electricity system and some energy and environmental policy instruments in place. *Each instrument is identified with a letter and a number. C – Command-and-Control; T – Tradable permits; P – price;*

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[1] This category includes a very broad range of instruments, from negotiated environmental agreements, self-auditing and voluntary disclosure, voluntary programmes and other education/information measures to enhance awareness.

[2] Other underlying causes besides market failure are missing markets, information gaps, policy inconsistency and implementation failure (RIVM, *et al.*, 2001).

V – moral suasion & voluntary and O – Other. The letter in between brackets indicates the type of action according to the DPSIR framework.

The instruments here depicted do not result from an exhaustive review and other specific policy instruments for waste management, transport, noise and accidents are not represented here. These 26 instruments are quite varied regarding mechanisms used and targeted stakeholders. Whereas most policy instruments target a specific stakeholder or groups of stakeholders, there are three environmental instruments (quality objectives, land and water use restrictions) that do not directly target any of the represented stakeholders and three instruments that are of a more transversal nature and directly affect all players (environmental impact assessment, environmental management systems and unbundling within the liberalisation of electricity market).

3.2 Qualitative assessment of interactions

The question to be answered when assessing interactions (synergies or antagonisms) between two or more policy instruments is to what extent and how their steering effects affect each other. To understand this, the objectives of the instruments, its mechanisms and the targeted stakeholders have to be looked upon, as follows:

1. A **screening** of the objectives of the different policy instruments is made to assess to what point these are overlapping (i.e. to what extent they steer related behaviour of same stakeholders).
2. The **objectives** of the different instruments are analysed to identify if they are complementary or antagonistic.
3. Their respective **mechanisms** are analysed to understand how well the instruments are coordinated. This can be done in simply two levels: a) no-coordination **-** the instruments do not acknowledge the existence of other or b) some coordination in the instruments (expressed as derogations or alterations in scope, among other).
4. Divergences in behaviour steered in same **stakeholders** are assessed.

Table 1 exemplifies the application of the above mentioned approach to a few of the characterised instruments. The interactions for each pair of instruments are assessed by determining if their objectives are complementary (+) or antagonistic (-); if there is (+) or not (0) coordination between its mechanisms and if the steering effects of the instruments are complementary (+) or antagonistic (-).

Table 1 – Assessment of interactions between energy and environmental policy instruments

Policy instrument	C7 IPPC	T3 CO_2 trade	P5 Refits	C6 Eff. Targets	P1 Tax exemptions	P2 On budget aid
C7 Individual emission standards IPPC		++ objectives + mechanisms + effect	+ objectives + mechanisms + effect	+ objectives + mechanism 0 effect	- objectives 0 mechanism - effect	- objectives 0 mechanism - effect
T3 CO_2 emission trading			+ objectives 0 mechanisms + effect	+ objectives 0 mechanisms + effect	- objectives 0 mechanisms - effect	- objectives 0 mechanisms - effect
P5 Subsidies to renewable electricity REFITS				+ objectives 0 mechanisms 0 effect	+ objectives 0 mechanisms - effect	- objectives 0 mechanisms - effect
C6 Efficiency Targets					+ objectives 0 mechanisms - effect	+ objectives 0 mechanisms 0 effect
P1 Tax exemptions on fossil fuels						+ objectives + mechanisms + effect
P2 On-budget aid to coal & gas industry						

For example, both emission standards within IPPC and the CO_2 emissions trading have emission reduction as an objective (++). IPPC permits should not consider CO_2 emissions of the plants within the scope of the CO_2 emission trading Directive, showing some coordination of the two instruments (+). Finally, both instruments steer stakeholders towards emission reduction. CO_2 emissions trading and energy efficiency targets applicable to industry have complementary (but not the same) objectives (+). However, the CO_2 emissions trading Directive does not establish a link with existing energy efficiency legislation (-). Coordination of the mechanisms of the two instruments might or not occur depending if the different national allocation plans adopt benchmarking as one of the allocation criteria. Nonetheless, the steering effects of the two different instruments lead to reduced energy consumption. On the contrary, the steering effects of tax exemptions on fossil fuels are likely to counteract the incentives to save energy (-) although both instruments (P1 and C6) contribute to the objective of promoting the security of energy supply (+).

By performing such a generic assessment to the characterised policy instruments in place it is possible to systematically identify the interactions between them. This is an essential first step in the quantification of its impact in cost-effectiveness of the instruments in place. With this knowledge, three policy instruments were selected for a first attempt of quantification using a bottom-up technology model.

4 Use of the TIMES_PT model for the quantification of interactions between policy instruments

4.1 Brief overview of the TIMES model

TIMES[3] is a linear optimisation bottom-up technology model generator developed by ETSAP (Energy Technology Systems Analysis Programme) of the International Energy Agency. The generic TIMES

[3] Acronym for The Integrated MARKAL-EFOM system. TIMES is the successor of two older ETSAP bottom-up energy models: Markal - MARKet Allocation Model and EFOM - Energy Flow Optimisation Model, developed in the 80's.

structure can be adapted for each user to simulate a particular energy system, which may be local, national or multi regional. TIMES is widely used to evaluate the impact of energy and environment policies (e.g. building codes, energy or emission taxes, investment subsidies, emission intensity standards and regulations), and to perform technological assessments.

A TIMES model requires the specification of the following inputs: the *end-use energy services demands* (e.g. residential lighting or machine drive requirements in industry), the *characteristics of the existing energy related technologies*, as well as of available *future technologies* (e.g. efficiency, stock, availability, investment costs, operation and maintenance costs, discount rate), and the *present and future sources of primary energy supply*, and their potentials. The model then finds the combination of technologies that satisfy the demand for energy services at minimum system cost. For this, TIMES simultaneously decides on equipment investment and operation, primary energy supply and energy trade (Loulou, Remne, Kanudia, Lehtila and Goldstein, 2005).

In TIMES, technologies and fuels are explicitly represented for the different economic sectors. The model[4] implemented by the authors representing the Portuguese energy system (TIMES_PT) considers the following sectors: primary energy supply, electricity generation, industry, residential, commercial, agriculture and transport.

The high level of detail representing energy-related technologies allows accurate modeling of the effects of policy instruments. Thus TIMES models, as TIMES_PT, are a valuable tool to evaluate the impact of energy and environment policies and to perform technological assessments, thus supporting decision-making.

This paper proposes to bring bottom-up technology models use one step further by illustrating how they can be used in energy and environment policy integration. The TIMES_PT model is used to provide quantitative data on losses in effectiveness and cost-efficiency due to antagonisms between existing policy instruments. This quantitative information can then be a precious help to guide policy makers in re-designing more coordinated and effective energy and environment policy instruments.

4.2 Quantification of antagonism and synergies between energy and environment policy instruments using TIMES_PT

The qualitative framework for assessing interactions between instruments is very useful for organizing thoughts and to identify which instruments are top priorities for the quantitative analysis using the TIMES_PT model, as described in this section. The objective now is to estimate in euros and in tonnes of CO_2e the interactions between the screened policy instruments, in order to i) identify most relevant antagonisms between policy instruments; ii) test alternative instruments' design to ensure better integration of energy and environment policy objectives.

To do so, the effects of the implementation of policy instruments reported in literature are transformed into technology changes (e.g. alterations in stock, costs, emission factors) into TIMES_PT, reflecting the impact of the policy instruments to be analysed (Figure 2). This is followed by simulations of the implementation of different combinations of policy instruments. The analysis of the different optimum

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[4] The implementation of the TIMES model for Portugal has been undertaken within the international research project NEEDS – New Energy Externalities Developments for Sustainability (www.needs-project.org). The NEEDS research team is responsible for the model structure and new technologies databases. The authors are responsible for the base-year information, for the validation of technologies information, and for calibration and validation of the national model.

solutions achieved by the model in the different situations, e.g. the different CO_2 emissions and total costs allow a quantification of the synergies and antagonisms between instruments.

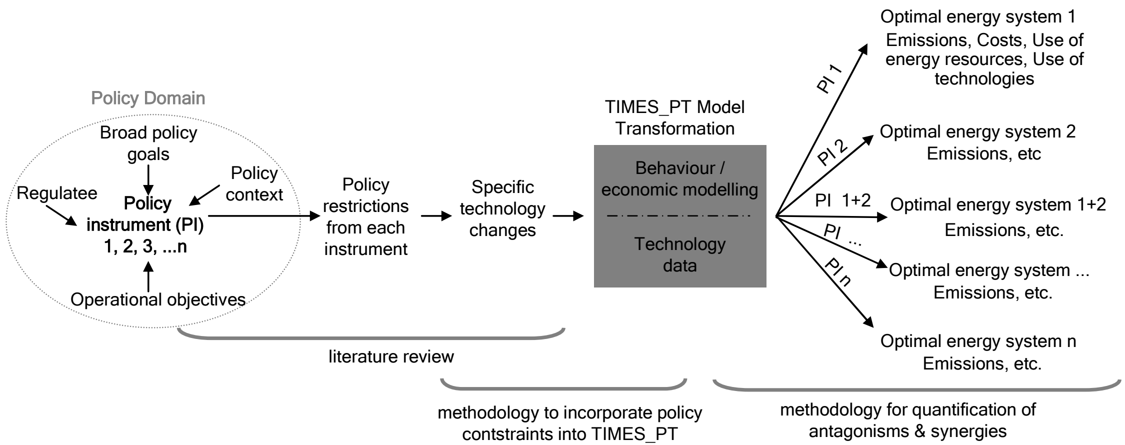

Figure 2 – Use of TIMES_PT for the quantification of interactions between instruments

For instance, let's consider the case of the following three policy instruments in place in Portugal: feed-in-tariffs to promote renewable electricity, CO_2 emissions trading, and on-budget aids to fossil fuel infrastructures (e.g. building of natural gas pipelines and storage facilities). For the time horizon of 2000 to 2010, it is possible to quantify both the effects that each of these three instruments had and will have in CO_2 emissions (increases and reduction), and the costs (for the society) associated to the implementation of each instrument.

The **feed-in-tariffs** will be modeled in TIMES_PT as an annual subsidy (in €/MWh) differentiated according to the 16 renewable electricity generation technologies considered in the model[5], and following the different monetary "prize" attributed to the different primary energy sources, as in Decree-Law 339-C/2001. This instrument effect is to increase electricity generation from renewable sources and thus, to reduce total CO_2 emissions associated to electricity generation. Its cost is given by the total value of the attributed subsidy.

The **CO_2 emission trading** is simulated in three parts: 1) a *CO_2 emissions restriction* for each participating sector/technology; 2) a *subsidy* attributed to the CO_2 emitting technologies of each participating sector representing the *free initial allocation* of licenses, and 3) a new technology representing the *possibility to buy licenses*. This instrument will lead to a reduction in CO_2 emissions from the industry, refineries and electricity generation sectors. Its implementation costs are equivalent to the value of the free initial allocation of allowances.

The **on-budget aid to the implementation of natural gas infra-structures** is simulated as a correspondent reduction on investment costs of the natural gas distribution technologies considered in TIMES_PT. This instrument leads to an increase of the use of natural gas which corresponds to an increase in CO_2 emissions. The value of the aid is equivalent to the cost of this instrument.

The model will be run for the 2000-2010, first without any policy instruments and then simulating each of these instruments one at a time. TIMES_PT will find the combination of technologies that will

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[5] 5 different wind generation technologies; 2 geothermal; 4 small hydro; 2 solar photovoltaic; 1 biomass, and 2 biogas.

satisfy the energy demand in 2010 at the least possible cost, considering the emission restrictions in place. The model estimates the total society cost and CO_2 emissions for each optimal solution, i.e. without policy instruments, with only one of the three studied instruments at a time, and with different combinations of more than one instrument. By comparing these different costs and emissions with the no-policy instrument scenario cost, it is possible to infer about the combined effects of the three instruments in CO_2 emissions and in costs. In sum, the comparison allow to understand if the no-coordination of the different instruments, that apparently have antagonistic and synergetic effects, leads to relevant losses in effectiveness and cost-effectiveness.

It should be noted that although it is important to represent as accurately as possible the effects of the instruments, the main objective here is to compare the different scenarios to estimate the interactions between the three policy instruments. Therefore, the differences between the total system costs estimated by the model are more revealing than its absolute values.

The drafted methodology for quantification of interactions between instruments will be implemented and refined firstly for the 1990-2000 period. Simulation models have always limitations and oversimplify reality. In this case TIMES_PT assumes that stakeholders have perfect market foresight, which is far from reality. Thus the quantitative methodology is firstly developed and stabilized for the past. The past evaluation for the 1990-2000 period will allow improving the robustness of the analytical methodology, because there is data for the past and thus the model results on the quantification of antagonisms can be verified and corrections can be made. By comparing the model results for the year 2000 with which in fact has happened (regarding emissions, technology stocks and costs) it is possible to identify the systematic methodological limitations to bear in mind for future usage when suggesting alterations in future policy design.

The knowledge gained in the backcast analysis will then be used for an exploratory analysis of future policy making (2000-2030) considering the rapid changes taking place in electricity systems across the EU, due to liberalisation of the markets and decentralisation of supply. At this point it is not possible to accurately predict what will be the future structure of electricity markets and how energy and environment policies will be developed to cope with those changes. Therefore, future scenarios will be considered regarding the electricity markets structure in the medium-term. Possible alternatives to the existing set of policy instruments on the medium-term will be generated, and its interactions quantified, using the developed methodology.

5 Discussion

The overview of energy and environment policy instruments along electricity systems reinforces the need for policy integration. There are a large number of instruments in place, sometimes pushing towards complementary objectives but most of the times clearly antagonistic. The seemingly most relevant conflicts are between hidden subsidies provided to energy supply infrastructures and environmental command-and-control regulation. Although there are policy instruments acting both on the supply and the demand side, this does not lead to integration of supply and demand-side policy instruments. To be able to improve this situation it is necessary to supply policy makers with quantitative information on losses (and gains) due to integration deficiencies between policy instruments.

This paper presents a draft methodology to do so, using a bottom-up technology model. The ultimate objective of the quantitative analysis of interactions between energy and environmental instruments is to produce useful information for effective energy and environmental policy integration, at the level of the policy instruments.

This approach to assess the interactions between policy instruments is limited to only two of the components of the policy process (the policy instruments and actors or stakeholders). The other components - objects, goals and the structures and procedures – are not approached here. It has to be noted that to achieve policy integration it is not enough to simply secure the integration of its instruments, because the effects of the policy instruments are dependent of the context and thus of all the other components of the policy process. Nonetheless, integration at level of the policy instruments is considered by the authors as a good starting point towards the integration of the policy processes in all its components.

Finally, it should be noted that due to human limitations in understanding all the dimensions of complex problems (as to achieve sustainable electricity systems) it is not realistic to expect that policies can develop perfectly coordinated instruments capable of successfully addressing all social, economic and environmental problems. The step-by-step policy making approach, handling one issue at a time is in many cases the best possible solution.

Looking back to the times of implementation of the reviewed policy instruments, one can realise that they were implemented over a long time-frame (approximately 30 years), and the more recent ones seem better coordinated, mostly due to the great umbrella of climate change policy. Climate change policies seem to be the ideal meeting point between energy and other environmental policies, or at least for demand-side energy and environmental policies. Nonetheless, there is still large room for improvement in achieving commitments between these two areas as there are still many different policy objectives. Moreover, climate change is but one of the environmental problems to be dealt with. For other environmental problems this intrinsic drive for integration might not apply, such as conservation of biodiversity.

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