Combining climate and energy policies : synergies or antagonism ? Modeling interactions with energy efficiency instruments

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Combining climate and energy policies: synergies or antagonism?
Modeling interactions with energy efficiency instruments

Abstract

In addition to the already present Climate and Energy package, the European Union (EU) plans to include a binding target to reduce energy consumption. We analyze the rationales the EU invokes to justify such an overlapping and develop a minimal common framework to study interactions arising from the combination of instruments reducing emissions, promoting renewable energy (RE) production and reducing energy demand through energy efficiency (EE) investments. We find that although all instruments tend to reduce GHG emissions and although a price on carbon tends also to give the right incentives for RE and EE, the combination of more than one instrument leads to significant antagonisms regarding major objectives of the policy package. The model allows to show in a single framework and to quantify the antagonistic effects of the joint promotion of RE and EE. We also show and quantify the effects of this joint promotion on ETS permit price, on wholesale market price and on energy production levels.

Keywords: Renewable energy, energy efficiency, energy policy, climate policy, policy interaction.

JEL Classification: Q28, Q41, Q48, Q58

La combinaison des politiques du climat et de l'énergie : synergies ou antagonisme ?
La modélisation de leurs interactions avec les instruments d'efficacité énergétique.

Résumé

En complément du paquet Climat et Energie déjà existant, l'Union Européenne prévoit d'inclure un objectif contraignant pour réduire la consommation d'énergie. Nous analysons les raisons invoquées par l'UE pour justifier une telle superposition et nous développons un cadre minimal pour étudier les interactions dues à la combinaison d'instruments de réduction des émissions, de promotion de la production d'énergie renouvelable (ENR) et de réduction de la demande d'énergie au moyen d'investissements d'efficacité énergétique (EE). Bien que tous ces instruments tendent à réduire les émissions de gaz à effet de serre, et bien qu'un prix du carbone tende aussi à donner les incitations qui conviennent pour les ENR et l'EE, il apparait que la combinaison de plus d'un instrument conduit à des antagonismes significatifs au regard des objectifs de l'ensemble des politiques. Le modèle permet d'exhiber les effets antagonistes d'une promotion conjointe d'ENR et d'EE dans un cadre unifié et de les quantifier. Nous montrons et quantifions également les effets de cette promotion conjointe sur le prix des permis ETS, sur le prix du marché de gros et sur les niveaux de production d'énergie.

Mots-clés : énergie renouvelable, efficacité énergétique, politique énergétique, politique climatique, interaction entre politiques.

January 5, 2012

Combining climate and energy policies: synergies or antagonism?

Modeling interactions with energy efficiency instruments

Oskar Lecuyer*†‡ and Ruben Bibas‡

Abstract

In addition to the already present Climate and Energy package, the European Union (EU) plans to include a binding target to reduce energy consumption. We analyze the rationales the EU invokes to justify such an overlapping and develop a minimal common framework to study interactions arising from the combination of instruments reducing emissions, promoting renewable energy (RE) production and reducing energy demand through energy efficiency (EE) investments. We find that although all instruments tend to reduce emissions and although a price on carbon tends also to give the right incentives for RE and EE, the combination of more than one instrument leads to significant antagonisms regarding major objectives of the policy package. The model allows to show in a single framework and to quantify the antagonistic effects of the joint promotion of RE and EE. We also show and quantify the effects of this joint promotion on ETS permit price, on wholesale market price and on energy production levels.

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1 Introduction

The European Union (EU) has developed an integrated climate and energy strategy. Energy supply plays a central role in it, because of energy security concerns but above all because it represents the biggest opportunities for greenhouse gas (GHG) emission mitigation. According to the UNFCCC data (UNFCCC, 2011) the combustion of fossil energy makes up for 88 % of total GHG emissions in the EU, and electricity and heat for 29 % of total emissions.

The EU implemented instruments aiming to curb GHG emissions by 20 % compared to 1990 levels and to produce 20 % of its energy from renewable sources by 2020. In addition, the EU plans to release an energy efficiency directive including binding measures for energy consumption reductions, among others. A wide range of research papers has investigated rationales, scope and conditions for efficient and effective policies to reduce GHG emissions. But given the high degree of interdependency between emissions, various energy production sources and energy consumption reductions, interactions between those policies are inevitably significant.

What effects have then to be expected when several policies are in place to reduce emissions and promote renewable energy and energy efficiency separately? In order to answer those questions, after a short analysis of rationales to combine instruments we develop a minimal common framework including all elements allowing to study policies of the Climate and Energy Package: a GHG emitting energy, a renewable energy and energy efficiency investments possibilities. By adding several instruments from the Package and by differentiating the equilibrium, we investigate the interactions between instruments and the channels through which they are effective.

Part 2 analyzes the European policy framework and the rationales the EU uses to justify climate and energy policy overlapping, before making a short review on climate and energy policy interactions. Part 3 presents the minimal common framework and analyzes interaction terms arising from the combination of several price instruments and from the addition of an energy efficiency target. Parts 4 and 5 summarize the results and conclude.

2 Climate and energy policies in Europe

2.1 Existing framework

The EU has published a roadmap for 2020 (UE, 2011b), where climate change mitigation and energy objectives are among the 5 top priorities of the global EU agenda. These objectives, known as the 3 × 20, are:

- a reduction in EU GHG emissions of at least 20% below 1990 levels,
- 20% of EU energy consumption from renewable resources,
- a 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency (EE).

The EU implemented in this context an integrated climate-energy strategy and developed principles of action, such as the climate policy mainstreaming and the integration of climate objectives into sectoral policies.

Enforced in June 2009, the climate and energy (CE) package defines a legal framework for designing and implementing policies to reach the 3×20 objectives. It comprises four pieces of legislation:

- a revision of the Emissions Trading System (ETS) (UE, 2009b),
- an 'Effort Sharing Decision' governing emissions from sectors outside of the scope of the EU ETS (UE, 2009a),
- binding national targets for renewable energy which collectively will lift the average renewable share across the EU to 20% by 2020 (UE, 2009d),
- a legal framework to promote the development of carbon capture and storage (CCS) (UE, 2009c).

The energy efficiency objective is directly addressed by the energy efficiency action plan (UE, 2011a), but the process for a binding legislation is still underway, and European commissioner for energy Günther Oettinger has said he will give EU countries two years to get energy efficiency savings back on track before proposing legally binding targets[4].

The CE package strengthens the ETS, designed to share efforts among member states (MS). It sets binding targets at the national level for renewable production, letting MS chose the best suited instrument to reach it. Most member states use a feed-in tariff where renewable energy installations receive long-term contracts that guarantee preferential access to the grid at an elevated price. Some countries put up a quota system, where obligated parties (energy companies most of the time) have to provide a certain amount of green certificates, issued for each unit of renewable energy produced. In the US, a similar system called renewable portfolio standard (RPS) is widely used. Other instruments include preferential loans and fiscal treatment, investment subsidies, tenders and net-metering[5]. Finally, the EC package sets good practice principles and a framework to monitor and assess actions of member states.

Energy efficiency legislation is more sector-oriented, due to the scattered nature of energy savings. Current legislation focuses on especially energy-intensive sectors such as buildings, manufacturing, energy conversion and transport. It includes directives for energy labeling, ecodesign of products, building performance and combined heat and power production[6]. Recently published energy efficiency plan is part of a negotiation process for the definition of a future directive concerning energy efficiency that may include binding targets (UE, 2011d).

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[4] Source: Euractiv/Reuters 26 September 2011 `http://www.euractiv.com/energy-efficiency/doublespeak-energy-efficiency-eu-states-told-news-507879`

[5] "Net metering service means service to an electric consumer under which electric energy generated by that electric consumer from an eligible on-site generating facility and delivered to the local distribution facilities may be used to offset electric energy provided by the electric utility to the electric consumer during the applicable billing period" (cited from EERE, `http://www.eere.energy.gov/`).

[6] See `http://ec.europa.eu/energy/doc/energy_legislation_by_policy_areas.pdf` for a complete overview of the secondary EU legislation under the competence of the DG ENER.

2.2 Rationales for combining policies

According to basic economic theory, a single CO_2 price across the whole economy is the most efficient policy for mitigating emissions, because it allows for a first best allocation of resources. This perfect allocation is however never reached in reality, because of several shortcomings in the emission market. Market failures, technological failures and regulatory failures prevent the emission market from finding the right equilibrium. In the short term, the absence of transmission of CO_2 price effects to end-users, imperfect information and bounded rationality can limit the efficiency and relevance of the emission market. In the medium term, security of supply concerns, imperfect competition and liquidity constraints can hinder the proper evolution of the permit price trajectory. In the long term, innovation failures and market barriers limit the emergence of low carbon technologies.

As stated by Tinbergen (1952), ideally each of these externalities or market failures should be tackled by a specific instrument. Otherwise, a trade-off would have to be found that would favor one objective over another. More generally, Sorrell (2003) cites three justifications for adding an instrument to the carbon price set by the European ETS:

- to improve the design of the ETS (by regulating a sector not covered by the scheme, for instance),
- to correct market failures of the ETS that reduce the efficiency of the scheme,
- to meet other objectives besides emission mitigation.

Regarding the EU policy package, energy efficiency and renewable promotion instruments can be seen as improving in some way the ETS. In principle, their scope is non contiguous to the ETS. They are designed to deal with sectors not covered by the emission quotas, like distributed electricity generation or scattered efficiency potential, in order to reach additional emission reductions (see for instance impact assessments UE (2008, p. 34) and UE (2011c, p. 10)).

Mitigating market failures is nevertheless also often invoked as justification for a number of instruments promoting renewables and energy efficiency in the EU. Several directives set guidelines for promoting R&D of capital-intensive low-carbon technologies in order to overcome innovation failures and limit market barriers in the long run. Other instruments seek to limit the learning-by-doing spillovers by ensuring investors capture the full benefit of knowledge from the construction and exploitation of low-carbon technologies. Most renewable feed-in tariff schemes can thus be seen as a payback for the failure to capture benefits from learning-by-doing. Many tax incentive schemes and preferable loans seek to limit liquidity constraints and market barriers due to high initial costs of some technologies. Labels are designed to limit asymmetric and imperfect information, and labeling of goods is a major instrument of the European strategy to promote energy efficiency. In the EU, direct command-and-control regulations such as minimal energy efficiency thresholds are frequently used. For an exhaustive list of climate policy instruments and their potential impact on deviation from perfect markets, see Gillingham and Sweeney (2010). See also Gillingham et al. (2009) for a review of economic concepts underlying energy efficiency decision making and a review of market barriers, market failures, and behavioral failure related to energy efficiency.

Moreover, positive externalities associated with the development of low carbon technologies are often invoked by the EU to justify additional support for these technologies. In EC directive n° 2009/28/EC, following side-objectives are cited: "promoting the security of energy supply, promoting technological development and innovation and providing opportunities for employment and regional development, especially in rural and isolated areas,[...] export prospects, social cohesion and employment opportunities for independent energy producers" (UE, 2009d, p16).

Two different logics seem to coexist in the European climate and energy policy scheme. The first one places the climate mitigation objective as the main driver of economic changes, and other instruments are thought to limit the market failures that cannot be tackled by the European ETS. Energy efficiency and renewable energy policies are thus aiming at reducing knowledge and technology-based failures of the carbon market related to specific low-carbon technologies. The second logic considers several objectives together. Reaching 20 % of renewable energy production and 20 % of energy consumption reductions are important objectives in themselves, because of additional benefits they bring along.

This opposition shows at different levels. The first logic could be the view of a pure economist. The second one places more emphasis on technologies and is more end-sector oriented. At the European level for instance, the Climate Action DG argued in favor of the first whereas the Energy DG plead for the second.

2.3 Incidence of overlapping policies

Regardless of the reason invoked for their implementation, climate and energy policy instruments considered in this paper affect energy-related goods that are highly interchangeable. A change in renewable promotion will affect relative prices between alternative energy sources and have an effect on consumption of fossil energy. Comparably, energy efficiency-promoting instruments will affect the shape and the absolute level of the demand curve. In a more general sense, interactions can affect expected outcomes at any level: scope, objectives, implementation, operation or timing of a specific policy (derived from Sorrell, 2003, p.424). For an exhaustive review of interaction studies and a general framework to assess potential effects of interaction between two instruments or two policy schemes, see for instance Oikonomou and Jepma (2008).

In the literature, several approaches are used to study interactions. Some authors try to classify interactions in different manners, mostly on the basis of effect on expected outcomes, scope and governance (Sorrell, 2003, Sorrell et al., 2003). Other analyze and sometimes try to quantify those effects, using analytical or numerical models (Skytte, 2006, Sorrell et al., 2009, Abrell and Weigt, 2010). A last category of papers uses a sectoral approach to highlight interaction, mainly in the electricity generation sector (Traber and Kemfert, 2009, Fischer and Preonas, 2010).

As defined by Sorrell (2003), a relevant distinction between direct and indirect interactions can be based upon affected targeted groups. Direct interactions occur when groups targeted by two policy instruments overlap in some way. An indirect interaction takes place between two policy instruments when a target group is indirectly affected by one of the instruments, as when a renewable obligation on electricity producers and a tax on downstream electricity consumption both raise electricity price for end-users.

The INTERACT project report (Sorrell et al., 2003) makes further distinctions between internal and external interactions, and between vertical and horizontal interactions. Internal interaction refers to an interaction between two or more climate policy instruments whereas external to interactions between a climate and a non-climate policy instrument. Horizontal interaction refers to the same level of governance (the European level for instance) while vertical interactions refer to different levels. The report also defines trade policy interactions as the influence of one policy instrument on another by the exchange of an environmental trading commodity.

Analyzing mechanisms behind interactions, Skytte (2006) and Sorrell et al. (2009) develop graphical equilibrium analysis frameworks to separate effects in each considered market (environmental commodity, electricity or energy efficiency goods) and to distinguish effects on demand curve from effects on supply curve. They show in a graphical way that the promotion of one type of energy displaces demand and supply curves for all types of commodities, having an ambiguous effect on prices. Abrell and Weigt (2010) develop a static general computable equilibrium model of Germany with differentiated renewable technologies to test the effects of an emission trading scheme and renewable support mechanisms on each other. They show that adding an instrument promoting renewables to an ETS decreases environmental effectiveness by letting the carbon price drop to zero in some cases. This addition decreases also total welfare due to the additional financing needs of the renewable support scheme. This additional cost is highly sensitive on the learning rate assumptions for low carbon technologies. Numerical sectoral approaches, as developed by Traber and Kemfert (2009) allow to be more specific on supply technologies and quantify synergies between instruments. They show two frequently counteracting effects when combining an European ETS and national renewable promotion schemes: a substitution effect and a permit price effect. The latter occurs when substituting renewables to emitting fossil production. Increased renewable production then reduces total emissions, thus reducing the price of emission permits and the end-user price. But promoting renewables substitutes to fossil energy a more expensive energy, increasing therefore the final price and leading to the substitution effect.

Fischer and Preonas (2010) develop a static partial equilibrium analytical framework enabling to analyze variations in quantities and prices when various policies are combined. Applying it to the American electricity production sector, they discuss perverse effects of the addition of an emission cap or a renewable quota to a set of price-instruments (carbon tax, renewable subsidy or fossil fuel tax). The first major result is that overlapping price-instruments with an emission cap can lead to the development of relative dirty technologies. When an emission cap is in place, instruments raising the emission permit price discourage dirty technologies, whereas instruments that lower the emissions price allow dirty technologies to displace cleaner ones. In other terms, "when emissions are capped, none of the overlapping policies can simultaneously disadvantage both kinds of fossil generation" (Fischer and Preonas, 2010, p. 16). This merit-order effect has been previously described by Böhringer and Rosendahl (2009). The second major result is that when price instruments are combined to a renewable portfolio standard (RPS), any additional taxation of fossil energy will lower generation from renewable sources because of the market share constraint of the RPS.

Above described approaches tend to focus either on graphical or qualitative approaches or on specific interactions between two instruments, mostly the EU-ETS and an instrument promoting renewable energy. A comprehensive microeconomic approach of interactions between three objectives and three instruments is still lacking. This paper focuses on microeconomic interactions between all objectives of the Climate and Energy Package. It is an attempt to complement the previous approaches, more governance-oriented, by giving formal microeconomic definitions and analytical demonstrations of interaction effects. It leaves behind macroeconomic and systemic effects of interactions, describing a common microeconomic framework for climate and energy policy interactions. It will use and expand the framework developed in Fischer and Preonas (2010) by adding demand reductions through energy efficiency investments and considering the overlapping of quantity instruments promoting energy efficiency.

3 A minimal common framework to study microeconomic mechanisms of interaction effects

This section presents a framework integrating two types of energy sources and several policy instruments to analyze mechanisms by which interactions affect quantities and prices. The methodology, derived from Fischer and Preonas (2010) is extended to a system with investments in energy efficiency and applied to instruments of the European energy and climate policy scheme. We examine efficiency of policies along three objectives: emission reductions, renewables and energy savings development. The first part will introduce the general framework. Following parts will examine a situation with several price instruments included and where the energy demand is reduced by a quota. Annex A lists all variables used in the model.

3.1 General framework

Two energies are combined to satisfy an exogenous demand in energy (D): the energy from a fossil fuel (f) and the energy from a renewable source (r). This energy, accounted in Joules or in MWh, is assumed to be consumed through a non-specified energetic vector, for instance electricity, in order to satisfy a service such as lighting, transportation or heating. The demand can be reduced by an amount e through energy efficiency investments. This reduction refers to the production of the same energy service with a different efficiency. For instance, it can be the electricity savings following a switch to energy saving bulbs or a switch to an A+ labeled appliance. These reductions do not refer to sufficiency behaviors, where end-users adapt their consumption to price or specific programs. For a detailed discussion of the differences between efficiency and sufficiency, see Giraudet et al. (2011a,b). Sufficiency is represented by the decreasing slope of the net demand function. It represents all energy saving behavior components not related to technological improvement and which cannot be easily subsidized. The gross demand D is defined by a function decreasing with the wholesale price p ($D'(p) \leq 0$). It has to be satisfied according to following equation:

$$f + r = D(p) - e \tag{1}$$

The cost of producing energy from the two different sources (C_f and C_r) is assumed to be in both cases growing and convex ($C'_f(f) \geq 0$, $C''_f(f) > 0$ and $C'_r(r) \geq 0$, $C''_r(r) > 0$, where $C'_i = \frac{\partial C_i(i)}{\partial i}$ and $C''_i(i) = \frac{\partial^2 C_i(i)}{(\partial i)^2}$). Decreasing returns can be justified by the static framework adopted. With a given technology mix and production capacity, each energy producer uses first the most efficient installations and moves gradually to costlier ones, according to the merit order. Energy savings e are provided by investments in energy efficiency, assumed to have also decreasing returns with respect to the energy savings, for the same reasons. Thus we also have $C'_e(e) \geq 0$, $C''_e(e) > 0$.

We consider the following standard price-instruments, applying to energy goods:

- a tax on emissions from fossil fuel ($\phi \geq 0$),
- a subsidy on renewable production ($\rho \geq 0$),
- a subsidy on energy efficiency ($\epsilon \geq 0$).

The tax on emissions from fossil fuel is often referred to as a carbon tax, and has been implemented in various form in several European countries. The renewable production subsidy can represent a feed-in tariff, an instrument widely used among European countries. The subsidy on energy efficiency represents for instance a white certificate scheme, where participants must provide a certain amount of certificate at the end of each period. The white certificate are issued for each unit of energy saved compared to a baseline scenario. The future European directive under discussion considers to force the implementation of such a scheme in all member states.

The two energies and the energy-efficient goods allowing to reduce demand are produced by representative producers, assumed to be price-takers and satisfying following symmetric profit-maximization programs:

$$\begin{aligned}
\max_f \ \pi_f &= (p - \phi) \cdot f - C_f(f) && \text{for production from fossil source} \\
\max_r \ \pi_r &= (p + \rho) \cdot r - C_r(r) && \text{for production from renewable source} \\
\max_e \ \pi_e &= (p + \epsilon) \cdot e - C_e(e) && \text{for energy savings from efficient goods}
\end{aligned}$$

with $f, r, e \geq 0$ and p the wholesale price. In this setting, the wholesale price is the one faced by producers and comprises neither the tax and subsidy nor the public cost of the policy. For simplicity, we only consider the final savings of efficient goods and tune the cost curve accordingly. Put differently, we only consider the energy saving part of efficient goods. When replacing an old refrigerator for example, the choice is between taking an average-rated one or a more efficient one. The cost difference between both can be here seen as an energy efficiency investment. This investment leads to a saving corresponding to the consumption difference between both appliances during a given time. Considering the energy savings allows to develop a quasi-symmetric framework useful to apprehend interaction effects. The cost function $C_e(e)$ thus gives the portion of the total cost of a given efficient good corresponding to the energy savings.

First-order conditions for the three profit-maximization programs give following system:

$$C'_f(f) = p - \phi \tag{2}$$

$$C'_r(r) = p + \rho \tag{3}$$

$$C'_e(e) = p + \epsilon \tag{4}$$

Equations (1), (2), (3) and (4) define the market equilibrium. For simplicity reasons and to best describe real conditions, we assume that all variables are strictly positive.

3.2 Introducing price and quantity derivatives

We totally differentiate the market equilibrium equations (1), (2), (3) and (4), giving us following system to study instantaneous and infinitesimal variations of wholesale price, energy quantities and energy savings:

$$dp = \left(df + dr + de\right) / D'(p) \tag{5}$$

$$df = \left(dp - d\phi\right) / C''_f(f) \tag{6}$$

$$dr = \left(dp + d\rho\right) / C''_r(r) \tag{7}$$

$$de = \left(dp + d\epsilon\right) / C''_e(e) \tag{8}$$

Solving this system for df, dr, de and dp, gives following equations, describing variations in wholesale price, energy quantities and energy savings as a function of the various policy changes:

$$df = \frac{-d\phi \cdot (\eta_f\eta_r + \eta_f\eta_e + \eta_f\eta_D) - d\rho \cdot \eta_f\eta_r - d\epsilon \cdot \eta_f\eta_e}{\eta_f + \eta_r + \eta_e + \eta_D} \tag{9}$$

$$dr = \frac{d\rho \cdot (\eta_r\eta_f + \eta_r\eta_e + \eta_r\eta_D) + d\phi \cdot \eta_r\eta_f - d\epsilon \cdot \eta_r\eta_e}{\eta_f + \eta_r + \eta_e + \eta_D} \tag{10}$$

$$de = \frac{d\epsilon \cdot (\eta_e\eta_f + \eta_e\eta_r + \eta_e\eta_D) + d\phi \cdot \eta_e\eta_f - d\rho \cdot \eta_e\eta_r}{\eta_f + \eta_r + \eta_e + \eta_D} \tag{11}$$

$$dp = \frac{d\phi \cdot \eta_f - d\rho \cdot \eta_r - d\epsilon \cdot \eta_e}{\eta_f + \eta_r + \eta_e + \eta_D} \tag{12}$$

where $\eta_i($ with $i \in \{f, r, e\})$ is defined as $\eta_i = \frac{1}{C''_i} \geq 0$ and corresponds to the derivative of the inverse supply function with respect to price $\eta_i = 1/C''_i(q) = (C'^{-1}_i)'(p + \alpha_i)$ for both energy types and the energy savings, with α_i referring to price instruments ($\alpha_i \leq 0$ for taxes and $\alpha_i \geq 0$ for subsidies). The inverse supply function corresponds to the marginal cost curve if we consider a pure competition framework with price-taking producers. η_D is defined as $\eta_D = -D'(q) \geq 0$ in order to have a positive variable and facilitate the comparison with marginal cost curve derivatives.

Note that all η, including η_D are homogeneous to a variation of a quantity with respect to price, and they are all positive. Note also that all η are functions of quantities and prices. For a better lecture we often omit variables, but the η should be read: $\eta_f = \eta_f(f)$, $\eta_r = \eta_r(r)$, $\eta_e = \eta_e(e)$ and $\eta_D = \eta_D(p)$

In equations (9), (10), (11) and (12), the coefficient of policy variables $d\phi$, $d\rho$ and $d\epsilon$ corresponds to the partial derivatives of respective quantity or price variables with respect to corresponding policy variable. For instance, in equation (9), the coefficient of $d\phi$ corresponds to the partial derivative of fossil production with respect to carbon tax, $\frac{\partial f}{\partial \phi} = \frac{-(\eta_f\eta_r+\eta_f\eta_e+\eta_f\eta_D)}{\eta_f+\eta_r+\eta_e+\eta_D}$. It corresponds to the variation of fossil production when the carbon tax is changing.

In this example, the partial derivative is negative, meaning that increasing the carbon tax reduces energy production from fossil fuel at equilibrium. This is due to several effects. Increasing the tax increases the marginal cost of producing energy from fossil fuel. This increase shifts the supply curve ${C'}_f^{-1}(p-\phi)$ downwards (because it is an increasing function), raising the price at equilibrium. This shift is characterized by expression $-\eta_f\eta_D$ in equation (9), corresponding to the product of fossil energy supply curve and the opposite demand curve. An increase in ϕ will also have an effect on η_f itself, indirectly changing the slope of the supply curve. If C''_f is increasing with respect to production, the partial derivative of the fossil energy supply curve with respect to carbon tax is negative: $\partial {C'}_f^{-1}(p-\phi)/\partial\phi = (-1)\cdot 1/C''_f({C'}_f^{-1}(p-\phi)) \leq 0$. The decreasing slope of the supply curve adds up to the downward shift, leading to effects that add-up.

This increase reduces also the relative cost of renewable energy and energy savings compared to energy from fossil fuel. The change in relative costs induces a substitution between fossil energy and the two other energetic options, renewable energy and energy efficiency. This substitution is characterized by expressions $-\eta_f\eta_r$ and $-\eta_f\eta_e$ in equation (9). The symmetric expression can be found in equations (10) and (11). All above effects are tempered by the sum of all supply curves and the demand curve. The substitutions and the tempering can be seen as a first effect of instrument combination.

Table 1 summarizes the signs of the partial derivatives of both energy types (f, r), energy savings (e) and market price (p) with respect to the policy instrument levels (ϕ, ρ and ϵ). For instance, a – sign on the intersection of column df and line $d\phi$ means that $\frac{\partial f}{\partial \phi}$ is negative, an increase in ϕ comes with a decrease in f at equilibrium. The rate of variation of the market price is negative with respect to subsidies ρ and ϵ because we do not consider the funding of those policy instruments.

As mentioned in Fischer and Preonas (2010), the resulting changes in the wholesale price (equation (12)) can be interpreted as the weighted average of the tax and subsidy changes for all energetic goods. Note that $0 \leq \alpha_i \leq 1$, $i \in \{f, r, e\}$, and $0 \leq \alpha_f + \alpha_r + \alpha_e \leq 1$.

	df	dr	de	dp
$d\phi$	$-$	$+$	$+$	$+$
$d\rho$	$-$	$+$	$-$	$-$
$d\epsilon$	$-$	$-$	$+$	$-$

Table 1: Signs of the partial derivatives of both energy types (f, r), energy savings (e) and market price (p) with respect to the policy instrument levels $(\phi, \rho$ and $\epsilon)$

Equations (9), (10), (11) and (12) can also be interpreted as a whole, interpreting the effect on price or production of a combined change of two separate instrument levels. For instance, an increase of both ϕ and ρ will have two negative effects on fossil energy production that adds up. Similarly, an increase in both ϕ and ϵ will have two positive effects on energy savings that adds up. By contrast, an increase in both ρ and ϵ will have an ambiguous effect on renewable production, as the two effects have opposite signs. In this framework, we can give following definitions:

Definition 1 (synergy)**.** *Two policy instruments are in synergy with respect to a given variable (like production or price) when their partial derivative with respect to this variable have the same sign.*

Definition 2 (antagonism)**.** *Two policy instruments have antagonists effects with respect to a given variable (like production or price) when their partial derivative with respect to this variable have opposite sign.*

Here, subsidies for renewable energy and energy savings are antagonistic for renewable production and energy savings. A simultaneous increase in the level of the subsidies will result in an ambiguous effect on renewable production and on savings resulting from energy efficiency.

3.3 Addition of an energy efficiency target

To represent an energy efficiency target, we assume that all accountable reductions are made through energy efficiency investments. This is true for instance for the French white certificate scheme, where certificate are issued on the basis of standard procedures such as the replacement of an appliance. Additional consumption reduction can be the result of sufficiency behaviors. Those reductions are however difficult to account for. In the present setting, they are captured by the decreasing slope of the demand curve, or a possible shift to the left. Change in the energy price resulting from various policies can also lead to a rebound effect. A demand reduction will induce a price drop that itself lead to an demand increase.

For simplicity, we therefore display an energy efficiency target as a demand reduction requirement $e^\star$, corresponding to a certain percentage of total consumption. Global energy demand has to be lowered by a certain percentage A compared to the business-as-usual scenario. We moreover assume that the quota is binding. By doing so, we simply assume C_e is bigger than C_r and C_f:

other energy types are cheaper. This seems reasonable, otherwise promotion of energy efficiency would be unnecessary.

In the equations, all goods are linked by the quota constraint : $e = A\ D(p) = A(f + r + e)$. Totally differentiating this constraint, we obtain:

$$de = \frac{A}{1-A}(df + dr) + \frac{dA}{1-A}(f + r + e) \tag{13}$$

The system is resolved with following equations:

$$df = \frac{-d\phi \cdot (\eta_f \eta_r + \eta_f (1-A)\eta_D) - d\rho \cdot \eta_f \eta_r - dA \cdot \eta_f \cdot D(p)}{\eta_f + \eta_r + (1-A)\eta_D} \tag{14}$$

$$dr = \frac{-d\rho \cdot (\eta_r \eta_f + \eta_r (1-A)\eta_D) - d\phi \cdot \eta_f \eta_r - dA \cdot \eta_r \cdot D(p)}{\eta_f + \eta_r + (1-A)\eta_D} \tag{15}$$

$$de = \frac{d\phi \cdot A\ \eta_f \eta_D - d\rho \cdot A\ \eta_r \eta_D + dA \cdot D(p) \cdot (\eta_f + \eta_r + \eta_D)}{(1-A)\eta_D + \eta_f + \eta_r} \tag{16}$$

$$dp = \frac{d\phi \cdot \eta_f - d\rho \cdot \eta_r - dA \cdot D(p)}{\eta_f + \eta_r + (1-A)\eta_D} \tag{17}$$

This system can be analyzed in the same way as the previous one. In equations (14), (15), (16) and (17), the coefficient of $d\phi$, $d\rho$ and dA correspond to the partial derivatives of price and quantities with respect to the policy instrument. Compared to the general framework with only price instruments, the addition of a consumption reduction quota simplifies the system by removing some of the substitutions. This is due to the additional constraint, linking the energy savings to total demand, and reducing the number of variables in the system. With this constraint binding, the variations of e are due to the variation of the global energy demand, and are reducible to a shift along the demand curve (expressions $(A\ \eta_f \eta_D)$ and $(-A\ \eta_r \eta_D)$ in equation (16)). This effect is tempered by some substitutions between e and r, and between e and f, at a level depending on the relative slopes of inverse demand functions. Equation (14) and (15) thus display only one substitution term, symmetrical to the corresponding one in equation (16).

The addition of a consumption reduction quota affects the slope of the demand curve. The quota permanently reduces the demand and therefore it acts as if the slope of the demand curve was lower, and the slope η_D is replaced by $(1 - A)\eta_D$ compared to before the addition of the quota. This change of the demand curve slope has an effect on energy production when the quota A is moving. An increase in the quota level rises the energy savings compared to renewable and fossil energy productions ($\frac{\partial f}{\partial A} \leq 0$ and $\frac{\partial r}{\partial A} \leq 0$). The effect on the wholesale price follows this move of the demand curve and decreases too, at a rate proportional to BAU demand (i.e. the demand without the savings).

Table 2 summarizes the signs of rates of variations of both energy types (f, r), energy savings (e), market price (p) and certificate shadow price (ϵ) with respect to policy instrument levels (ϕ, ρ and A). The certificate shadow price is defined in the next section. Results are comparable as those presented in Table 1. Table 2 highlights some synergies and antagonisms (as defined in previous section). To cite the most notable effects, renewable subsidies and energy saving quota are antagonists with respect to energy saving promotion and renewable

	df	dr	de	dp	$d\epsilon$
$d\phi$	$-$	$+$	$+$	$+$	$-$
$d\rho$	$-$	$+$	$-$	$-$	$+$
dA	$-$	$-$	$+$	$-$	$+$

Table 2: Signs of rate of variations of both energy types (f, r), energy savings (e) and market price (p) and certificate shadow price (ϵ) with respect to policy instrument levels $(\phi, \rho$ and $A)$

production. Renewable subsidies and carbon tax are antagonists regarding the level of the certificate price, as well as energy saving quota and carbon tax.

Certificate price

With a consumption reduction quota, the constraint on energy savings e is quantitative. ϵ becomes an equivalent of a shadow price, or an indication of the price of a white certificate if the consumption reduction quota is backed by a certificate market. It can be seen as an addition to the wholesale price for the energy savings, in order to help them become competitive compared to energy production. Formally, it corresponds to the spread between the wholesale price p and the marginal cost of energy savings C'_e. Replacing $d\epsilon$ in the quota constraint (13) and solving for $d\epsilon$ gives:

$$d\epsilon = \frac{d\rho \cdot (\eta_r(\eta_e + A\eta_D)) - d\phi \cdot (\eta_f(\eta_e + A\eta_D)) + dA \cdot D(p)\ \ (\eta_e + \eta_f + \eta_r + \eta_D)}{\eta_f \eta_e + \eta_r \eta_e + (1 - A)\eta_e \eta_D} \tag{18}$$

Changes in the carbon tax or the renewable subsidy will cause some substitutions between fossil and renewable energy, and move the equilibrium price. An increase in renewable subsidy $d\rho$ will raise the certificate price, by increasing the spread between wholesale price and marginal cost of energy savings. On the contrary, the carbon tax, by raising the wholesale price p decreases this spread and causes the certificate price to fall.

A change in the quota level dA has several impacts. First, it moves the demand curve, causing the wholesale price to drop, and consequently the certificate price to raise. Second, it causes the relative share of the energy savings to raise compared to renewable and fossil energy, leading to an increase of the marginal cost of energy savings, and thus an increase in ϵ.

It is noteworthy that when an energy efficiency quota is in place, the energy savings cost curve has no impact on the equilibrium any more. Put differently, it is as if investments in energy efficiency were no longer the result of profit-maximizing decisions.

3.4 Addition of price and quantity instruments to an emission quota

This framework allows to analyze impacts of instrument combination on the ETS permit price. In order to do so, we model a binding emission reduction quota as a fixed energy production from fossil fuel. The quota being binding, the emissions are constant, and thus fossil production is fixed. This translates in following constraint:

$$df = 0$$

ϕ becomes the shadow price of the emission constraint, equal to the absolute value of the spread between market price and the marginal cost of producing energy from a fossil fuel. ϕ can be interpreted as a proxy of the ETS permit price.

Addition of two price instruments

By substituting df from equation (9) and resolving for $d\phi$, we obtain following equation:

$$d\phi = -d\rho \frac{\eta_r}{\eta_r + \eta_e + \eta_D} - d\epsilon \frac{\eta_e}{\eta_r + \eta_e + \eta_D} \tag{19}$$

We see that an increase in either the renewable or the energy saving subsidy has a negative impact on the emission permit price, weighted by a ratio denoting the substitution between fossil energy and alternatives to fossil energy when they are subsidized. When for instance renewable energy is subsidized, it increases its market share compared to fossil energy. This reduces the burden on fossil energy producers, it is less costly to comply with the emission quota and the permit price drops.

This result illustrates the recent debate the necessity to "set aside" some of the emission permits in parallel of implementing energy-efficiency measures, in order to prevent the carbon price to collapse. An increased objective on renewable energy production or energy savings would put a downward pressure on carbon price, weakening the price signal given to the whole economy.

Addition of a renewable subsidy and a consumption reduction quota

With an energy saving quota, $d\phi$ can be derived from equation (14), giving following equation:

$$d\phi = -d\rho \frac{\eta_r}{\eta_r + (1 - A)\eta_D} - dA \frac{D(p)}{\eta_r + (1 - A)\eta_D} \tag{20}$$

The results are comparable to the situation with only price instruments. An increase in the energy saving quota will have a negative influence on the emission permit price. This time only, the magnitude of the influence is proportional to total demand and not the slope of the curve, resulting in a potentially larger effect on permit price.

4 Summary of results

Regarding the primary objective of the European climate and energy strategy, namely the reduction of GHG emissions, the model shows that all the instruments considered reduce fossil energy consumption and therefore associated

GHG emissions (see Tables 1 and 2). The impact of different instruments on the wholesale price is however variable. If the impact on public finance is overlooked and no charge is put on end-users, a carbon tax will raise the price with the emission reductions whereas renewable and energy saving subsidies lower it. Interaction between emission permits and subsidies for renewable energy production and energy savings is negative. At equilibrium, the two subsidies reduce the emission permit price. This allows to understand the current "set-aside" debate about the EU-ETS. Strengthening the renewable production objective has a negative impact on the ETS price, as it has been seen for forward products on the carbon markets. A set-aside of some of the emission permits would help keep the market under pressure and would help guarantee a high permit price to reassure investors.

Regarding all objectives of the Climate and Energy Package, the model shows that a carbon tax promotes at the same time the reduction of fossil energy consumption, the development of renewable energy and consumption reductions through energy efficiency investments. In the presence of quantified objectives for renewables and energy savings, this instrument may however not be sufficient. It only ensures renewable energy and consumption reductions evolve in the right direction, not that they will reach the specified target. Instruments specifically promoting renewables and energy efficiency have to be added to the system to ensure renewable production is above and energy consumption below targeted levels. When they are implemented together, the two subsidies have however opposite effects on market price and tend to reduce the absolute level of each other.

We give a formal definition of synergistic and antagonist effects in the model. Two policy instruments have antagonists effects with respect to a given variable (like production or price) when their partial derivative with respect to this variable have opposite signs. Two policy instruments are in synergy when those partial derivatives have the same sign. When they are implemented together, a carbon tax, a renewable subsidy and an energy saving subsidy have antagonist effects with respect to market price. The two subsidies are antagonistic with respect to renewable production and energy savings. The promotion of renewables comes at the expense of energy savings promotion and vice versa. Those instruments allow however to bring the market price down, mitigating the effect of the carbon tax. The fact that renewables and energy efficiency investments are complementary (regarding their standing in the climate and energy strategies) explains why they are linked in most policy bundles but advocates for a single instrument promoting both. This analysis holds in a static point of view and ignores in particular technology-based market failures justifying technology-specific promotion such as wind feed-in-tariff.

According to the model, the addition of a consumption reduction quota or a white certificate scheme has some effects on the demand. By reducing the net demand, the energy saving quota reduces the need for fossil energy (and thus GHG emissions) and reduces the market price. But energy efficiency investments are in competition with renewables and in the model, an increase of the quota comes with a decrease in renewable production at equilibrium. Furthermore, an increase of the consumption reduction quota is followed by a decrease in carbon price. This decrease is proportional to total demand, resulting in a potentially large effect on permit price.

5 Conclusion

After having discussed the rationales the EU gives to justify climate and energy instruments, we develop in this paper a stylized analytical model of the European energy sector. It is an attempt to develop a minimal common framework to study interactions between all elements of the Climate and Energy Package. We use it to understand the interaction mechanisms between policy instruments from the Climate and Energy Package and future instruments reducing final energy demand by promoting energy efficiency investments. We give a formal definition of synergistic and antagonist interaction effects. We show that regarding the objective of GHG emission reductions all instruments are effective, but that major antagonisms arise when several objectives are considered concerning wholesale and emission permit price as well as renewable energy production and energy saving levels. We address the question with two types of energies, one emitting and one renewable.

In a very broad sense, one instrument allows to control the absolute production of one energy type, but it only ensures that the other energy types evolve in the right direction. Additional instruments are needed to control the absolute production of several energy types at the same time, but at the expense of possible antagonisms between instruments. With three constraints, as considered in this model, it is possible to control the absolute production of three energy types. The absolute level of price can be controlled, but at the expense of loosing the control on one energy type production level. In the existence of an objective on the price level (for distributional reasons for example), an additional constraint is also necessary, but is likely to have a significant negative effect on welfare.

In our model, a single carbon price allows to reduce fossil fuel production. Additional measures are necessary to ensure renewable energy and energy consumption reductions are above targeted levels. Those additional measures reduce the efficiency of any instrument taken independently. Putting a price on renewable energy or energy efficiency promotion reduces the carbon price, and thus the incentive of carbon-free investment economy wide. The joint promotion of renewable energy and energy efficiency has antagonist effects by substituting renewables to energy savings and vice-versa. This justifies current concerns about a future carbon price drop following the tightening of renewable or energy efficiency development objectives.

We model the introduction of a binding consumption reduction objective. We show that by reducing the net demand, the energy efficiency quota reduces GHG emissions and reduces the market price. This leads however again to antagonist effects with instruments promoting renewables. Despite having several positive effects on its own (like lower dependency on energy imports, lower future capital-intensive investment needs and additional positive externalities such as local employment), a demand reduction instrument may not be compatible with other instruments in the Climate and Energy Package.

The existence of these interactions suggests the need for an integrated approach of climate and energy policy definition. The objectives have to be tuned together, and instrument levels have to be defined taking into account all other instruments. If considered important, the price reduction objective (through energy markets liberalization), a European priority not so long ago, should also be integrated into the definition process. This work has to be completed along several directions. The introduction of a welfare function would allow to discriminate two policy bundles on an absolute basis, whereas defining some functional forms for supply and demand would allow to illustrate some of the effects shown here.

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A List of variables

List of variables	
f	Fossil energy
r	Renewable energy
e	Energy savings
p	Wholesale price
D	Energy demand
C_i	Cost curve for energetic good i
C_i'	Marginal cost curve for good i
C_i''	Marginal cost curve variation for i
η_i	Slope of the supply curve of good i
η_D	Opposite of the demand curve slope
ϕ	Carbon tax
ρ	Renewable energy subsidy
ϵ	Energy savings subsidy
A	Consumption reduction quota
$d\alpha$	Small variations of variable α