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The missing link: The influence of instruments and design features on the interactions between climate and renewable electricity policies

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ABSTRACT

Climate and energy targets and instruments coexist in many countries, leading to interactions. In particular, the combination of CO_2 targets, the European Union (EU) emission trading scheme and promotion of electricity from renewable energy sources (RES-E) have raised significant concerns in the past, given the allegedly negative influence of RES-E support on CO_2 prices. This (negative) interaction has been analysed with modeling techniques, but an assessment of the impact of specific instruments and design features on those interactions has so far been neglected. The aim of this paper is to provide an initial attempt to cover this gap. An analytical framework to discuss the impact of instruments and design features on the interactions is provided and the comparative impact of different instruments and design features on the interactions between RES-E support and CO_2 mitigation instruments is evaluated. Our results show that, while negative interactions can be mitigated through coordination, adaptability depends on the choice of instruments and design features. The negative interactions are more likely under quantity-based than under price-based CO_2 mitigation instruments. In contrast, they are more likely with price-based than with quantity-based RES-E support instruments. Notwithstanding, the choice of design features critically affects this result.

1. Introduction

The analysis of policy mixes has received considerable attention in the energy and climate areas (see, e.g., [1–7]). However, while those contributions have tried to advance in either the theoretical or empirical fronts, justifying the co-existence of different instruments and analysing the interactions between those instruments, the impact on those interactions of different types of climate and energy instruments as well as the design features within instruments has not received a comparable attention. This paper aims to cover this gap in the literature, focusing on the micro aspects of those interactions.[1]

Climate and energy targets and instruments will continue to coexist in a number of countries, including European Union (EU) member states. While climate instruments are those with emissions reductions as the primary goal and primary outcome, energy instruments are implemented primarily for other reasons with emissions reductions being one of their benefits [8]. The coexistence of targets and instruments which have some overlaps unavoidably leads to interactions between them. These interactions can be negative (conflicts) or positive (complementarities or even synergies). They can be regarded as an inherent feature of the climate policy/instrument mix in the EU, where targets and instruments for greenhouse gas (GHG) emissions, RES deployment, energy efficiency and carbon capture and storage (CCS), among others, have been set [9]. Some of these targets and instruments are adopted and designed at the EU level, others at the Member State (MS) level. Some cover several sectors, while others address specific sectors. Those targets and instruments interact with each other in complex ways [10]. Such mix and their interactions have raised the concern of policy makers. Inconsistencies between different energy and climate targets and instruments have been criticised by different types of stakeholders (see, e.g., [11]).

In particular, the combination of CO_2 targets and the EU emission trading scheme (EU ETS) and instruments for the promotion of electricity from renewable energy sources (RES-E) has raised significant concerns in the past, given the allegedly negative influence of RES-E support on CO_2 prices (see Section 2). This (negative) interaction has been analysed in the past with modeling techniques [12–14]. A similar case is the interaction between energy efficiency policies and the ETS. Although the focus of this paper is on the EU ETS, the analysis and results can be extrapolated to other countries with a cap-and-trade ETS

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[1] The terminology of Rogge and Reichardt [5] will be used throughout this article. Our design features refer to the "descriptive design features" in Rogge and Reichardt [5], i.e., not to the "abstract design features".

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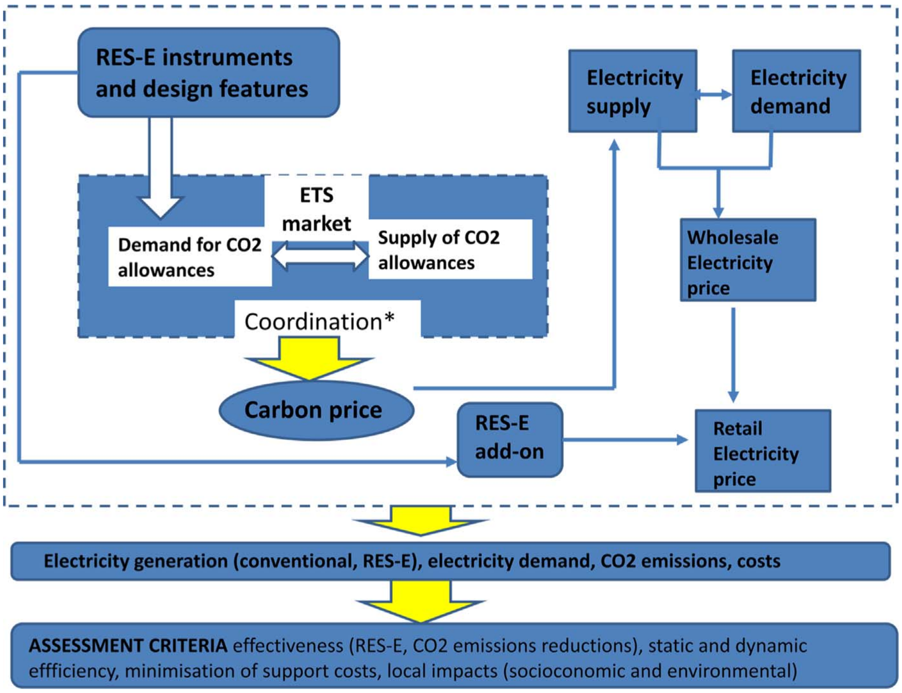

Fig. 1. Illustrating the analytical framework.
*Coordination is between the demand for allowances (affected by RES-E support) and supply of allowances (given by the CO_2 cap).

(but not a credit-based ETS).

While the literature on interactions between an ETS and RES-E support is very abundant (see [2,15] for comprehensive reviews), an analysis of the impact of specific instruments and design features on those interactions has so far mostly been neglected. NERA [16] discusses the interactions between RES-E support and an ETS, but the analysis is circumscribed to only one RES-E instrument and one CO_2 mitigation instrument. Although the design features for quotas with tradable green certificates (TGCs) are described, their influence on the interactions is not discussed. Duscha and del Río [10] have analysed the interactions between RES-E support and other climate and energy instruments in the EU, but these authors do not provide an analytical framework to systematically analyse the effects of different instruments and the assessment of design features is lacking. On the other hand, the analysis of the impact of design features on different assessment criteria has received scant attention in the literature. One exception is del Río [17], which provides an analysis of the effects of different design features of FITs on dynamic efficiency (innovation effects). Hood [8] provides a brief discussion on the impact of different carbon price intruments (CO_2 tax and ETS) on the interactions with other instruments but does not pay attention to different RES-E support instruments and design features. She proposes the idea that the nature of interactions can be different for carbon taxes and ETS and argues that the precise details of interactions will depend on the design details of the ETS.

Despite acknowledgement of the relevance of instruments and design features in the interactions [16,17,8], there is a lack of analysis on the possible influence of regulatory design on those interactions. This is unfortunate since it is well-known that the success of policy crucially depends on the choice of instruments and design features and CO_2 mitigation and RES-E instruments can be designed in quite different ways. Furthermore, the choice of instruments and design features can minimize the negative interactions between targets/instruments. Design details may need to be adapted to ensure the climate-energy policy mix is well aligned [8]. This may allow policy makers to carry out potential adjustments with a view to stronger integrating renewable targets and instruments and carbon pricing. From an academic perspective, this analysis might be incorporated in modeling of climate and energy policy strategies, which has abstracted from the choice of RES-E support instruments and design features.

The aim of this paper is to provide an initial attempt to cover this gap, illustrating the influence of instruments and design features on the interactions between climate and energy policy strategies, focusing on the case of the combination of climate mitigation instruments with RES-E support. An analytical framework to discuss the impact of instruments and design features on the interactions is provided and the comparative impact of different instruments and design features on the interactions between CO_2 mitigation and RES-E support instruments is evaluated.

Accordingly, the article is structured as follows. The next section provides the analytical framework. The method used in this paper is described in Section 3, whereas the results are provided and discussed in Section 4. The paper closes with some conclusions.

2. Analytical framework

The analysis of the negative interactions between RES-E support and CO_2 mitigation is based on the assumption that different instruments and design features can influence two main variables (effectiveness in support and possibility to coordinate the targets/instruments). The focus here is on the impact of RES-E support instruments and design features on carbon prices (whether from an ETS or a carbon tax).[2] Effectiveness refers to the extent to which a RES-E instrument encourages RES-E deployment (i.e., measured as either generation or capacity). The adaptability of targets/instruments refers to the capability to take into account the expected outcomes of one policy on the design of the other policy, and make adjustments accordingly.[3] These “intermediate” variables have an impact on: 1) the possibility that both policy fields interact in a negative way. This negative interaction would occur if a reduction of CO_2 prices results; 2) the ability to coordinate targets/instruments in both policy fields. However, such interaction should be viewed as part of a more general picture on the effectiveness and efficiency of climate and energy policies (Fig. 1). In this broader setting, the final goal is to have a successful transition to a decarbonised energy system, of which the electricity system is a main element. This success can be assessed with several criteria, including effectiveness (in CO_2

[2] For an analysis of the impact of an ETS on RES-E instruments, see Jensen and Skytte [52].

[3] Note that we do not refer here to the literature on policy coordination.

Table 1
RES-E support instruments.
Source: Own elaboration.

Instruments	Description
FIT	They provide total preferential and guaranteed payments per kWh of electricity of renewable origin, combined with a purchase obligation by the utilities.
FIP	A guaranteed payment per kWh on top of the electricity wholesale-market price is granted, combined with a purchase obligation by the utilities.
Quotas with TGCs	TGCs are certificates that can be sold in the market, allowing RES-E generators to obtain revenue. This is additional to the revenue from their sales of electricity fed into the grid. The issuing (supply) of TGCs takes place for every MWh of RES-E, while demand generally originates from an obligation (quota) on electricity distributors. The TGC price covers the gap between the marginal cost of renewable electricity generation at the quota level and the price of electricity.
Auctions	The government invites RES-E generators to compete for either a certain financial budget or a certain RES-E generation capacity. The cheapest bids per kWh are awarded contracts and receive the subsidy. The operator pays the bid price per kWh.

emissions reductions and RES-E generation), static and dynamic efficiency (CO_2 emissions reductions and minimum generation costs in the short and long-terms), minimization of support costs (paid by the government or consumers) and maximization of the net local impacts (environmental and socioeconomic) (see [10] for further details). A credible and sufficiently high carbon price is strategic in attaining those objectives, but it is not the only relevant element (given different government goals and market failures, see Section 2.3). RES-E investments are also important. Based on an abundant literature, we assume that both variables interact directly and indirectly through the electricity market. The focus of this paper is on a specific relationship, i.e., the lower carbon price which results from a higher level of RES-E generation. We start from the assumption that an efficient and effective transition to a decarbonised electricity system cannot be achieved with very low carbon prices, although these low prices could have some beneficial effects on some sectors and actors.

Therefore, we first describe the instruments and design features belonging to those policy fields, then discuss the negative interaction between RES-E support and CO_2 mitigation targets and instruments, the conditions under which such negative interaction may (not) occur, the main variables mediating these negative interactions and how they are affected by the choice of instruments and design features. These two variables are effectiveness in RES-E support and adaptability of targets and instruments.

2.1. *Instruments and design features for CO_2 mitigation and RES-E support*

The focus in this article is on instruments for CO_2 mitigation and RES-E support.

2.1.1. *CO_2 mitigation*

Market-based CO_2 mitigation instruments include an emissions trading scheme (ETS) and a CO_2 tax. Under the former, a cap is set on the total emissions allowed from a group of sources and the number of allowances corresponding to the cap is distributed. Sources have to surrender an allowance when they emit a tonne of CO_2, or pay a penalty. Within an ETS, a relevant design feature in the context of this paper is a floor on the carbon price which can not fall below a certain level. A CO_2 tax is a price-based instrument whereby a tax is levied on the carbon content of fuels (€/tCO_2). A carbon tax for the electricity generation sector (the one relevant for this article) would mean that electricity-generating units would have to pay an amount of money for the fuels they burn to produce electricity. The tax rate would be highest for the most polluting sources (coal), lower for less polluting ones (gas) and cero for carbon-free sources (renewables).

2.1.2. *RES-E support*

Public promotion of RES-E has traditionally been achieved with one of four instruments, whose costs are usually borne by consumers: Feed-in tariffs (FITs), feed-in premiums (FIPs), quotas with tradable green certificates (TGCs) and auctions (Table 1). Most RES-E investments in EU countries have been triggered by FITs or FIPs, whereas other instruments have played a minor role, with some exceptions.

Note that there might be combinations of instruments. For example, auctions can be combined with FITs and FIPs, i.e., the remuneration level under these instruments can be set in an auction rather than administratively. But auctions (as well as quotas with TGCs) have a target volume, i.e., they are quantity-based RES-E support instruments. In contrast, FITs and FIPs are price-based instruments.

Although FITs have dominated in the last decade in the EU, a move away from FITs to more market-based instruments (FIPs and auctions) can be observed in recent times (see [18] for further details).

On the other hand, we focus here on those design features which are more likely to affect the interaction between an ETS and RES-E support.

There are three types of design features in RES-E support [19,20]: those which are common to all RES-E support instruments, those which are common to different instruments but whose implementation is instrument-specific and instrument-specific design features. The latter are organized per type of instrument: FITs, FIPs, quotas with TGCs and auctions for RES-E (see 4.2).

2.2. *The negative interaction between RES-E support and CO_2 mitigation*

The interaction between both policy fields has been judged as negative by some authors [21–23]. It has been argued that adding a RES-E support instrument to an already existing ETS does not make much sense, given that RES-E is an expensive way to tackle CO_2 emissions and, since CO_2 emissions are covered by a cap in an ETS, RES-E deployment triggered by RES-E instruments does not lead to additional CO_2 emissions reductions [21,22]. Renewable energy technologies are generally more expensive low-carbon technologies, and RES-E targets and instruments allow them to take part in the electricity generation mix [24]. This leads to higher compliance costs with the CO_2 target than would be the case in the absence of RES-E instruments. Although costs have come down substantially for some renewable technologies (i.e., solar PV and wind), there is still a significant cost-gap for others (i.e., concentrated solar power). Moreover, it is claimed that “green promotes the dirtiest” [25], e.g., with a given CO_2 cap, additional RES-E in the system reduces the CO_2 price in the ETS. The lower CO_2 price benefits conventional fossil-fuel generators because it leads to an increased production from coal power and other CO_2-intensive power generation technologies than would be the case with an ETS alone. Furthermore, this lower price would decrease innovation efforts aimed at low emission technologies in the electricity generation sector. The authors sharing this traditional view usually question the need to adopt RES-E support instruments.

Fig. 2 illustrates the rationale behind the argument that RES-E generation leads to lower CO_2 prices. Let’s assume that, before the implementation of a RES-E support instrument, but with an ETS, there are 7 electricity generation technologies (T1–T7). Technologies T1–T5 are conventional technologies which burn fossil fuels to produce electricity. T6 and T7 are renewable technologies, with higher mitigation costs but, since they are CO_2-free, they do not set the carbon price. This is set by the last conventional technology needed to reduce the last unit

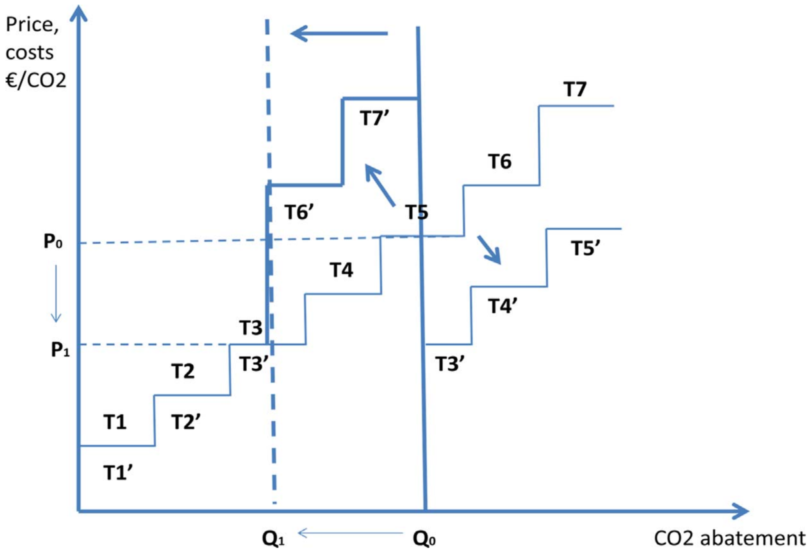

Fig. 2. Impact of RES-E support on CO_2 prices.
Source: Own elaboration, adapted from del Río et al. [34].

of emissions to meet the CO_2 target, e.g. by the most expensive conventional technology. Given a CO_2 target of Q0, this technology is T5. Now, let's assume that a RES-E support instrument is adopted, which encourages the uptake of renewable energy technologies. The carbon price is still set by the conventional technologies (because RES-E is carbon-free) but the emissions reductions achieved by RES-E means that the cap that has to be covered by these conventional technologies is lower and, thus, the carbon price will also be lower (at a level of P1 set by T3). The ETS cap is achieved at lower costs (i.e., compare the areas below Q0 and Q1), but the overal emissions reductions are achieved at a higher total abatement costs (since the more expensive technologies crowd out the cheaper ones).

This literature on the negative interactions between RES-E support and carbon prices is based on neoclassical economics and uses quantitative analysis with energy models. The analyses are mostly static and important details are ommitted, including innovation incentives as well as the impact of instruments and design features.

2.3. Justifying the combination

However, other authors justify the combinations of both types of policies on economic grounds given the existence of different types of market failures and policy goals (see [26] for a detailed discussion). The so-called *deployment externality* is a main economic argument to support the combination. The increased deployment of a technology results in cost reductions and technological improvements due to learning effects and dynamic economies of scale. Even companies that did not initially invest in the new technologies may benefit and produce or adopt the new technology at lower costs. Investors do not capture all these learning benefits.[4] Thus, investments in the new technology will stay below socially optimal levels. An ETS is able to internalize the *environmental externality* (which refers to firms not paying for the damages caused by their GHG emissions and which was the main justification for the adoption of the EU ETS), but does little to tackle the deployment externality. In addition, the different financial risk exposure of investments in renewable energy technologies with respect to conventional technologies under current power market designs provides an additional reason to complement a "carbon market only" approach with RES dedicated support in order to reduce the costs of capital for RES-E investors (see [27,28]).

The existence of different goals, which cannot be achieved with only one instrument, has provided an additional rationale for policy makers to adopt a policy mix. An ETS and RES-E deployment support share one common goal (CO_2 emissions reductions), but RES-E deployment contributes to other goals in addition to CO_2 reduction, including the diversification of energy sources leading to a lower fossil-fuel dependence, the promotion of innovation and the creation of opportunities for employment and rural and regional development. Finally, while targets and instruments that interact with the EU ETS will not contribute to additional international emission reductions during the current compliance period, they may contribute to the negotiation of more stringent emission caps in subsequent climate periods [16].

Furthermore, the negative interactions between both policy fields do not necessarily have to occur if RES-E support is not effective enough to trigger RES-E deployment or if targets in both policy fields are coordinated, an issue which is addressed in the next subsection.

2.4. Main variables mediating and mitigating the negative interaction between RES-E support and CO_2 mitigation

All instruments supporting RES-E deployment can potentially affect CO_2 prices. An additional kWh of RES-E would reduce the demand for allowances and, thus, drive down carbon prices, whatever the promotion instrument used to support it.

This impact depends on several factors. Some of them are related to RES-E instruments and design features, although others are not. The technology mix in the power generation sector is a relevant one. An additional kWh of RES-E generation may substitute different types of technologies in different countries depending on their electricity mix. The greater the carbon intensity of the country, the greater the dampening effect of RES-E generation on carbon prices. In countries with a large share of low-carbon electricity (non-hydro RES, nuclear or hydro), an additional unit of RES-E generation is less likely to replace a kWh of fossil-fuel generation than in countries where coal has a dominant role in electricity generation. Obviously, while the relevant technology mix is national (since support instruments are national), the CO_2 savings resulting from the substitution have an EU effect on the EU ETS carbon prices.

The focus here is on effects related to RES-E support. And several relevant aspects can be discerned in this context. In general, the impact of RES-E instruments on CO_2 prices will depend on the extent to which those instruments are (too) effective in triggering RES-E deployment, their impact on the technology mix in the electricity generation sector and the ability to coordinate both RES-E targets and CO_2 targets under different instruments.

[4] Different types of learning effects have been considered in the literature, including learning by doing, learning by using and learning by interacting.

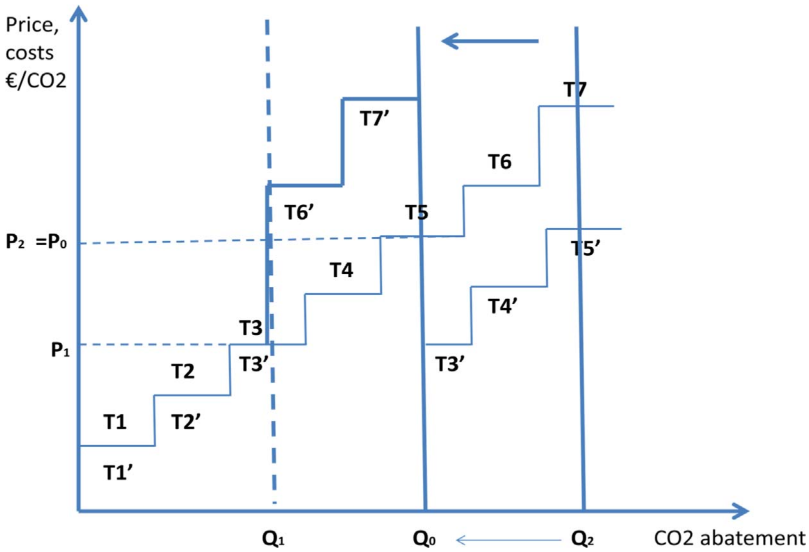

Fig. 3. Role of coordination among targets in avoiding CO_2 price reductions.
Source: Own elaboration, adapted from del Río et al. [34].

1) Impact on the technology mix. Different instruments may promote different renewable energy technologies which, in turn, may lead to different substitution of conventional (fossil-fuel) energy sources. If this is so, then an instrument which promotes those renewable energy technologies which lead to a greater replacement of more carbon-intensive power generation technologies would result in a greater negative interaction. A priori, FITs and FIPs could be expected to promote the more costly, less mature renewable energy technologies, such as CSP or wind offshore, in addition to the most mature ones, such as wind on-shore or PV. In contrast, quotas with TGCs and tenders have not been successful in triggering an increase in the deployment of high-cost gap technologies (see, among others, [19,29–31]). The issue is then: would a greater deployment of one specific RES lead to a greater substitution of more carbon intensive technologies than other RES? How do different RES affect replacement of conventional sources (coal, gas, fuel) at peak demand times and at base load? If one RES mainly replaces a more carbon intensive conventional source, then a greater deployment of this technology would have a more negative impact on the interactions. However, identifying the replacement of specific technologies is an empirical issue which is beyond the scope of this paper. The focus in this article will then be on the other two variables.
2) Effectiveness of the instruments. Effectiveness has been defined in the literature in different manners, including as a mere increase in RES-E deployment, compliance with a pre-set target and increase in deployment relative to the resource potentials (see [19,32] for further details). For the International Renewable Energy Agency, effectiveness is "the extent to which intended objectives are met, for instance the actual increase in the amount of renewable electricity generated or share of renewable energy in total energy supply within a specified time period" ([33], p.14). del Río et al. [19] provide two alternative definitions: Ratio of the change in the normalised electricity generation during a given period of time and the additional realisable mid-term potential until 2020. For del Río [20], effectiveness is the degree to which an instrument results in the deployment of RES-E projects. As argued by Hood (), if energy policies rather than the ETS market deliver most of the emissions reductions required to meet an ETS cap, this can make carbon prices highly dependent on the success of those energy policies. The greater the increase in RES-E generation, the lower the emissions in the power sector and the lower the carbon price (with an ETS). In other words, very effective RES-E support instruments, while positive in other aspects, would lead to a more negative interaction with carbon prices.
3) Adaptability. This refers to the capacity to ex-ante coordinate instruments and targets. If the CO_2 emissions which are expected to be reduced as a result of the dedicated support provided to RES-E can be predicted with a reasonable level of accuracy, then the CO_2 target can be adjusted accordingly. In other words, it can be made more stringent when the expected RES-E deployment is greater. Some instruments and design features may be more amenable for coordination than others. In particular, instruments with an in-built target (quantity-based ones) would be easier to adapt than those without a cap on RES-E generation. Note that capacity here does not refer to the literature on government capacities but rather to the "adjustability" of the instrument itself (regardless of context).

Note that the focus of this paper is on instruments and design features, but also on whether the targets to which the instruments contribute can be adjusted to mitigate negative interactions. Fig. 3 illustrates this role of coordination among targets in order to avoid CO_2 price reductions. The cap could be adjusted to reflect the CO_2 emissions being reduced with the RES-E deployment as a result of RES-E support. In other words, the cap would be made more stringent (at a level of Q2 instead of Q0). The reduction in the CO_2 emissions as a result of RES-E would lead to a carbon price of P2 instead of P1, i.e., the carbon price would not be reduced [34].

Indeed, such coordination between the ETS and RES-E support has improved in the EU ETS over the years. While in the first compliance period of the EU ETS (2005–2007) this coordination between both targets was quite imperfect [4,26], the 2020 targets for GHG, RES and energy efficiency were coordinated ex ante and also reflected in the ETS cap setting [35,36]. See del Río [26] for further details.

3. Method

Our starting assumption is that the impact of design features and instruments is mediated by their effects on the two intermediate variables (effectiveness and adaptability). Therefore, the method aims to provide substance for those links.

The assessment of the impact of RES-E instruments and design features on the interactions between the policy fields of CO_2 emissions and RES-E support is a qualitative one. Its aim is to identify the sign of the effects. It is based on a theoretical analysis and the empirical literature on RES-E support instruments, which provides information on relevant links among variables.

Information on RES-E instruments and the way those instruments have been designed in the real world (i.e., design features) as well as on their impact on effectiveness in RES-E support is based on a throughout literature review of schemes from all over the world carried out for two

Table 2
RES-E design features considered in the analysis of interactions.
Source: Own elaboration.

Common Design Features	
Target setting	Targets are an inherent design features in TGCs (quotas) and tenders. They can be set in absolute (MW, MWh) or relative terms (% of electricity demand). Absolute targets can be set as capacity (MW), generation (MWh) or budget (M€) caps.
Budget vs. consumer-financed.	The cost burden for RES-E support may fall on either electricity consumers or taxpayers (i.e., the public budget). In the EU, it usually falls on consumers.
Instrument-specific Design Features	
FITs	
Capacity caps	The amount of capacity installed in a given period is limited.
Generation cap	Maximum number of full-load hours supported
Periodic revisions	Support levels are revised (for new plants) periodically
Total budget cap	Maximum amount of total financial support for a given period
Traditional degression	A pre-set reduction of support levels over time for new plants.
Flexible degression	The reduction in support levels over time depends on the total installed capacity in a previous period (year, quarter or month).
FIPs	
Fixed	FIP payments can be designed to be constant, e.g. as a fixed, predetermined add-on.
Sliding	The premium varies as a function of the spot market electricity price [46]. Also called floating or contract-for-differences. The tariff is guaranteed as target-price and paid out in the form of an adjusting add-on to the market price so that the market price is topped-up (or reduced) to the guaranteed price.
Cap and floor	Total support (price of electricity + premium) might be capped. Under a floor, a minimum level of support is guaranteed.
TGCs	
Minimum prices	Minimum TGC prices guaranteed to ensure a minimum level of revenue to the investors.
Auctions	
Penalties for non-compliance or delays	Penalties can take different forms: termination of contracts, lowering of support levels, shortening support periods by the time of the delay, confiscation of bid bonds guarantees or penalty payments. The later can be in the form of a fixed amount (the Netherlands) and modulated by the delay (Denmark, India). They can be set per MW (Quebec, Peru, India, Argentina), per kWh (Denmark) or as a % of the investment made (Brazil) (see [31,30] for further details).
Pre-qualification criteria	They are required to participate in the bidding procedure and checked at an early stage of the bidding procedure. They can refer to: specifications of the bid/offered project, such as technical requirements, documentation requirements and preliminary licences or to the bidding party and require certifications, proving the technical or financial capability of the bidding party [30].
Regularity/periodicity of auctions	Existence of a long-term schedule for regular auctions with sufficient anticipation (i.e., 3 years, depending on the technology).

EU-funded projects (BEYOND2020 and AURES). In these projects, the identification of relevant design features for RES-E support instruments has been based on a literature review of past instruments around the globe (see [19,20]).

All issues of key established journals from 2000 to 2014 were revised.[5] This was complemented with other documents (i.e., reports). The titles and abstracts that appeared to identify the implementation and discuss the influence of instruments or design features in a specific country were selected. While there is an abundant literature on RES-E instruments, the literature on the analysis of the design features of RES-E support instruments is relatively recent, possibly because, in the past, the focus has been on the abstract comparison between instruments.

Three main types of contributions in this literature are worth mentioning.

First, some contributions have already identified different design features in RES-E support instruments in the EU or in the rest of the world and have analysed their advantages and drawbacks. Relevant references in this context include Klein et al. [37], Mendonça et al. [38], IEA [39], Teckenburg et al. [40], Ragwitz et al. [41], del Río et al. [19], Held et al. [30], IRENA [42], and del Río [20].

Second, there are several databases on the design features of RES-E support instruments: RES Legal [43], Eurobserv'er RES policy reports [44] and IRENA-IEA Policies and Measures database [45]. These provide details on the design features of RES-E support instruments in EU and non-EU countries.

Finally, case studies of the design of RES-E instruments in specific countries also provide relevant insights on those design features. 40 contributions were found in this category. They are not reported here for reasons of space.

Given length limits, we will focus on the impact of those design features which are deemed most relevant, i.e., those which can be expected to have the strongest effects on the interactions (reduction in carbon prices). Table 2 classifies and describes the most relevant design features in this context (for a full list of design features, see [20]).

4. Main results

4.1. Influence of RES-E instruments on CO_2 prices

A priori, we can expect that price-based RES-E support instruments (i.e. FITs and FIPs) would be more likely to have negative effects on CO_2 prices than quantity-based ones (quotas with TGCs and auctions). We take into account "reference" instruments, i.e., basic designs without the design features considered in Table 2 above.[6]

First, ceteris paribus, the greater the level of RES-E generation, the greater the impact on CO_2 prices, i.e., the greater the interaction between RES-E support and CO_2 targets/caps. The effectiveness of instruments to induce RES-E deployment depends on the expected revenues for RES-E minus generation costs. Revenues are a function of support levels. Whereas support levels minus generation costs (i.e., net benefits) have been lower under FITs than under quota with TGC schemes for wind on-shore in the EU, the opposite is the case for higher-

[5] These include Energy Policy, Renewable and Sustainable Energy Reviews, Energy & Environment, Energy Journal, Energy, Applied Energy, Economics of Energy and Environmental Policy, Electricity Journal, Utilities Policy, Renewable Energy, Journal of Renewable and Sustainable Energy, Climate Policy, Mitigation and Adaptation Strategies for Global Change and International Journal of Electrical Power & Energy Systems.

[6] For FITs, this means support per MWh without cost-containment mechanisms. For FIPs, apart from the absence of cost-containment mechanisms, a fixed FIP is considered without a cap and floor. In TGC schemes, this involves the absence of minimum TGC prices.

cost technologies such as solar PV [47]. Perceived risks for investors also influence the attractiveness of RES-E deployment for potential investors. These have been found to be lower under price-based instruments, such as FITs, compared to quantity-based instruments such as TGCs, with FIPs in the middle (see [48,49]).

There is a substantial amount of evidence showing that price-based instruments have generally been more effective in driving RES-E investments in the past [41,47,29]. In fact, for such a dynamic technology as solar PV, support levels under FITs seem not to have been properly adjusted to the cost of the technologies. The latter were lower than expected, which created widespread solar PV booms all around Europe. This is unlikely to happen under quantity-based instruments, with quantity limits given by the quota (under TGCs) or the amount of capacity or budget to be contracted (under auctions). The empirical evidence also shows that auctions have led to underbuilding or delays in building RES-E projects [31,50]. Therefore, since greater RES-E deployment can be expected under price-based instruments, negative interactions on the CO_2 price are more likely with this type of instruments than with quantity-based ones.

On the other hand, instruments for RES-E support may not lead to negative interactions with respect to the carbon price if both RES-E and CO_2 targets are coordinated. If ex-ante coordination is aimed at, then the amount of RES-E generation in the future should be estimated. Given that quantity-based instruments have an in-built target, this is easier done under these instruments, although some design features under price-based RES-E instruments can also facilitate such coordination (e.g. binding capacity or generation caps, see next subsection).

Note that the aforementioned negative interactions between RES-E support and an ETS, leading to a reduction of carbon prices in the absence of coordination, would not occur under a carbon tax since, in this case, RES-E deployment does not affect the carbon price (i.e., the level of the carbon tax). In other words, the choice of quantity-based versus price-based mitigation instruments could also make a difference in this regard. Thus, under a carbon tax, the resulting problems attributed to reductions in the carbon price would not take place. The impact would be on the level of abatement, but not on the carbon prices, i.e., RES-E targets and instruments would drive emissions reductions that would not have occurred with just the carbon tax. This could lead to adjustments (reductions) in the carbon tax in the future, but the carbon tax could be established as an independent policy with a clearly-defined price path into the future that will not be adjusted [8]. To sum up, the negative interactions are more likely to occur under quantity-based than under price-based CO_2 mitigation instruments. In contrast, they are more likely with price-based than with quantity-based RES-E support instruments. However, these impacts are likely to be mediated by the design features of the instruments. To this issue we now turn.

4.2. Design features

The interactions between RES-E deployment and a CO_2 mitigation instrument, such as an ETS, can go in both directions. On the one hand, as argued above, RES-E deployment may lead to a reduction of CO_2 prices under an ETS, with the aforementioned negative consequences. On the other hand, higher CO_2 prices as a result of a tighter CO_2 cap (as suggested by climate economists) may lead to a higher RES-E deployment than expected, resulting in higher total support costs. The design features of CO_2 instruments and RES-E support instruments are important for both types of interactions. In this article the focus is on the latter, however.

4.2.1. ETS design features

Several design features in an ETS may influence the degree of the aforementioned price interaction and, thus, mitigate conflicts in the policy mix. But perhaps the most direct is the existence of a floor price, since this would avoid that CO_2 prices fall below a given level as a result of RES-E deployment (or other factors), influencing the CO_2 cap. Therefore, a floor price would mitigate the influence of RES-E deployment on the carbon price. Such a floor price was applied in the U.K. in 2013 (at a level of about 20€/tonne). France planned to have a floor by January 1st 2017, but suspended its implementation [51].

4.2.2. RES-E support design features

Since there is a wide array of RES-E support instruments, each with their design features, a discussion of the impact of those design features on the results of the interactions should be organized per instrument. However, as mentioned in Section 3, some choices for design features are not instrument-specific, but common to all instruments. Therefore, the discussion will take into account this distinction and focus on the most relevant design features (see Table 2).

Some of these choices could have a clear impact on those interactions, while others are much less influential in this regard. According to our analytical framework, their impact is related to the comparative impact of the design features on RES-E deployment (i.e., effectiveness) and their contribution to the adaptability (ease of coordination) of targets. This section will assess them according to their impact on those two variables. Since the interactions between RES-E support and a carbon tax would be modest (see 4.1.2), the discussion focuses on the interactions with an ETS. Table 3 summarizes the results of the analysis.

4.2.2.1. Common design features. Regarding common design features, a main distinction is between *budget or consumer financing* of the RES-E support. A priori, little differential effects on the interactions can be expected. However, since budget-related financing of the RES-E support is usually associated with greater risks for RES-E investors [38], lower

Table 3
Sumarizing the impact of the design features on the interactions between RES-E and CO_2 targets.

Instrument	Choice of design features	Impact on effectiveness (*)	Impact on the capacity to coordinate targets	Net impact on the interactions
Common	Consumer financing (vs. budget financing)	(−)	(=)	(−)
	Absolute targets(vs. relative targets)	(=)	(+)	(+)
	Generation caps (vs. capacity caps)	(=)	(+)	(+)
	Capacity caps (vs. budget caps)	(=)	(+)	(+)
FITs/FIPs	Cost-containment mechanisms (vs. their absence)	(+)	(+)	(?)
FIPs	Sliding (vs. fixed FIP)	(−)	(+)	(?)
	Floor prices in fixed FIPs (vs. their absence)	(−)	(+)	(?)
TGCs	Minimum TGC prices (vs. their absence)	(−)	(=)	(−)
Auctions	Schedule for auctions (vs. irregular auctions)	(−)	(+)	(?)
	Prequalification requirements (vs. their absence)	(−)	(+)	(?)
	Penalties (vs. the absence of penalties)	(−)	(+)	(?)

Note: (+) positive impact; (−) negative impact. (=) No differential positive or negative impact can be expected. (?) opposing effects * A negative (positive) impact in this case means that the design feature is effective (not effective) with respect to the alternative and, thus, more (less) likely to lead to lower carbon prices under an ETS.

deployment levels can be expected, i.e., there would be a slightly greater impact on CO_2 prices with consumer-related financing. No differential impact on the capacity to coordinate targets can be expected, however.

Target setting, i.e., the alternatives to set RES-E targets, can certainly have an influence on the interactions. On the one hand, the level of RES-E deployment under absolute caps (either generation or capacity caps) is more certain that under relative targets set as a percentage of energy (electricity) consumption. This makes it easier to coordinate RES-E and CO_2 targets under the former. Therefore, a more negative impact on the interactions can be expected under relative targets. Relative targets have been the norm in the EU (since the 2001 and 2009 Directives set EU and national targets in relative terms), but absolute targets (volumes auctioned) have been set in capacity terms in the recent auctions organized in many EU countries. These capacity-based volumes will contribute to the achievement of those relative targets.

Absolute caps can be set either through *budget, capacity or generation caps*. Generation caps are more easily coordinated with CO_2 targets than capacity targets, with capacity caps being easier to coordinate than budget caps. The reason is simple: the future RES-E generation (and, thus, the extent of substitution for conventional electricity) is obviously more easily to predict under generation caps. Capacity caps do not ensure a certain level of RES-E generation (this depends on metheorological conditions in a given year) and, thus, the extent to which it replaces conventional generation is uncertain. With budget caps, this is even more uncertain since the dedicated budget may lead to quite different levels of installed capacity and generation, depending on the choice of instruments and other design features. Capacity caps have been and are much more common than generation and budget caps in RES-E support instruments around the world.

Large differential impacts on the interactions can not be expected regarding other design features since the same level of RES-E generation can be achieved under the different alternatives and their ability to coordinate targets is similar.

4.2.2.2. Instrument-specific design features. Since, as found above, price-based RES-E support instruments (i.e. FITs and FIPs) would be more likely to have negative effects on CO_2 prices than quantity-based ones (quotas with TGCs and auctions), it is worth identifying which design features under price-based support instruments could mitigate such negative impact. Therefore, we will focus the discussion on the design features of those two instruments (FITs and FIPs).

- **FITs**

The implementation of cost-containment mechanisms could have a considerable influence on the interactions. Cost-containment elements, which are not an inherent in-built feature of FITs, include *caps* (whether capacity, generation or budget caps), *periodic revisions* and *degression* (see Table 2). Without these mechanisms, explosive growth in RES-E deployment is more likely, especially for very dynamic technologies such as solar PV (as experienced in the past), driving down the carbon price and triggering the negative effects associated to this reduction. Cost-containment mechanisms would also make coordination between RES-E deployment and CO_2 targets easier. However, not all would have the same influence in this regard. A generation cap would have the largest impact compared to budget or capacity caps, since it is the cap which makes the coordination more useful. The adoption of degression (whether traditional or flexible) would not improve the adaptability (ease of coordination) between the targets.

- **FIPs**

Similarly to FITs, having cost-containment mechanisms would significantly reduce the potential negative interactions resulting from the coexistence of FITs with an ETS. With cost-containment mechanisms, there is a lower probability that FIPs and an ETS interact in a negative way. As with FITs, cost-containment mechanisms for FIPs also refer to generation, capacity and budget caps, periodic revisions and degression but, in addition, sliding premiums and cap-and-floor prices effectively limit the amount of support. Regarding the main FIP modality (*fixed vs. sliding*), remuneration control and, thus, cost and volume control (whether capacity or generation) is easier under *sliding premiums* than under *fixed premiums*. Under *fixed premiums*, the total remuneration (electricity price and dedicated RES-E support through the premium) is not capped and, thus, capacity or generation may increase more than under sliding FIPs. Since there is a price ceiling, coordination is somehow less difficult under sliding FIPs. Therefore, negative interactions are more likely to occur under fixed FIPs. Coordination between instruments and targets is easier under sliding FIPs since it is slightly less difficult to predict the future amount of RES-E generation in this case than with fixed FIPs.

Within fixed FIPs, two relevant design features are the existence of a cap and a floor for the total remuneration (fixed premium + electricity price). The functioning of the cap and, thus, the impact on the interactions, would be similar to a sliding FIP. Under a floor price, a greater effectiveness would result compared to its absence. The reason is that the reduction in wholesale electricity prices as a result of the merit order effect with an increasing penetration of mature RES-E could make the activation of this floor price a likely event.[7] This would lead to more RES-E generation than in its absence, but also a better ability to coordinate targets, two opposing effects with an uncertain net impact on the interactions.

In general, it can be argued that coordination between price-based RES-E support instruments and the CO_2 targets under an ETS can only be imperfect and more complicated than with quantity-based ones. Cost-containment mechanisms can only mitigate the weakness of FITs and FIPs in this regard.

- **Quota with TGCs**

Few design features in quotas with TGCs can be expected to have a substantial influence on the interactions. The reason is that the existence of a target or cap mitigates the possibility that RES-E deployment increases above what was initially expected (explosive growth) and makes it easier to coordinate the respective RES-E and CO_2 targets. However, one design feature could have some relevance in this context: Minimum TGC prices. By ensuring a revenue flow and, thus, by mitigating the risks for investors, a greater level of RES-E deployment could be expected under *minimum TGC prices*. Therefore, the negative interactions are more likely to occur under this design feature.[8]

- **Auctions**

As with quotas with TGCs, few auction-specific design features can be expected to make a difference regarding the interaction between RES-E support and CO_2 targets. It has been empirically shown that the absence of some design features can seriously hamper the effectiveness of auctions: the absence of an schedule for auctions, prequalification requirements or non-compliance penalties [31,30,20,50]. Therefore, the lack of any of these three design features may lead to an amount of RES-E deployment which is lower than that defined by the target and, thus, a lower degree of interaction with the CO_2 cap, but also a lower

[7] This refers to the reduction in prices in the wholesale electricity market as a result of an increasing share of generation technologies with low variable costs (such as RES-E), which replace conventional power plants with higher variable costs in the merit order.

[8] It could be argued that another relevant design feature would be maximum prices (penalties). However, there is not really a choice between implementing or not implementing *maximum prices, penalties or buy-out prices*. It is an inherent design feature in quotas with TGCs. The instrument is unlikely to function well if non-compliant obligated actors are not penalized.

capability to coordinate targets ex-ante.

It can be observed that some design features would have a negative impact on the interactions, including consumer financing and minimum TGC prices in a TGC instrument. Unfortunately, consumer financing is more widespread than its alternative (budget financing), whereas minimum TGC prices are as common as TGC schemes without them. Regarding those design features with a positive impact on the interactions, these include absolute targets, generation caps and capacity caps. Relative targets are common in the EU (since the EU RES Directive targets have been set in relative terms), but the recent widespread adoption of auctions in the EU and elsewhere has seen a move to absolute targets set in capacity terms.

5. Conclusions

Energy transitions are likely to lead to policy mixes. This is so because the challenge in these transitions is to change infrastructures, behavior and technologies in different sectors and where different types of actors are involved. Different types of instruments need to be combined in order to trigger those changes. This has also been the case in the EU, where the crowded climate and energy policy space has led to interactions between instruments.

In particular, although there is a clear justification to complement a carbon price with dedicated RES-E deployment support, given the presence of market failures and different goals, those instruments are not isolated from each other. On the contrary, interactions between both types of support instruments can occur. These interactions may be negative as it might be the case with RES-E deployment support and an ETS.

This article has analysed the interactions between RES-E support instruments and the ETS as mediated by the impact of instruments and design features on two main variables (effectiveness and adaptability).

With respect to instruments to mitigate CO_2 emissions directly, the results of the interactions may depend on whether the instruments are quantity-based or price-based. In particular, a carbon tax would remove the potential negative interactions that dedicated RES-E support may have on the carbon price under an ETS. However, at least one design feature (floor prices) would mitigate the possibility of negative interactions in an ETS.

Regarding RES-E support instruments, their impact on those interactions depends on the extent to which they contribute to increase RES-E deployment in a non-controlled manner and their adaptability of targets. From our analysis we can conclude that the negative impact on the interactions is more likely with price-based instruments than under quantity-based ones, which are easier to coordinate with the CO_2 target and generally have an in-built cost-containment mechanism leading to a control of the increase of RES-E deployment. Notwithstanding, some design features within price-based instruments could reduce the potential negative impact of RES-E support on the CO_2 price. In particular, cost-containment mechanisms would mitigate the risks of explosive growth in RES-E deployment as a result of the RES-E targets and instruments and, thus, facilitate coordination with the CO_2 target.

This paper has provided an analytical framework for the analysis of the impact of instruments and design features on the (negative) interactions between CO_2 mitigation and RES-E support. It has also illustrated the application of this framework, providing a first attempt to analyse such impact, as mediated by the effects on two variables (effectiveness and ability to coordinate targets). The existing literature on interactions with energy models has abstracted from relevant details with a considerable influence on the interactions (i.e., instruments and design features). In contrast, the very tiny literature on the influence of those instruments and design features has mostly been theoretical or based on single case studies for specific technologies in given countries, i.e., without a solid empirical base, but also without considering the overall picture of influence on the whole economy. How the divide between both approaches can be narrowed by combining them represents a crucial way forward. In particular, future research efforts should be devoted to the formalization of the analytical framework provided in this paper. This could be the basis for the inclusion of the impacts of instruments and design features on the interactions in analyses with energy-economic models. This would allow carrying out empirical analyses or simulations which help to overcome one of the main limitations inherent to the qualitative approach adopted in this paper, i.e., that a sense of proportion in the analysis of the impact of the different instruments and design features is missing. Further research should also investigate the relevance of other intermediate variables in the interactions and, in particular, the role of impacts on the technology mix. Finally, the analysis can be expanded to the impact of the design features of other energy instruments (such as energy efficiency) on the interactions.

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