Interactions Between Climate Policies in the Power Sector

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Abstract For the purpose of limiting global temperature increases, governments have designed a broad range of policy instruments in order to reduce carbon emissions such as carbon taxes, carbon markets and renewable energy support policies. Although such instruments aim to serve the same purpose, they are rarely fine-tuned to guarantee their consistency. Carbon markets are in theory the most efficient instrument to reduce emissions. The use of other instruments is justified under the presence of circumstances that undermine the effectiveness of carbon markets such as market design flaws or innovation externalities. In such cases, the optimal climate policy mix should be carefully designed to take into account the potential interactions between policy instruments.

1 Introduction

In the context of the United Nations Framework Convention on Climate Change, countries have agreed that greenhouse gas (GHG) emissions need to be reduced so that global temperature increases are limited to below 2 °C.

For that purpose governments all over the world have designed a broad range of instruments in order to reduce carbon emissions and consequently limit the global temperature increase (in addition to mitigation measures addressed to reduce the

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impact of climate change). Such measures include carbon taxes, carbon markets, subsidies to renewable sources of energy, subsidies to R&D and energy efficiency measures. Often they have set different targets for different instruments such as the European 20/20/20 setting targets for emissions reduction, renewables and energy efficiency.

Instruments and targets might complement each other but often their interaction might lead to lower effectiveness and higher costs for reducing emissions. This is the case when instruments and targets are not set and designed consistently. For example, measures adopted to meet a potential renewables target will affect the emissions price reducing the effectiveness of carbon policies. If such measures imply the funding of expensive or ineffective technologies, the final outcome will be suboptimal (since other more efficient ways to reduce carbon emissions might be displaced).

The design of optimal climate policies should bear in mind the goals pursued, whether the proposed instruments are appropriate to meet such goals and whether the interactions between objectives and instruments might reduce the effectiveness of the policy mix.

The optimal policy mix should guarantee the effectiveness in meeting its ultimate goal, e.g. the reduction of emissions, in the most efficient way.

The power sector in the European Union is a good illustration of the coexistence of several climate policy instruments and targets: The power sector takes part in the European Emissions Trading Scheme (ETS) carbon market and thus generators need to hold permits in order to be able to emit GHG gasses. In addition, most EU countries have in place support mechanisms for the deployment of Renewable Sources of Energy for Electricity (RES-E) either though Feed-In Tariff (FIT) systems or Tradable Green Certificates (TGC) in order to meet their assigned RES-E quota.

Under some circumstances, the coexistence of several policy instruments can make sense from an efficiency perspective: for example, RES-E support mechanisms might complement the carbon market if, due to the existence of market failures or design flaws, this does not function properly. Also, in the presence of innovation externalities, promoting the deployment of RES-E (if such externalities arise from learning by doing) or funding R&D in RES-E or carbon efficient technologies (if such externalities arise from R&D-driven innovation) might help to increase innovation and reduce the carbon abatement cost, accelerating the decarbonisation path.

In summary, in order to be effective, the policy mix should be carefully designed: first, additional instruments should respond to market failures and, second, the potential interactions between policies should be internalised in the design of additional instruments to guarantee the minimal distortions across instruments.

This chapter analyses the coexistence of policy instruments to fight climate change and the interactions between them with a focus in the power sector. In particular, the chapter first reviews the empirical evidence on the impact of the coexistence of several climate policy instruments in the power sector and then, through the use of a simple theoretical model, analyses when it is justified the use of several instruments and how such instruments should be designed. It is assumed that carbon abatement is the only objective of climate policies. Other objectives such as job creation, industrial policy related goals or energy independence are not included in the analysis.

The chapter is organized as follows. Section 2 briefly presents the potential contradictions and deficiencies of the current EU climate policy framework as an illustration of the poor coordination of multiple instruments. Section 3 reviews some empirical evidence on the interaction of several policy instruments and the implications for carbon prices, power prices and the policy costs. Section 4 presents a simple theoretical model that will be used to analyse different policy scenarios where additional policies might be used. Section 5 analyses, using the theoretical model, how different market imperfections and failures can be internalised in the design of optimal policies. Section 6 concludes with policy recommendations.

2 Interaction Between Policy Instruments: The Case of EU Climate Policies

The European Commission (EC) recently announced the EU climate objectives for 2030: A reduction in GHG emissions by 40 % below the 1990 level and an EU-wide binding target for renewable energy of at least 27 %.[1] The new 2030 targets are a continuation of the ambitious 20/20/20 plan launched by the EC in 2009.[2]

The EU climate policy route is an example of multiple non-consistent targets and instruments. Such inconsistency comes from two sources: first, from the lack of evidence on the complementarity between the different targets and between the different instruments and, second, from the different geographic dimension of the policy instruments, which combine Europe-wide instruments such as the ETS with domestic policies such RES-E support mechanisms without explicit coordination mechanisms across member states.[3]

The EU framework sets a target for GHG emission reduction and national quotas for renewables. The ETS is the most ambitious instrument to reduce emissions. It consists of a cap-and-trade scheme that covers almost 50 % of EU GHG emissions. In addition to the ETS, there is a range of mostly domestic measures designed to reduce emissions in sectors not covered by the ETS.

The attainment of the renewables target has been mostly delegated to national governments. Each member state is free to design the necessary instruments to meet its domestic target. In particular, in the power sector two RES-E support

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[1] See IP/14/54 (22/01/2014): "2030 climate and energy goals for a competitive, secure and low-carbon EU economy" available at http://europa.eu/rapid/press-release_IP-14-54_en.htm.

[2] The Climate and Energy Package set the guiding principles for the EU climate policy until 2020: a 20 % reduction in greenhouse gas emissions from 1990 levels, an increase of the share of EU energy consumption produced from renewable resources to 20 % and a 20 % improvement in the EU's energy efficiency.

[3] Batlle et al. [2] provide a comprehensive review of the interactions between EU climate policy instruments in the power sector.

instruments have been widely used to promote the deployment of renewable energies: TGCs which are based on an obligation to produce a certain amount of renewable energy (a certificate is created per unit of renewable energy produced) and direct subsidies per unit of renewable energy produced or FITs, which constitute direct subsidies to the production of RES-E.

The ETS is the central piece of EU climate policies. The ETS allows flexibility to reduce carbon emissions across sectors without prescribing a specific technology. However, the ETS has proved not to be that effective because of design issues and the lack of predictability.

Additional policy instruments and targets, such as RES-E support mechanisms, seem to compensate the lack of confidence on the ETS. However, there is no evidence that such targets have been set consistently with the GHG emission reduction targets.[4] Moreover, the fact that RES-E support policies are designed at national level does not guarantee their consistency across countries. Also, there is no evidence that governments have considered the interaction between their national policies and the EU ETS when designing them. This has resulted, on the one hand, in overinvestment in some technologies such as solar photovoltaic in Spain and Germany and, on the other hand, a poor performance of the ETS.

There have been several factors that have affected the functioning of the ETS and that might justify the use of additional instruments:

First, the excessive number of emission permits has made the ETS ineffective. Companies have received a large amount of permits to pollute limiting its obligations to reduce their carbon emissions. The excess of emission permits has been estimated on an overall surplus of 267 $MtCO_2e$ in the first phase (2005–2007)[5] and 970 $MtCO_2e$ in the second phase (2008–2012).[6] The excessive number of permits leads to lower carbon prices and a poor performance of the ETS.

Second, the systematic free allocation of permits resulted in “windfall profits” for the industry. Economic theory suggests that companies will partially pass through the costs of the freely obtained permits and that has been proven the case with the free permits allocated on energy-intensive industries. Bruyn et al. [8] show that carbon prices have a significant influence on several product prices, and estimated that windfall profits in the refineries, iron and steel and chemical sectors accounted for 14 billion of euros during the period 2005–2008.

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[4] In fact, according to the Commission impact analysis of the 2009 Climate Package (ANNEX TO THE IMPACT ASSESSMENT. Document accompanying the Package of Implementation measures for the EU objectives on climate change and renewable energy for 2020, p. 34), meeting the GHG reduction target would only require 15.8 % of renewables in total energy consumption. This implies that the remaining 4.2 % increased the cost of reducing emissions and, thus, did not constitute a cost efficient way to reduce GHG emissions. The Commission naively stated that putting a renewables policy in place would lower the carbon price necessary to deliver the GHG reduction commitment from €49/tCO_2 to €39/tCO_2 but did not evaluate the total cost of meeting the GHG target under the different scenarios.

[5] CTW [9].

[6] Kossoy and Ambrosi [19].

Third, the existence of high price volatility could have discouraged investment in low carbon technologies and undermined carbon reduction objectives. High volatility has been present in the market since its creation. For instance, prices remained around 26€ from January until the end of April 2006, but dropped to around 10€ as response to the publication of verified data for 2005.[7]

Fourth, the ambitious renewables target and the generosity of some national schemes have had a negative impact on the price of carbon, reducing the effectiveness of the ETS.

Finally, the economic crisis has reduced the economic activity and thus the demand for carbon permits which has resulted in important reductions on the permit's price. Prices decreased to 10.15 in 2009 compared to 30 in July 2008.[8] Recently, prices have been consistently around 5€. In response to this, the European Union recently approved a "back-loading" plan that aimed to boost the flagging price of carbon by removing carbon permits from the market.

The lack of effectiveness of the European carbon market has taken some authors to claim for the use of additional instruments. However, in some cases, like in the case of RES-E support mechanisms, such instruments have contributed negatively to the effectiveness of carbon markets.

The next section reviews some empirical evidence on the interaction of climate policies and the impact on carbon prices, power prices and the cost of policies. The object is to illustrate how a wrong policy mix can distort carbon and power markets and reduce welfare.

3 Interaction Between Policy Instruments: Empirical Evidence

The quantitative evaluation of the impact of the interaction between policies requires the simulation of the power industry under different policy scenarios. The exercise is not absent of complexity given the combination of supranational and domestic policies, the long term-nature of climate policies and the complex interaction between the different policies makes the exercise rather complex. The current section reviews some of the existing evidence on the quantification of policy interactions. Such evaluation is made through sophisticated partial equilibrium models of the power sector[9] or through he simulation of stylized models.[10]

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[7] Betz [3].

[8] Morris and Worthington [23].

[9] For example, the TIMES-D model used by Götz et al. [15] which is based on the model generator TIMES, which has been developed in the scope of the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA), or the MARKAL model used by Unger and Ahlgren [24].

[10] For example, Fischer and Newell [11].

In particular, the review focuses on the comparison of scenarios where only a carbon price instrument is used with scenarios where a carbon price is combined with RES-E support mechanisms. The comparison across studies is not feasible given the different assumptions and parameters.[11] However, it is possible to extract some general conclusions: first, the empirical evidence shows that the impact of RES-E support policies on the price of carbon is substantial and extreme cases might drive the carbon price close to zero, making the ETS a superfluous instrument; second, RES-E support mechanisms lower the wholesale power price but, if they are financed through an uplift on final consumers, they might end up increasing electricity retail prices; and finally, RES-E support mechanisms are an expensive policy instrument that increases the abatement costs and reduces welfare. Table 1 in the annex summarises the main results.

3.1 Impact on Carbon Prices

Practically all the studies analysed conclude that the combination of carbon markets and renewable support mechanisms reduce the carbon price. The existence of RES-E support mechanisms creates incentives to invest in renewable energy and reduces the demand for carbon certificates. This makes the carbon market constraint less binding and therefore the permit price lower. As pointed by De Jonghe et al. [10], for a relatively high quota of renewables, the carbon allowance price is more dependent on the quota than on the carbon restriction. In the extreme case, for a sufficiently high renewables quota, the carbon price can be close to zero.[12]

The impact on carbon prices of policies based on renewable targets varies substantially from case to case but they imply in most cases price reductions above 50 %.

3.2 Impact on Electricity Prices

The impact of combining policy instruments on retail electricity prices varies substantially from case to case. There are several issues at stake that may have opposite impacts: on the one hand, the increase in the renewables quota reduces the carbon price and will therefore tend to reduce power prices. Also, since the production of renewable energy usually will enter the spot market at a price close to zero, the

[11] The comparison of the results of the different analysis is complex given the large number of scenarios and parameters involved, the different assumptions, targets and diverse geographical coverage and the timeframe of the different exercises. The analysis at national level requires for example strong simplifying assumptions regarding the existing interferences in other countries.

[12] Abrell and Weigt [1] reach this result for a quota of 20 %. However, their results seem too low as compared to Götz et al. [15].

Table 1 Evidence on interaction between climate policies

		Scenarios			Impact		
Study	Country	CO_2 target	RES-E target	Instrument	CO_2 price €/ tCO_2	Retail power prices (% change with reference to no policies * or to carbon price only**)	Policy costs
Götz et al. [15]	Germany	21%	–	TEP	19.10	–	FIT additional costs rise strongly until 2020 up to 15 billion € per year and then drop substantially until 2030 as renewables become competitive. Even though the FIT system has the dampening effect on ETS certificate prices, the additional cost burden of this support scheme leaves to a rise in energy system costs in Germany with a cumulated difference for the time period of 2015–2030 of 7.3 billion € per year
		21%	No explicit target	TEP +FIT	14	6.3 %**	
Abrell and Weigt [1]	Germany	20 %	–	TEP	3.43	2.16 %*	Renewable policies lead to a higher welfare loss than the pure reduction scenario (−0.019 %) since electricity producers deviate from their cost minimizing generation portfolio. This effect is only slightly more negative for the case of differentiated feed in tariffs (−0.0194 %)
		20 %	20 %	TEP + TGCs	0	1.11 %*	
		20 %	20 %	TEP+FIT	0	1.12 %*	
Böhringer and Rosendah [15]	Germany	25%	–	TEP	20	12 %*	The compliance cost of reaching an emission target increases with the stringency of the emission target, but also with the green quota. That is, there is significant excess cost of introducing a binding green quota on the top of the emission constraint if the only goal is to reduce emissions of CO_2.
		25 %	23 %	TEP +TGCs	8	4 %*	

(continued)

Table 1 (continued)

		Scenarios			Impact		
Study	Country	CO_2 target	RES-E target	Instrument	CO_2 price €/ tCO_2	Retail power prices (% change with reference to no policies * or to carbon price only**)	Policy costs
Unger and Ahlgren [24]	Nordic countries	30 %	10 %	TEP + TGCs	14	0 %**	The reduction in CO_2 emissions due to a TGC system including a quota of only 10 % is seven times more costly than a TEP system with the same CO_2 reduction over time. The cost difference is at its minimum, i.e. roughly 3 times, at a TGC quota of approximately 30 %. For higher TGC quotas than that, there is hardly any further reduction in CO_2 emissions from the TGC system since all electricity supply is virtually emission-free
		30 %	20 %	TEP + TGCs	6	−3.22 %**	
Hindsberger et al. [16]	Baltic region	55.9 Mt CO2	-	TEP	18	14.49 % (Spot prices)	
		55.9 Mt CO2	23.60 %	TEP +TGCs	7.50 €	−3.42 % (Spot prices)	
De Jonghe et al. [10]	Benelux	20%	-	TEP	20	25 %*	
		-	20 %	TGCs	-	17.5 %*	
	France	20 %	-	TEP	20	0 %*	
		-	20 %	TGCs	-	17.5 %*	
	Germany	-	-	TEP	20	40 %*	
		20 %	20 %	TGCs	-	17.5 %*	

(continued)

Table 1 (continued)

		Scenarios			Impact		
Study	Country	CO_2 target	RES-E target	Instrument	CO_2 price €/ tCO_2	Retail power prices (% change with reference to no policies * or to carbon price only**)	Policy costs
Linares et al. [21]	Spain	30 %	-	TEP	22.05	34.91%*(Wholesale)	The combination of instruments features higher costs, although it shows some synergies: the simultaneous achievement of the emissions reductions and high penetration of renewable energies only increases costs by 3 % with respect to the emissions trading system only.
		30 %	17.5 %	TEP+RPS	14.71	32.04 %*(Wholesale)	
Fischer and Newell [11]	US	4.8 %	-	TEP	-	−2.2 %*	The most efficient policy is the emissions price, leading to the least cost in terms of surplus. The emissions performance standard is the second most cost-effective instrument, reaching costs 41 % higher than the emissions price. The other policies can be described as offering different combinations of these incentives, which have different consequences for the distribution and the over all size of the burden of meeting an emissions reduction target.
		4.8 %	-	Emission Price	$7	5 %*	
		4.8 %	-	RPS	-	−0.9 %*	

(continued)

Table 1 (continued)

		Scenarios			Impact		
Study	Country	CO_2 target	RES-E target	Instrument	CO_2 price €/ tCO_2	Retail power prices (% change with reference to no policies * or to carbon price only**)	Policy costs
Morris et a.l [22]	US	80.0 %	-	TEP	$235	-	There is a negative effect on welfare related to the introduction of RPS policy. Specifically, the effect of adding a 20 % RPS requirement to the existent cap-and-trade policy, implies a loss of 1.50% in terms of welfare for the year 2030, and −2.3 % for the year 2050.
		80 %	20 %	TEP + RPS	$191	-	

FIT: Feed-in Tariff, TEP: Tradable Emission Permits, RPS: Renewable Portfolio Standard, TGCs: Tradable Green Certificates wholesale electricity price will decrease. On the other hand, if costs of FITs or TGCs are recouped via uplifts on electricity retail prices, then they will contribute to increase retail prices. Therefore, the final impact on electricity prices is uncertain. However, if the costs of supporting RES-E are funded via any other source, then the impact of combining both instruments will be a reduction of retail power prices.

In summary, it can be expected that for a high renewables quota, retail electricity prices will normally increase since the volume of subsidies will be larger than the wholesale savings. While for a low renewables quota or for cost of renewable funded out of consumer prices, the wholesale savings effect might dominate and the retail price might decrease.

The empirical findings illustrate these effects. For example, in Unger and Ahlgren [24] the wholesale price is decreasing on the renewables quota. However, the retail price decreases for a quota below 25 % and increases from there on. Notice that as soon as the FIT or TGC required for a specific target becomes positive, then the policy costs of renewables increases rapidly since subsidies are normally paid also to all renewable production, even to the energy that would be produced in the absence of a RES-E support scheme.

The net impact of the combined policies also depends very much on the energy mix. For example, as shown by De Jonghe et al. [10], France has a relatively carbon-free energy mix so the imposition of a carbon price will practically not affect the electricity prices but the imposition of a renewables quota will do. On the contrary, for Germany and the Benelux they show that the imposition of a 20 % renewables quota will reduce the retail price (if FITs are optimally set). Finally, Götz et al. [15] show that if the quota reaches 40 %, then, the impact on retail electricity prices will be positive.

3.3 Cost of the Policies

All the studies analysed conclude, as expected, that the most efficient policy in terms of cost or welfare is the use of tradable emission permits. The additional policies, since they imply a bias towards specific technologies which are not necessarily the most efficient, lead to higher policy costs. In particular, the establishment of a RES-E support mechanism generally leads to higher costs. Unger and Ahlgren [24] show, for example, that the reduction in carbon emissions due to a TGC system including a quota of only 10 % is seven times more costly than a TEP system with the same carbon emission reductions over time. The cost difference is not however monotonic: it is minimal for a quota of 30 % (3 times) and beyond that there is hardly any impact on carbon emission reductions (since all energy would be produced from renewables, hydro and nuclear).

Böhringer and Rosendahl [5] estimate that the compliance cost of reaching a 25 % carbon emission reduction in Germany is twice as high with a green quota than in the absence of it (2200 million Euros vs. 1100 million Euros). Compliance costs double when there is an increase of 10 % in the renewables penetration.

4 Climate Policy Instruments: A Simple Model

We develop a simple theoretical stylized model to analyse the interaction between the different policies in the power sector and the implications for policy design. We focus on the electricity sector that amounts for close to 40 % of the emissions of the economy and where emissions reduction policies and renewables polices concur. The model is deliberately kept simple to identify the key features of the arguments (a more comprehensive stylized model can be found in [11, 12].

4.1 Supply and Demand

Assume there is a monopolist that produces electricity using two technologies: a fossil-fuelled technology and a renewable technology.

The cost of producing q_1 units with the fossil-fuelled technology is $c_1(q_1)$. The conventional technology emits $e_1 = f(q_1)$ carbon units when producing q_1, where $f'(q_1) > 0$.

The cost of producing q_2 units with the renewable technology is $c_2(q_2)$, where $c'_2(q) > c'_1(q)$ for all q,[13] the associated emissions e_2 are zero.

Assume the inverse demand for electricity is P(Q) where Q is the quantity demanded and P is the price for electricity. Renewable energy and fossil-fuelled generation are assumed to be perfect substitutes.

4.2 Policies

We initially consider two policies: a renewables subsidy and a carbon market. The renewables policy consists of a subsidy r per unit of electricity produced from renewable sources up to a target R. The carbon market consists of a cap E on the total carbon emissions of the economy and tradable certificates which are priced according to supply and demand. Carbon emissions of the rest of the economy are a function of the carbon price, p_e, and are determined by the equation

$$e(p_e) = H - hp_e$$

[13] Strict marginal cost of renewables is close to zero. However, since renewable generation plants are of a smaller scale, the cost of increasing fossil-fuelled capacity at a given point in time will be lower than the cost of increasing renewable capacity. To simplify, we embed marginal capacity costs into the renewable energy cost function such that marginal costs include not only operational costs but also the investment costs to increase capacity.

where H is the level of emissions from the rest of the economy for a emissions price equal to zero and h reflects how emissions from the rest of the economy react to changes in the carbon price.

The market clearing price is determined from equalling the demand for certificates from the power sector, e_1, and from the rest of the economy, $e(p_e)$, to the emissions cap, E:

$$e_1 + e(p_e) = E$$
$$e_1 + H - hp_e = E$$

Under this setting, the monopolist will maximise its profits subject to the policy incentives and constraints:

$$\text{Max } P(Q)(q_1 + q_2) - c_1(q_1) - c_2(q_2) + rq_2 - p_e e_1$$
$$\text{S.t. } e_1 + H - hp_e \leq E$$

where r is such that $q_2 \geq R$.

Rearranging,

$$\text{Max} P(Q)(q_1 + q_2) - c_1(q_1) - c_2(q_2) + rq_2 - p_e f(q_1)$$
$$\text{S.t.} f(q_1) + H - hp_e \leq E$$

4.3 Optimal Policy

The primary reason for the existence of environmental policies is the existence of a negative externality. In particular climate policies are designed to reduce GHG emissions that constitute a negative externality. Fossil-fuelled energy producers emit GHGs. If the cost of such emissions is not internalized, there will be an excessive production of the externality affecting negatively welfare. Conventional economic theory teaches us that a tax on the externality (or a subsidy on the "avoided" externality) can restore social efficiency.[14]

The introduction of a tax on emissions from fossil-fuelled electricity generation restores efficiency. Carbon markets and carbon taxes aim at internalizing the cost of

[14] Under the presence of a negative externality from the production of a product, a tax on the externality or a subsidy for not producing the externality are equivalent. A subsidy to green energy can however affect negatively the price of fossil-fuelled energy and cause an inefficient increase in its consumption. Gelabert et al. [13] estimate that an increase of 1 GWh in the production of renewable energy implies a fall in the price of 2 € per MWh. Also, given the heterogeneity of energy sources, it is not trivial to design a subsidy that reflects avoided emissions (while in the case of a tax, the identification of the object of the tax is easier). See Borenstein [6] for a discussion on this issue.

the emissions externality and thus restoring efficiency.[15] Alternatively, a Pigouvian subsidy on avoided carbon emissions could have equivalent effects: by subsidising emission reductions (from a pre-specified benchmark), the global optimal might also be restored.[16] Both instruments, under certain circumstances, lead to the same outcome.

In principle, a carbon price through the setting of a system of tradable "black"[17] (CO_2) quotas such as the EU ETS or through carbon taxes should be sufficient to abate emissions and restore optimality. A carbon price provides a price signal to firms which is incorporated into their production and investment decisions and allows them to adopt the most efficient decision on how and by how much to reduce their carbon emissions.

In the absence of any policy, the electricity mix would be such that the marginal costs of the fossil-fuelled generation and the non-emitting sector are equal, i.e. $c_2'(q_2) - c_1'(q_1) = 0$.

In our simple model, the existence of a carbon market (and no renewable subsidies) would be equivalent to setting $r = 0$ (and $R = 0$). Producing one more unit of electricity through fossil-fuelled technologies would imply incurring the production costs and the emissions costs. This would increase the demand for carbon permits which would cause an increase in the emissions price. Therefore, the marginal cost of producing one more unit of electricity through fossil-fuelled technologies would be higher than in the absence of a carbon price. This would promote non-emitting generation.

Under this scenario, the electricity mix would be such that marginal costs of both technologies are equalised, i.e.$c_2'(q_2) - c_1'(q_1) - p_e f'(q_1) - p_e' f'(q_1) \leq 0$. Now, the marginal cost of the fossil-fuelled technology would be higher (since it would internalise the emission costs). A carbon market would therefore be sufficient to restore optimality.

Thus, a carbon market would suffice in principle to solve the emissions externality. Setting an optimal price for carbon would provide economic agents covered by the carbon market with a signal to reduce their emissions. Such a signal could trigger investments in renewable energies. The decision to invest in renewable energy will be driven by the relative cost of producing non-emitting energy versus the cost of producing fossil-fuelled energy once the emissions externality has been internalised. A carbon market does not necessarily entails the development of a renewables sector since economic agents might decide to reduce their emissions through clean investments in other sectors where the abatement costs might be lower.

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15 For a discussion of the role and determination of the carbon price see Bowen [7]. In the US, there is no carbon price so the internalisation of GHG emission costs corresponds to renewables support mechanisms. See Joskow [18].

16 Note however that such a subsidy would not justify different subsidies to different non-emitting technologies.

17 Böhringer and Rosendahl [5].

The superiority of carbon pricing policies alone over any alternative policy mix is based on the additional cost that support mechanisms for renewable energy sources for electricity (RES-E) imply for the abatement of emissions, the lower effectiveness of RES-E to reduce carbon emissions and the negative impact RES-E deployment has on emission prices, which might delay investments in other more efficient options to reduce carbon emissions.[18] Therefore RES-E support mechanisms are at best, redundant and likely to generate excess cost.

5 The Case for Additional Instruments

What could justify the existence of additional instruments on top of carbon pricing policies? The economic literature finds basically two main groups of reasons for setting additional instruments to reduce carbon emissions[19]: First, if there are imperfections in the carbon market which lead to too low a carbon price; and second, to promote the positive externalities of non-appropriable investments in R&D that will contribute to reducing the carbon abatement cost.[20]

There are many other reasons why governments might decide to support renewables such as promoting renewables as industrial policy, job creation or energy independence. However, such reasons do not seem to respond to the existence of market failures or, at least, not to market failures exclusive to the renewables industry. Therefore, such justifications will not be addressed here.

5.1 Carbon Market Imperfections

The first argument would be related to the existence of market imperfections or design flaws which make that the carbon price alone is not effective to attain a specific target. Such lack of effectiveness could be caused for example by an allocation of excessive number of carbon credits that makes the CO_2 target non-binding (and thus, the carbon price close to zero) or by the possible inconsistencies between short-term carbon markets and long term climate objectives which might result in an inefficient carbon price path.

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[18] See e.g. Del Río [20], Böhringer and Rosendahl [5], Abrell and Weigt [1].

[19] See Borenstein [6].

[20] Other common market failures discussed by the literature are asymmetric and imperfect information and principal-agent problems (which might explain household decisions to underinvest in renewable technologies but are not very much applicable to firms as explained by Gillingham and Sweeney [14]. Other justifications such as energy security, job creation, and driving down fossil fuel prices, are generally not supported by sound economic analysis.

As explained in Sect. 2, the EU ETS has presented several market imperfections that have depressed the price mostly due to the excessive number of permits in the market.

In our model, this would be equivalent to the cap E being set too high so that the emissions permit price would be close to zero. The cap E can be set too high for political reasons, i.e. governments might not want to impose a heavy burden on their domestic industries and therefore might opt for relaxing the emission caps, or for technical reasons, i.e. because of uncertainty about the right level of emissions or because of market imperfections.

Under this scenario, a second target such as a RES-E quota, might act as a safety policy to guarantee a minimum level of emissions reduction. In other words, a policy based on reducing emissions through a subsidy to renewables might increase the cost of abatement but, on the other hand, might be the only feasible option to reduce emissions.

In our model, imagine that the optimal level of emissions is E^* and because of political reasons or measurement errors is set at $E > E^*$ (or simply assume that because of market imperfections the carbon market will not be able to meet a cap of E^*). Should the fixing of the carbon market not be feasible, a subsidy to the deployment of renewables could be used as an alternative instrument to reduce emissions.

Using a RES-E quota to reach a specific emissions reduction, would require setting the renewables target R^* that will guarantee that the level of emissions will be E^*. That is, R^* is such that $f\left(q_1^*\right) + H - hp_e \leq E^* \leq E$ where q_1^* is such that solves

$$\text{Max } P(Q)(q_1 + q_2) - c_1(q_1) - c_2(q_2) + rq_2 - p_e f(q_1)$$
$$\text{S.t.} f(q_1) + H - hp_e \leq E^* \leq E$$

where r is such that $q_2 \geq R^*$. Solving the above equation, the necessary subsidy to produce R^* will be equal to the difference between the marginal cost of the renewable and the conventional technologies minus the emissions marginal cost of the fossil-fuelled technology, i.e., $r^* = c_2'(R^*) - c_1'\left(q_1^*\right) - p_e f'\left(q_1^*\right) - p_e' f\left(q_1^*\right)$.

Notice that a large R^* will increase the marginal cost of producing renewable energy and will simultaneously depress the emissions price. Therefore, the larger R^* the larger the necessary subsidy via these two effects.

The lower abatement cost associated to a lower emissions price will not however compensate the higher costs associated to the subsidisation of renewables: subsidising renewables beyond the optimal level will increase total abatement costs.

In summary, the support to RES-E to overpass the imperfections of carbon markets is a second best policy option. The first best policy to reduce emissions would be to fix the carbon market but this might not be politically feasible, might take time, might not be feasible due to the large degree of uncertainty about future emissions or might not be effective because of the incompleteness of the carbon market. In the meantime, a direct subsidy to the deployment of renewables might do the job though at a higher cost. Such subsidy should internalise the impact of the renewables quota on the carbon market.

5.2 Non-appropriable Technology Externalities

A second argument to justify the existence of renewable energy support mechanisms would be the existence of non-appropriable technological externalities. Positive externalities of innovation exist in several sectors and per se do not justify the existence of specific subsidies. Innovation externalities justify horizontal support to R&D, but not sector-targeted support. However, in the case of climate technologies, innovation can decrease abatement costs. Thus, supporting positive innovation externalities would help to reduce the cost of the emissions externality. Innovation in climate technologies is a tale of two market failures: synergies between the innovation externality and the environmental externality help to reduce the abatement costs (See [17]).

Innovation externalities can arise from the investment in R&D or from learning-by-doing. Learning by doing occurs when a technology becomes more efficient the more it is used. Investment in R&D can reduce the cost of non-emitting technologies or can reduce the emissions of fossil-fuel technologies through better carbon efficiency or through carbon sequestration. The appropriate policy is different in each case, and also the interaction between policies.

5.2.1 Learning by Doing

Learning by doing implies that the costs of producing renewables are reduced the more renewable energy is produced. To analyse the effect of learning by doing we need to add a second period to our model: During the first period the monopolist decides how much energy from renewables sources to produce. The more renewables it produces during the first period the less costly will be to produce renewables in the second period.

This would be equivalent to adding a second stage to our model where the renewables cost function is $g(q_2^1) * c_2(q_2^2)$ where $g(0) = 1$, $g(q) \leq 1$ and $g'(q) \leq 0$ and q_2^1 and q_2^2 are the renewable energy production in periods 1 and 2 respectively. That is, $g()$ would reflect the decrease in the costs of producing renewables due to the effect of learning by doing i.e. the more renewables are produced in period 1, the lower the cost of producing renewable energy in period 2.

In the case of a monopolist, learning-by-doing effects would provide more incentives to produce renewable energy during the first period that in the absence of such effects (even if there is no subsidy). Since all the benefits will be captured by the firm in the second stage, the firm will produce more renewable energy during the first period than in the absence of learning by doing (or, equivalently, the necessary subsidy to reach a specific target R will be lower) in order to reduce the costs in the second period.

Therefore, learning-by-doing effects do not justify the existence of a subsidy to renewables when firms will be able to capture the benefits from learning by doing effects during the second period. In such a case, firms will have incentives to produce more renewables during the first period without additional support. The ability to capture the benefits from learning by doing is not necessarily associated to monopoly power, but may also be associated to the existence of patents.

However, in the case where firms are not able to appropriate the results of their investment, public support is justified. If learning by doing effects constitute a public good (i.e. cost reductions arise from general industry experience and not only from individual industry experience) then, as in the case of other public goods, firms will produce suboptimal amounts during the first period. That can justify a renewables target during the first period and, consequently, a subsidy to promote the production of RES-E during the first period.

In summary, only in the presence of learning-by-doing based on industry experience and of sufficient competition in the production of electricity, a subsidy to renewables would be justified. Ideally, such a subsidy should be proportional to the learning-by-doing spillovers.

There is however little evidence of the existence of learning by doing in the renewable industry and, also, such effects are not easily quantifiable.[21] It is therefore complex to justify a RES-E support mechanism based on learning-by-doing effects (and also to assess whether the amount of such subsidy responds to the learning-by-doing spillovers).

5.2.2 R&D Investment in Renewables

Investment in R&D reduces the cost of producing renewables. In our model R&D investment can be modelled as an investment cost I which reduces the production costs by $1 - G(I)$, where $G(0) = 1$, $G(I) \leq 1$ and $G'(I) \leq 0$. The renewables cost function in the presence of R&D would be $G(I) * c_2(q_2) - I$. The profit function of the monopolist would therefore be:

$$\text{Max } P(Q)(q_1 + q_2) - c_1(q_1) - G(I)c_2(q_2) + rq_2 - p_e e_1 - I$$

R&D investment would increase the competitiveness of the renewable technology and would therefore reduce the subsidy necessary to meet a specific renewable target.

The existence of positive externalities from R&D investment could justify subsidies to R&D but not subsidies to the deployment of renewables. Again, subsidies to R&D make sense only if there are positive externalities from R&D and these cannot be captured by individual firms. If benefits from R&D are fully captured by the R&D investors, then there is no justification for subsidies.

[21] As Borenstein [6] states, "most studies of learning-by-doing are not able to separate learning-by-doing from other changes" and "the evidence of strong learning-by-doing is thin and credible results on spillovers are even more rare".

5.2.3 Investment in Carbon Efficiency

Improvements in the carbon efficiency of fossil-fuelled technologies would affect the emissions function $e_1 = f(q_1)$. Improvements in the carbon efficiency reduce the emissions per unit of output of fossil-fuelled energy. This would translate into lower carbon prices and larger production of the fossil-fuelled energy.

Paradoxically, the improvement in carbon efficiency would increase the competitiveness of carbon emitting technologies and thus higher subsidies would be required to meet a specific renewables target R. However, better carbon efficiency of fossil-fuelled technologies reduces emissions and thus reduces the need for supporting renewables.

6 Conclusions and Policy Recommendations

We know that the use of fossil fuels generates GHG emissions and, thus, imposes external costs on present and future generations that are not reflected in its market price. This encourages the consumption of non-renewable energy above its socially optimal level. Pricing correctly the externality costs is therefore the most efficient policy to restore optimality. Consequently, GHG emission caps (and associated carbon prices) or carbon taxes are the best policy to reduce carbon emissions. However, additional policies may be justified when the carbon policies show imperfections and design flaws, or in the presence of other market failures.

This chapter focuses on the interaction between carbon markets and RES-E support mechanisms. A number of conclusions can be reached in such context:

First, if emissions are subject to a binding cap and the emissions market is well designed, then expanding the renewables production does not bring any additional benefits in emissions reductions. Yet, theoretical and empirical studies show that such policies tend to increase the cost of emissions reduction in comparison with a policy based on carbon prices.

Second, additional policies aiming to support the production of RES-E may be justified in the presence of imperfections or design flaws in carbon policies and in the presence of non-appropriable spillovers from technological innovation. Nevertheless, empirical evidence shows that the cost of reducing emissions is larger when the two policies are simultaneously activated. Therefore, the use of other policy instruments should be limited to the cases where their expected benefits are verifiable.

Third, RES-E support policies tend to reduce carbon prices and decrease wholesale electricity prices. However, retail prices will be higher if subsidies are recouped via uplifts on electricity retail prices. This, in turn, reduces the relative costs of fossil fuels versus renewable energy, which carries two major risks that should be addressed. One is the reduction of the final demand for electricity and the increase in the share of fossil fuels final consumption. The other risk is low-emissions fossil fuel, for instance gas, being replaced by high-emissions fossil fuels, such as coal, in the production of electricity. So, paradoxically, it may turn out that RES-E support programmes end up promoting the dirtiest technologies.

Fourth, subsidies or other support schemes to renewables aiming to correct carbon market flaws should be set according to marginal damages. R&D subsidies should reflect the spillover rate and RES-E production should be subsidised in proportion to the spillovers resulting from learning-by-doing. However, in practice this is not always feasible and the promotion of specific technologies is linked to the cost difference with the marginal competitive technology. This may bring inconsistencies that should be carefully addressed.

Fifth, the climate policy mix should be carefully designed to take into account potential interactions between policy instruments. RES-E support mechanisms should address the market failure they aim to solve, be it carbon market imperfections or non-appropriable technology externalities. The impact of RES-E support mechanisms on carbon prices should be included in their design to avoid unwanted effects. The danger that a bad design increases the cost of carbon reduction and fosters the use of dirtier technologies is real.

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