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Opportunity Cost of Carbon Pricing and White Certificate Programs: A Business Case

Giacomo Di Foggia[1] & Massimo Beccarello[1]

[1] Department of Business and Law, University of Milano-Bicocca, Italy

Correspondence: Giacomo Di Foggia, Department of Business and Law, University of Milano-Bicocca, Italy. E-mail: giacomo.difoggia@unimib.it

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Abstract

Carbon pricing aims to capture the external costs of emissions and link them to their sources through a price signal, while market-based policy tools support investments in energy efficiency, rewarding investors following certified energy savings. The interplay between the emission trading system and the white certificate scheme is complex, especially regarding opportunity costs and the efficiency of the two mechanisms combined in achieving environmental goals. Using monthly data covering six years, we analyze how carbon pricing and white certificate programs intertwine. We consider the opportunity cost as the savings from an energy efficiency intervention under the white certificate program in a firm covered by the emission trading system. We calculate the €/MWh savings corresponding to a one MWh reduction in energy consumption to assess the contribution of white certificates and the emission trading system as determinants of the savings induced by an energy efficiency intervention. We then simulate how the economic determinants of saving vary as the dynamics of the gas and emission permit markets change. The relative weight of the components on saving differs significantly according to the dynamics of the related commodity and environmental markets. Provided that the emission trading system is mandatory for certain industries while participation in a white certificate scheme is voluntary, we argue that the overlap between the two mechanisms can be effective. This is important for policymaking, periodic fine-tuning interventions to market-based mechanisms, and increasing flexibility. The paper also has business implications, given that energy managers may use this framework in building energy management strategies.

Keywords: carbon pricing, ETS, White certificates, environmental policy, overlapping policies, energy efficiency, environmental management

1. Introduction

There is a broad consensus on the importance of carbon pricing programs in the economic decarbonization path and for climate mitigation policies (de Perthuis & Trotignon, 2014; Fragkos & Fragkiadakis, 2022; Hintermayer, 2020). Carbon pricing is one of the tools of the environmental policies necessary to reduce emissions; it can also be a source of revenue and a competitiveness lever (Li et al., 2019; Verde, 2020) and can be a valuable means to promote efforts in employing the best available technologies. Indeed, while firms may analyze carbon pricing to assess its impact on their operations, their investment decisions, and as a tool to identify potential environmental risks and strategic opportunities, investors use carbon pricing to analyze the potential impact of climate change policies on their investment portfolios (World Bank, 2022b). Policymakers assess its effectiveness in achieving their policy goals to fine-tune policies best suited to their specific needs, circumstances and goals.

Carbon pricing mechanisms cover about a quarter of world emissions. However, the carbon price is often deemed under optimal value. The gap between carbon prices worldwide and the prices needed to meet climate mitigation goals could be closed by improving the public acceptability of carbon prices through the appropriate use of revenue (Klenert et al., 2018). Among the main environmental policies, a prominent carbon pricing tool is the emission trading system (ETS) mechanism (Verbruggen et al., 2019), a cornerstone of the European environmental policy that is now being widely developed. The mechanism works on the cap-and-trade principle (Narassimhan et al., 2018). A cap is set on the total emissions the firms covered by the system can emit yearly. The cap decreases over time so that total emissions fall, and within the cap, firms negotiate allowances. Carbon pricing is a prerequisite for carbon mitigation strategies but, implemented alone, it struggles overcome many barriers to cost-effective energy efficiency actions.

Therefore, carbon pricing policies should coexist with energy efficiency instruments to ensure optimal outcomes for a combination of economic, social, and climate change objectives. Many countries have introduced market instruments to support investments to reduce emissions by innovation in processes and plants through energy-efficient interventions (Anser et al., 2020). A recent study analyses global data regarding market-based energy efficiency instruments and identifies more than fifty instruments corresponding to approximately 10% of the global annual investment in energy efficiency (Oikonomou, 2017).

Prominent market-based instruments are based on tradable certificates that prove end-use energy savings achieved through energy efficiency interventions to support investments in energy efficiency (Morganti & Garofalo, 2022). Such mechanisms, known as white certificate (WhC) schemes, work in several market conditions and generate energy savings (Di Foggia, 2016). WhCs can enable investments in the energy transition to help achieve the 2030 and 2050 objectives in terms of energy efficiency, production from renewable sources and reduction of emissions.

Provided that WhC has gained consensus given the results, complementary instruments are deemed crucial to boost their effectiveness. Therefore, it is no wonder that the intersection between the mentioned approaches can pave the way for efficiency gains. For example, following the Energy Efficiency Directive (EED) adoption, European countries have implemented policies and measures to meet the Directive's requirements (Zangheri et al., 2019).

However, the interaction between carbon pricing tools based on cap and trade and other market instruments has also given rise to some complex issues and worries, mainly in terms of opportunity costs and the relative efficiency of the two mechanisms when combined (Böhringer et al., 2008; Cludius et al., 2020; Wiese et al., 2020).

It is important to emphasize that carbon pricing can address energy efficiency market failures that fall into four general categories: imperfect competition, incomplete markets, conflicting information and asymmetric information (Sorrell et al., 2004).

We delve into the interaction between the main European carbon pricing policy named the European Emission trading system (EU-ETS) and a successful energy efficiency policy, focusing on a WhC scheme to add pieces of information regarding their interaction and potential incentive in promoting energy efficiency investments and contributing to the decarbonization of industrial processes.

The European ETS, defined by Directive 2003/87/EC, is one of the leading EU measures to reduce emissions in industrial sectors with the most significant impact on climate change. One of the objectives of the ETS is to steer investments in a sustainable direction through price signals based on market dynamics (Flora & Vargiolu, 2020).

Subsequently, several European countries have introduced mechanisms based on WhC (Giraudet & Finon, 2015). For example, in Italy, the WhC scheme was introduced in 2005 and is still the main instrument for promoting energy efficiency. In this regard, previous literature shows that countries sometimes pursue specific initiatives that may overlap with the wider carbon pricing mechanisms. Some policies may leverage additional climate benefits elsewhere in the system, while others may backfire by raising aggregate emissions (Perino et al., 2019).

Environmental and economic theory emphasizes how policies can influence the production behavior of firms through the implementation of policy instruments theoretically divided into two macrocategories: policies command and control and policies based on market mechanisms (Böcher, 2012; Guerriero, 2013). Some authors point out potential efficiency losses resulting from overlapping measures (Böhringer et al., 2008). We believe it is important to contribute to the analysis of interactions between the ETS and, in this case, WhC with a view to the complementarity of the two mechanisms. Furthermore, we intend to verify how their incentive potential depends on price volatility in the main environmental reference markets.

Moreover, previous literature has analyzed the pros and cons of the co-existence of different instruments that may also generate problems in terms of effectiveness in achieving environmental goals and in terms of the efficiency with which the goals are met (Beck & Kruse-Andersen, 2020; Herweg, 2020; Perino & Willner, 2016). However, combining ETS and other policies can help achieve their respective purposes. Therefore, we assume that there are several points in favor of the coexistence of the ETS with different approaches. Namely, the possibility of achieving multiple objectives that would be difficult to achieve with a single policy, reducing market failures, and the multiplying effect of incentives for investments in energy efficiency projects.

We develop this idea in detail through two related research questions. Specifically, we aim to understand how the total saving of an energy efficiency intervention varies according to the environmental markets' dynamics and how the relative incentive weights of the two instruments mutate under different market conditions.

We believe that the multiplying effect mechanisms depend to a large extent on the dynamics of the environmental reference markets. We answer the research question through an empirical analysis using six years of monthly data during which periods of relative market stability and periods characterized by high price volatility due to economic shocks fall. Specifically, we analyze data from July 2016 to June 2022 because during the last year and especially last semester, prices of commodities have steadily increased, and according to the World Bank, most energy and environmental market prices are now expected to remain high in the medium term (World Bank, 2022a).

We calculate the marginal savings from reduced energy consumption so that the contribution from WhC and ETS as determinants of energy efficiency savings can be assessed in a complementary manner. Our results help clarify the multiplying effects of the mechanisms under different gas and carbon market prices. This paper has implications for policy arising primarily from the emerging evidence that helps to better understand and refine policy instruments complementary to the ETS. Moreover, given that both mechanisms covered in this analysis are attracting increasing global interest as a cost-effective means of encouraging investment by energy-intensive businesses, this study on their complementarity becomes essential.

2. Materials and Methods

While carbon pricing creates financial incentives to reduce emissions to avoid the cost associated with emissions, WhC primarily addresses the cost of energy efficiency interventions such as new, often expensive, technologies aimed at improving the energy efficiency of, for example, a production plant. Therefore, the combined effect should be explored between the two instruments and, eventually, other enabling policies to create the right market conditions for greening industrial processes. The overlapping and complementarity of different policy instruments may impact the incentive to reduce emissions, carbon prices, and distributional impacts on businesses. The interactions can be resumed in three categories: complementary policies can help improve incentives, overlapping policies can help with duplicate incentives, and countervailing policies can contradict the incentives (IEA, 2017), as shown in Figure 1.

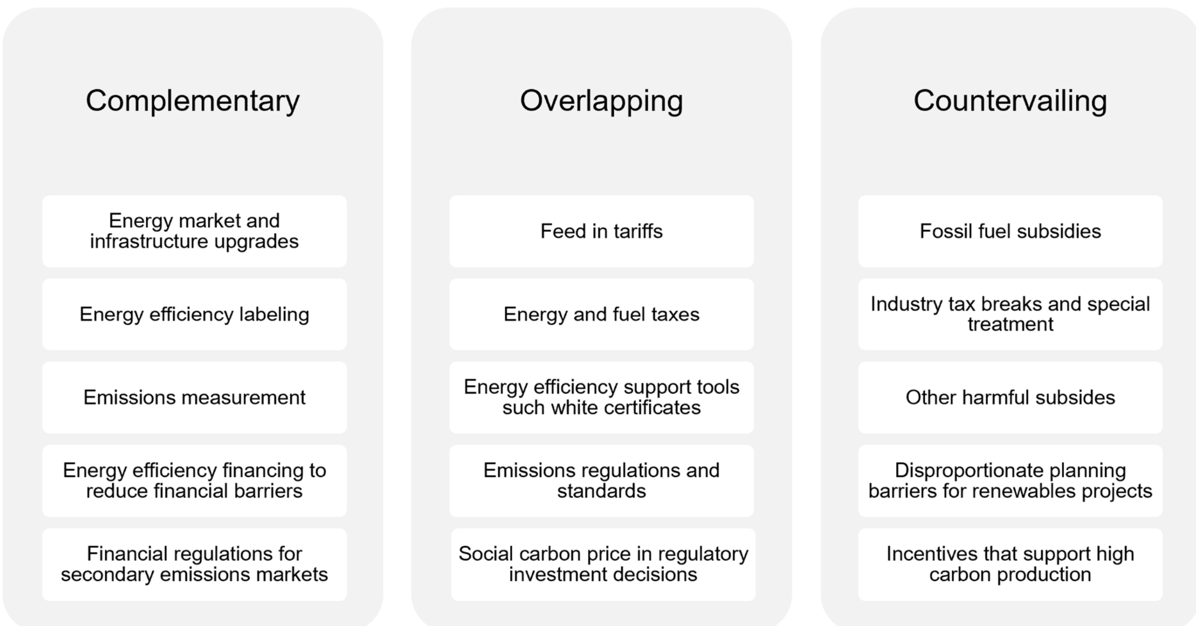

Figure 1. Interaction among policies

Source: adapted from (Partnership for Market Readiness, 2021)

Assessing the effectiveness of subsidies and classifying them according to their environmental sustainability is often challenging. From this perspective, it is interesting to note the significant reduction in the release of quotas assigned free of charge within the ETS, for example, in Italy, from 1.58 billion in 2019 to 1.4 billion in 2020 (MITE, 2022).

Similarly, it is important to underline the role of feed-in tariffs through which a tariff is granted to certified renewable source plants for all the energy produced and fed into the grid for a certain period. The energy is sold to the network at a single subsidized rate, which includes the energy's incentive and economic enhancement component. Finally, carbon offsetting allows organizations to offset their emissions by supporting certified emission reduction projects, which absorb or avoid emissions.

This mechanism is achieved through the purchase of carbon credits. These voluntary interventions can be complementary if they do not distort the price. It can be a valuable tool for decarbonization if the social cost of carbon converges globally; otherwise, situations of imbalance emerge. For example, certification activities must be uniform. Otherwise, there can be counterproductive effects or offsets of emissions, particularly direct emissions, defined as scope 1 emissions, at lower costs than optimal ones with disincentive effects regarding investments in decarbonization technologies.

To perform the empirical analysis, we proceeded in the following way: once the research question was defined, we developed the hypotheses and gathered the data. Subsequently, we defined the marginal saving and its components induced by an energy efficiency intervention measured in €/MWh resulting from reducing one MWh of electricity consumption. Afterward, we calculated the relative weight of each component over the six years. Finally, we analyzed the influence of exogenous variables on the two components of saving under examination from a complementary perspective: the component related to the ETS mechanism and the component related to the WhC scheme.

In this paper, the opportunity cost is meant as the savings deriving from an investment in energy efficiency in an industry that also falls into the emission trading system; therefore, the opportunity cost can also be meant as the missed savings associated with an energy efficiency intervention compliant with the white certificate mechanism program.

We provide insights into the relative weight and evolution of the ETS and the WhC schemes meant as incentives for energy efficiency investments. Consequently, starting from the underlying research motivation we intend to assess is reasonable.

First, we aim to shed light on how an energy efficiency intervention's opportunity cost, i.e., saving, is impacted by the dynamics of the relevant environmental market change. Second, we explain how the contribution of WhC and the ETS to the savings induced by an energy efficiency intervention mutates. We do not consider the impact of investment costs to implement energy efficiency projects, as we only focus on the complementary role of the two policy tools.

We motivate these questions bearing in mind that our results are helpful for planning periodic interventions to improve incentive systems and may serve policymakers regarding planning policies to boost energy efficiency investments. Indeed, the effectiveness of carbon pricing and energy efficiency policies depends on how much they can prompt investments, making them strategic for firms and positive for society.

2.1 Data and Variables

We conduct an empirical analysis based on data retrieved from official sources. Specifically, the gas market prices were retrieved by querying the database published by the Italian energy market manager, i.e., the body in charge of organizing and managing the Italian electricity market (GME, 2022). The carbon prices were downloaded by the European Energy Exchange (EEX, 2022); the tariff reimbursement of WhC was obtained by the Italian Regulatory Authority for Energy, Networks and Environment (ARERA, 2020). Oil prices were obtained from the International Energy Agency, while the carbon intensity emission factor was taken from the Italian Institute for Environmental Protection and Research (ISPRA, 2022).

We designed our research based on the following criteria to provide an extensible and repeatable result in different contexts. The historical range is sufficiently long to allow sensitivity analyses and, at the same time, not too long to avoid the risk of results decontextualized from the current situation.

The database contains the monthly data of the variables used to conduct the simulation from July 2016 until June 2022. The case study is the Italian market following the policy instrument under analysis, that is, the Italian WhC scheme, given that it is one of the most long-lasting schemes.

Below are the variables used to calculate marginal saving and its components: the variable named gas is the gas price in €/MWh as published by the Italian electricity market manager, while carbon is the carbon price (EUA) expressed in €/tonne of carbon and spread corresponds to the spark spread, i.e., the gross margin from the sale of a unit of electricity, after purchasing the fuel to produce this unit of electricity as well as the other costs that are included in the spark spread.

Next, the commodity variable was calculated by multiplying the price of gas in the Italian market by two, given that the approximate production loss factor is 50%, plus the spark spread; carbon_q is the carbon price multiplied by the emissions factor, whc_q is the value of WhC multiplied by 0.187, i.e., the conversion factor kWh - tonnes of oil equivalent since the conversion factor is set by the Authority equal to $1KwH = 0.187 \times 10^{-3}TOE$, service is the sum of transport and dispatching cost, i.e., the variable network and system charges that are aimed at covering costs related to general interest activities for the electricity system.

Finally, f_co2mwhp is the carbon emission intensity factor for electricity production that is a useful tool to monitor projects that aim to produce energy savings and increase final use efficiency; oil is the price of oil, precisely the average spot price of Brent, GDP is the EU-27 gross domestic product at market prices, which is a proxy of the European economy demand evolution that, in turn, correlates with prices of European environmental markets. We calculate the marginal savings measured in €/MWh resulting from the reduction of one MWh energy consumption. With this approach, we can evaluate the effect of incentives arising from the WhC and the ETS as components of the saving induced by an energy efficiency intervention.

The underlying concept of this approach is straightforward and helpful in filling the gap in the literature regarding the potential impact of the two instruments that, although different, have the common goal of reducing greenhouse gas emissions. Regarding WhC, the incentive corresponds to the value of the WhC awarded to the company that carries out a compatible energy efficiency intervention. On the other hand, as far as the ETS is concerned, the incentive corresponds to the avoided cost resulting from the reduction of verified emissions, which are the ones underlying the ETS. In addition to the components mentioned above, we consider the avoided costs of energy transmission and distribution resulting from reduced electricity consumption and system charges, which are also avoided costs. The sum of these four components represents the opportunity cost of the energy efficiency intervention; it should be noted, however, that this is a partial analysis since the cost of the intervention is not contemplated in our analysis. We can perform these calculations using conversion factors from tonnes of oil equivalent to MWh. We analyze the data using the variables and factors described in the dedicated section. In this regard, the table below shows some descriptive statistics of the variables.

Table 1. Descriptive statistics of variables

Variable	Unit	Obs	Mean	Std. dev.	Min	Max
gas	€/MWh	72	29.271	27.829	5.975	128.317
carbon	€/ton	72	28.104	23.584	4.310	90.790
Oil	€/barrel	72	62.586	18.618	18.196	121.483
GDP	€mn	72	1145.58	48.476	1027.127	1244.825
commodity_q	€/MWh	72	68.297	58.843	13.807	277.805
ets_q	€/MWh	72	11.543	9.373	1.923	36.498
service_q	€/MWh	72	70.000	0.000	70.000	70.000
whc_q	€/MWh	72	45.254	0.000	45.254	45.254
com_sh	%	72	31.068	12.238	10.069	65.634
ets_sh	%	72	5.433	2.976	1.180	11.310
ser_sh	%	72	38.566	8.175	16.538	51.048
whc_sh	%	72	24.932	5.285	10.692	33.002
month	time	72	713.500	20.928	678.000	749.000
lf	Factor	72	0.5	0.000	0.000	0.000
f_kwtoe	Factor	72	0.187	0.000	0.000	0.000
f_co2mwhp	Factor	72	0.42	0.0197	O.402	0.446

Starting from the variables listed in table 1, we can proceed with the following calculation that can be summarized as saving in (€/MWh) for each MWh of electricity saved.

Equation 1 formalizes the marginal saving.

$$saving = commodity + whc + ets + service \tag{1}$$

where:

$$commodity = gas \times 2 + spark\ \ spread \quad (2)$$

and

$$service = network + charges \quad (3)$$

Equation 1 is a simplified but representative point of view of a firm. Using the same variables, we can also assess the cost-effectiveness of WhC considering the ETS mechanism. Indeed, WhC represents a cost to public finance, the effectiveness of which can be measured by the value of the resulting avoided emissions. Figure 2a shows the price trends in the relevant environmental markets: the gas and carbon markets are useful for our analysis. They are the main determinants of the change in the relative weight of the marginal saving components under consideration. Such information is important as many factors come into play when analyzing and hypothesizing the future development of gas prices; some of the most important are the development of oil prices and the dynamics of economies worldwide. On the other hand, according to the World Bank, the rapid increase in carbon prices and the start-up of the new ETS have seen a surge in revenues. However, prices in most jurisdictions remain below the threshold to meet the Paris Agreement targets.

3. Results

The savings induced by each MWh of electricity saved because of an energy efficiency intervention compatible with the WhC scheme are shown in figure 2b. First, we can see that over the six years, the share of the commodity in the marginal savings is approximately 31.1%; this percentage increases to 54.75% considering the available last year. Similar considerations can be drawn for other components. The share of ETS is 5.43% considering six years, while it surges to 9.35% in the last year, and the share of WhC is 24.93% considering six years, while it is approximately 12.56% in the last year.

The primary evidence is the evolution of the saving of an energy efficiency intervention. Indeed, the average savings are 195.09 €MWh. It surged from 164.46 €MWh in July 2016 - June 2017 to 330.65 €MWh from July 2021 to June 2022. Therefore, starting from the results depicted in Figure 2b, we can now consider how the economic determinants of saving induced by an energy efficiency intervention vary in the context, particularly the dynamics of the environmental markets.

We also note an opposite trend regarding what can be defined as an incentive effect of the ETS and the WhC scheme.

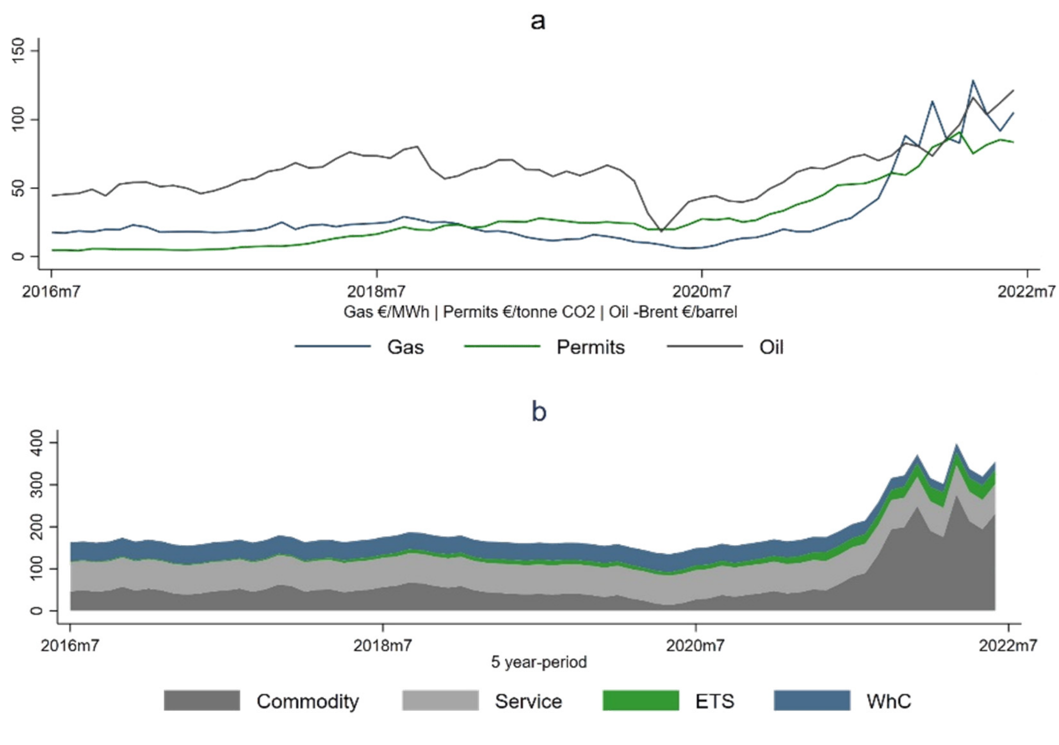

Figure 2. Relation between commodity and carbon prices and marginal saving

As mentioned above, the component attributable to the ETS increases, while the component referring to WhC decreases. In addition, we can add further consideration to the cost-effectiveness of the WhC scheme. Indeed, the WhC component can also be meant as the direct marginal cost of the mechanism and can be compared with the marginal benefits corresponding to the environmental externalities from reduced energy consumption. Consequently, break-even can be identified as the point at which the unit cost of the mechanism equals the environmental benefits corresponding to the components net of the *service* and WhC. Once we have normalized the saving in €/MWh induced by the reduction in MWh electricity consumption by calculating the relative share of the components, we can investigate how certain context variables influence the role of ETS and WhC through the relationship formalized in equation 4.

$$comp = \propto + \beta_1 gas \ + \beta_2 carbon + \beta_3 oil + \beta_4 spread + \ \beta_5 gdp + \beta_6 tr + \varepsilon \tag{4}$$

Table 2 contains the regression analysis results to highlight the impact of certain variables on the relative weight of the two components under our analysis.

Table 2. Regression model

VARIABLES	(1)	(2)
	ETS	WHC
gas	-0.328***	-0.343***
	(0.0173)	(0.0157)
carbon	0.972***	-0.0326
	(0.0381)	(0.0347)
oil	0.0778	0.0493
	(0.0493)	(0.0448)
spread	-0.0600***	-0.0572***
	(0.00977)	(0.00888)
GDP	0.687**	0.896***
	(0.311)	(0.283)
month	-0.00534***	-0.00307**
	(0.00144)	(0.00130)
Constant	-1.608	0.139
	(2.489)	(2.263)
Observations	70	70
R-squared	0.995	0.972

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. all values in logarithms except for month.

Table 2 relates the saving portion relating to ETS and WhC with some context variables that influence them. Regarding the gas market, we note how this affects, as expected, the relative weight of both variables since this variable affects electricity consumption, which is, therefore, a hypothetical direct avoided cost; the price of gas indeed is the main diver of the component of saving named commodity.

It is no wonder, therefore, that considering recent gas price increases due to the geopolitical crisis, we note from Figure 2b that its impact is significant and, according to world bank forecasts, likely to persist. Turning to the price of permits, the situation changes. As we expect, the carbon price positively impacts the relative weight of the ETS mechanism, but at the same time, we note a negative effect on the relative weight of WhC. Considering the oil price, a positive impact emerges, although without statistical significance.

The trend of the European economy also has an impact compatible with our forecasts; in fact, the European GDP positively impacts both variables, and the reasons are multiple, such as the demand impact on energy markets and a deemed increase in available financial resources. To conclude, the interplay between ETS and WhC may prompt investments in energy efficiency due to opportunity costs and the weight of marginal saving components that depend on the relevant commodity and carbon market.

4. Discussion

In light of the 2015 Paris Agreement that embraced the goal of restricting the growth in global temperature to 1.5–2 °C above pre-industrial levels (Di Foggia, 2021), carbon pricing plays a prominent role (Boyce, 2018). Carbon pricing aims to capture the external costs of emissions and link them to their sources through a carbon price. Pricing carbon helps put the burden of damage caused by emissions back on those who generate them by creating an incentive to reduce emissions. It allows them to decide whether to transform their businesses, reduce their emissions, or continue to issue and pay the price (World Bank, 2022b).

Our results bring value to the debate on the cost-effectiveness of market mechanisms to support decarbonization, considering the evolution of commodity and carbon markets. Thus, we note how the weight of saving components induced by an energy efficiency intervention differs as the context changes. Therefore, our work contributes to understanding how the economic determinants of energy efficiency savings vary as the dynamics of environmental carbon and gas markets change.

Although this information is, to some extent, taken for granted given the steady correlation between environmental markets and the opportunity cost of energy efficiency interventions, it is important in this historical period to emphasize this concept for at least three reasons. First, the uncertainties associated with global economic trends; second, the international political and economic stability; and third, the decarbonization targets most states intend to achieve by 2050. At this point, we provide some considerations supporting the complementarity between the WhC scheme and the ETS in support of the thesis that the overlap between the different policies can be efficient if well governed by policymakers and market regulators. First, the ETS is compulsory, whereas WhC applies to voluntary interventions that require a preliminary strategic analysis by the companies, apart from companies obliged to do so by law. We believe that the scope of application is also noteworthy.

The ETS range is broader, applying to different industries and technologies. In contrast, the scope of WhC is limited to energy efficiency interventions. Moreover, although the ETS is a global mechanism, it applies to specific sectors, introducing distortions between industries, as evident from the European decarbonization targets providing stricter constraints for industries covered by the ETS than for companies outside the ETS perimeter. Then, the ETS applies to the whole plant, thus both to parts of the production process that can be improved and those parts on which it is not possible to intervene. In contrast, the WhC scheme applies selectively to those parts where intervening is possible.

Based on market dynamics, periodic interventions should be planned to improve incentive mechanisms. Another interesting feature of our approach and the results obtained is that scholars can easily replicate them in other cases. Therefore, we hope similar studies focusing on other states will be developed to strengthen the literature and lay the groundwork for developing international benchmarks. Benchmarks and comparable data are useful to policymakers and system operators in developing and applying regulatory instruments and policies to support the transition of the economy considering global climate and circular economy goals (Di Foggia & Beccarello, 2022).

5. Conclusion

The need to better understand how carbon pricing schemes and market-based energy efficiency incentives intertwine has gained momentum, strengthened by the increasing decarbonization goals. We have analyzed such a relationship from an economic standpoint, assessing opportunity cost. In particular, we consider the opportunity cost as the savings from an energy efficiency intervention within the white certificate program in a firm covered by the emission trading system. This research aims to understand how carbon pricing and WhC programs' opportunity cost interact to shed light on their combined role in energy efficiency investments. Indeed, there are reasons why the two mechanisms can contribute to multiple goals that are difficult to achieve with a single policy.

We first calculated and comparatively evaluated the savings components that could be associated with WhCs and the ETS for one MWh of energy consumption. Next, through a set of macrolevel determinants, we investigated the impact of such exogenous variables on the relative weight of the two components, shedding light on how international energy and environmental markets can impact investment decisions.

Such information is important given that the interaction between carbon pricing schemes and WhC schemes can be complex, especially regarding the opportunity costs and efficiency of the two mechanisms combined in achieving environmental goals.

Our analysis reveals some evidence that can be used for proper market-based energy efficiency governance. The results also confirmed that the relative weight of the components of marginal saving and, thus, the incentive potential of the WhC and ETS mechanisms fluctuate significantly with the dynamics of the related environmental markets. Provided that carbon pricing is needed to integrate climate change costs into economic decision-making, it is not enough to meet clime mitigation targets; other policy tools such as WhC are needed to complement it to achieve climate targets.

Nevertheless, sound governance of both instruments is essential to prompt investments in cleaner technologies. This paper's main added value is providing empirical evidence and insights into the interaction between two of the most important environmental policy tools for decarbonization, underlining how the tools can complement each other.

References

Anser, M. K., Yousaf, Z., & Zaman, K. (2020). Green Technology Acceptance Model and Green Logistics Operations: “To See Which Way the Wind Is Blowing”. In *Frontiers in Sustainability* (Vol. 1). Retrieved from https://www.frontiersin.org/article/10.3389/frsus.2020.00003

ARERA. (2020). *Resolution 270/2020/R/efr*. Retrieved from https://www.arera.it/allegati/docs/20/270-20.pdf

Beck, U., & Kruse-Andersen, P. K. (2020). Endogenizing the Cap in a Cap-and-Trade System: Assessing the Agreement on EU ETS Phase 4. In *Environmental and Resource Economics* (Vol. 77, Issue 4). Springer Netherlands. https://doi.org/10.1007/s10640-020-00518-w

Böcher, M. (2012). A theoretical framework for explaining the choice of instruments in environmental policy. *Forest Policy and Economics*, *16*, 14–22. https://doi.org/10.1016/j.forpol.2011.03.012

Böhringer, C., Koschel, H., & Moslener, U. (2008). Efficiency losses from overlapping regulation of EU carbon emissions. *Journal of Regulatory Economics*, *33*(3), 299–317. https://doi.org/10.1007/s11149-007-9054-8

Boyce, J. K. (2018). Carbon Pricing: Effectiveness and Equity. *Ecological Economics*, *150*, 52–61. https://doi.org/https://doi.org/10.1016/j.ecolecon.2018.03.030

Cludius, J., de Bruyn, S., Schumacher, K., & Vergeer, R. (2020). Ex-post investigation of cost pass-through in the EU ETS - an analysis for six industry sectors. *Energy Economics*, *91*, 104883. https://doi.org/10.1016/j.eneco.2020.104883

de Perthuis, C., & Trotignon, R. (2014). Governance of CO2 markets: Lessons from the EU ETS. *Energy Policy*, *75*(2014), 100–106. https://doi.org/10.1016/j.enpol.2014.05.033

Di Foggia, G. (2016). Effectiveness of Energy Efficiency Certificates as Drivers for Industrial Energy Efficiency Projects. *International Journal of Energy Economics and Policy*, *6*(2), 273–280.

Di Foggia, G. (2021). Drivers and challenges of electric vehicles integration in corporate fleet: An empirical survey. *Research in Transportation Business and Management*, *41*. https://doi.org/10.1016/j.rtbm.2021.100627

Di Foggia, G., & Beccarello, M. (2022). Introducing a system operator in the waste management industry by adapting lessons from the energy sector. *Frontiers in Sustainability*, *3*, 984721. https://doi.org/10.3389/frsus.2022.984721

EEX. (2022). *Environmental markets - EUA*. Retrieved from https://www.eex.com/en/

Flora, M., & Vargiolu, T. (2020). Price dynamics in the European Union Emissions Trading System and evaluation of its ability to boost emission-related investment decisions. *European Journal of Operational Research*, *280*(1), 383–394. https://doi.org/10.1016/j.ejor.2019.07.026

Fragkos, P., & Fragkiadakis, K. (2022). Analyzing the Macro-Economic and Employment Implications of Ambitious Mitigation Pathways and Carbon Pricing. In *Frontiers in Climate* (Vol. 4). Retrieved from https://www.frontiersin.org/article/10.3389/fclim.2022.785136

Giraudet, L.-G., & Finon, D. (2015). European experiences with white certificate obligations: A critical review of existing evaluations. *Economics of Energy and Environmental Policy*, *4*(1), 113–130. https://doi.org/10.5547/2160-5890.4.1.lgir

GME. (2022). *Gas market data*. Retrieved from https://www.mercatoelettrico.org/it/

Guerriero, C. (2013). The political economy of incentive regulation: Theory and evidence from US states. *Journal of Comparative Economics*, *41*(1), 91–107. https://doi.org/10.1016/J.JCE.2012.05.003

Herweg, F. (2020). Overlapping efforts in the EU Emissions Trading System. *Economics Letters*, *193*(2020), 109323. https://doi.org/10.1016/j.econlet.2020.109323

Hintermayer, M. (2020). A carbon price floor in the reformed EU ETS: Design matters! *Energy Policy*, *147*, 111905. https://doi.org/10.1016/j.enpol.2020.111905

IEA. (2017). *Market-based Instruments for Energy Efficiency. Policy Choice and Design*. Retrieved from https://www.iea.org/reports/market-based-instruments-for-energy-efficiency

ISPRA. (2022). *Efficiency and decarbonization indicators in Italian energy and power sector*. Retrieved from https://www.isprambiente.gov.it/files2022/pubblicazioni/rapporti/r363-2022.pdf

Klenert, D., Mattauch, L., Combet, E., Edenhofer, O., Hepburn, C., Rafaty, R., & Stern, N. (2018). Making carbon pricing work for citizens. *Nature Climate Change*, *8*(8), 669–677. https://doi.org/10.1038/s41558-018-0201-2

Li, M., Weng, Y., & Duan, M. (2019). Emissions, energy and economic impacts of linking China's national ETS with the EU ETS. *Applied Energy*, *235*, 1235–1244. https://doi.org/10.1016/j.apenergy.2018.11.047

MITE. (2022). *Catalog of environmentally harmful subsidies and favorable environmental subsidies 2019-2020 [Catalogo sussidi ambientalmente dannosi e dei sussidi ambientali favorevoli 2019-2020]*. Retrieved from https://www.mite.gov.it/pagina/catalogo-dei-sussidi-ambientalmente-dannosi-e-dei-sussidi-ambientalmente-favorevoli

Morganti, P., & Garofalo, G. (2022). Interactions between market forces and regulatory interventions in the Italian market of white certificates. *Energy Efficiency*, *15*(4), 18. https://doi.org/10.1007/s12053-022-10027-y

Narassimhan, E., Gallagher, K. S., Koester, S., & Alejo, J. R. (2018). Carbon pricing in practice: a review of existing emissions trading systems. *Climate Policy*, *18*(8), 967–991. https://doi.org/10.1080/14693062.2018.1467827

Oikonomou, V. (2017). Interactions between white certificates for energy efficiency and other energy and climate policy instruments. In *The Social and Behavioural Aspects of Climate Change: Linking Vulnerability, Adaptation and Mitigation* (pp. 177–201). Routledge. https://doi.org/10.4324/9781351278768

Partnership for Market Readiness. (2021). *Carbon pricing assessment and decision-making: a guide to adopting a carbon price*. Retrieved from https://openknowledge.worldbank.org/handle/10986/35387

Perino, G., Ritz, R. A., & van Benthem, A. (2019). Overlapping Climate Policies. In *National Bureau of Economic Research Working Paper Series* (No. 25643). https://doi.org/10.3386/w25643

Perino, G., & Willner, M. (2016). Procrastinating reform: The impact of the market stability reserve on the EU ETS. *Journal of Environmental Economics and Management*, *80*, 37–52. https://doi.org/10.1016/j.jeem.2016.09.006

Sorrell, S., O'Malley, E., Schleich, J., & Scott, S. (2004). *The Economics of Energy Efficiency: Barriers to Cost-Effective Investment*. Edward Elgar.

Verbruggen, A., Laes, E., & Woerdman, E. (2019). Anatomy of Emissions Trading Systems: What is the EU ETS? *Environmental Science and Policy*, *98*(January 2019), 11–19. https://doi.org/10.1016/j.envsci.2019.05.001

Verde, S. F. (2020). the Impact of the Eu Emissions Trading System on Competitiveness and Carbon Leakage: the Econometric Evidence. *Journal of Economic Surveys*, *34*(2), 320–343. https://doi.org/10.1111/joes.12356

Wiese, C., Cowart, R., & Rosenow, J. (2020). The strategic use of auctioning revenues to foster energy efficiency: status quo and potential within the European Union Emissions Trading System. *Energy Efficiency*, *13*(8), 1677–1688. https://doi.org/10.1007/s12053-020-09894-0

World Bank. (2022a). *Commodity Markets Outlook, April 2022 : The Impact of the War in Ukraine on Commodity Markets. Commodity Market Outlook*. Retrieved from https://openknowledge.worldbank.org/handle/10986/37223

World Bank. (2022b). *State and Trends of Carbon Pricing 2022*. World Bank. https://doi.org/10.1596/ 978-1-4648-1895-0

Zangheri, P., Economidou, M., & Labanca, N. (2019). Progress in the Implementation of the EU Energy Efficiency Directive through the Lens of the National Annual Reports. *Energies*, *12*(6). https://doi.org/10.3390/en12061107