FONDAZIONE ENI ENRICO MATTEI

NOTA DI LAVORO

99.2011

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By **Francesca Bonenti**, Department of Quantitative Methods, University of Brescia, Italy
Giorgia Oggioni, Department of Quantitative Methods, University of Brescia, Italy
Elisabetta Allevi, Department of Quantitative Methods, University of Brescia, Italy
Giacomo Marangoni, Fondazione Eni Enrico Mattei, Italy

Energy: Resources and Markets Series
Editor: Giuseppe Sammarco

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Summary

In this paper we investigate the economic impacts of the European Emission Trading Scheme (EU-ETS) on the Italian electricity market by a power generation expansion model. In particular, we assume that generators make their capacity expansion decisions in a Cournot or in a perfect competition manner. This model is used to measure the effects of the EU-ETS Directives on electricity prices and demand, investments and generators' profits both in an oligopolistic and in a perfectly competitive organization of the power market. We adopt a technological representation of the energy market which is discretized into six geographical zones (North, Center-North, Center-South, South, Sicily, Sardinia) and five virtual poles (Monfalcone, Foggia, Brindisi, Rossano, Priolo) with limited production for a total of eleven zones. We assume that generators operate in different zones connected by interconnections with limited capacity and produce energy by running existing or new plants in which they directly invest. We consider several investment scenarios under the CO2 regulation with and without incentives to renewables. The scenarios also include simulations on future effects of the third EU-ETS phase on the system. Our analysis shows that perfect competition induces generators to invest more than in an oligopolistic framework, but in both market configurations, investments are mainly concentrated in fossil-red plants (CCGT and coal), leaving a small proportion to new wind plants. This happens also in presence of incentives given to renewable technologies. We can thus conclude that investments in a secure and efficient technology like CCGT are preferable compared to those in renewables that cannot be used with continuity. This investment policy affects electricity prices that significantly increase in 2020 compared to their 2009 levels. The raise of electricity prices in 2020 is particularly favorable for generators operating as Cournot players which are able to increase their profits compared to 2009, despite the full auctioning system foreseen for the allocation of CO2 allowance to the power sector in the third EU-ETS phase. The solution of the overall system is found by exploiting the mixed complementarity theoretical framework and solution algorithms. The developed model is implemented as complementarity problems and solved in GAMS using the PATH solver.

Keywords: Complementarity Conditions, General Equilibrium Models, EU-ETS, Italian Electricity Market

JEL Classification: Q4, Q48

The work has been financially supported by the grant "Regione Lombardia: Metodi di integrazione delle fonti energetiche rinnovabili e monitoraggio satellitare dell'impatto ambientale", EN-17, ID 17369.10 financed by the Lombardy Region, Italy.

Address for correspondence:

Giacomo Marangoni
Fondazione Eni Enrico Mattei
Corso Magenta 63
20123 Milano
Italy
E-mail: giacomo.marangoni@feem.it

Evaluating the impacts of the EU-ETS on prices, investments and profits of the Italian electricity market*

Francesca Bonenti[†] Giorgia Oggioni[‡] Elisabetta Allevi[§] Giacomo Marangoni[¶]

December 20, 2011

Abstract

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Our analysis shows that perfect competition induces generators to invest more than in an oligopolistic framework, but in both market configurations, investments are mainly concentrated in fossil-fired plants (CCGT and coal), leaving a small proportion to new wind plants. This happens also in presence of incentives given to renewable technologies. We can thus conclude that investments in a secure and efficient technology like CCGT is preferable compared to those in renewables that cannot be used with continuity. This investment policy affects electricity prices that significantly increase in 2020 compared to their 2009 levels. The raise of

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[†]Department of Quantitative Methods, University of Brescia, 25122 Brescia, Italy. E-Mail: francesca.bonenti@eco.unibs.it

[‡]Department of Quantitative Methods, University of Brescia, 25122 Brescia, Italy. E-Mail: oggioni@eco.unibs.it

[§]Department of Quantitative Methods, University of Brescia, 25122 Brescia, Italy. E-Mail: allevi@eco.unibs.it

[¶]Fondazione Eni Enrico Mattei, Milan, Italy. E-Mail: giacomo.marangoni@feem.it

electricity prices in 2020 is particularly favorable for generators operating as Cournot players which are able to increase their profits compared to 2009, despite the full auctioning system foreseen for the allocation of CO_2 allowance to the power sector in the third EU-ETS phase.

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1 Introduction

In the last twenty years, the restructuring process of the electricity system has deeply changed the organization of this market around the world. In Europe, following the examples of United Kingdom and Norway, the European Commission issued the Directive 96/92/EC in order to liberalize the power sector and create an Internal Electricity Market (IEM). This Directive imposed the unbundling of generation, transmission and distribution that, since then, were vertically integrated and controlled by a sole entity (power company) operating in a monopolistic regime. The aim of this Directive was to improve efficiency and avoid abuses of dominant positions, especially in setting power prices.

In Italy, the disposals of the European Directive 96/92/EC were acknowledged by the Bersani decree in 1999, but only in 2004 the Power Exchange GME ("Gestore del Mercato Elettrico") became operative on the Italian energy market (IPEX). With the Bersani decree, the old monopolist Enel had to disinvest 15 GW of its production capacity in order to reduce its market share. The current Enel's contribute to the Italian power production is of 28,1%, significantly lower than its 2004 level of 43,9%[1]. However, the Italian market cannot be yet considered fully competitive as highlighted by Floro (2009).

Since 2005, the energy sector is involved in the European Emission Trading Scheme (EU-ETS)[2]. The EU-ETS is an environmental policy developed in the framework of the Kyoto Protocol that aims at reducing the European CO_2 emissions generated by carbon-intensive installations of the energy and industrial sectors. Such a goal is achieved through the implementation of a cap-and-trade system that imposes a CO_2 emission limit to all covered installations and creates a market that prices CO_2 where ETS participants can exchange their emission permits. The EU-ETS was initially subdivided into two phases as indicated by Directive 2003/87/EC. The first phase (2005-2007), the so-called "learning by doing phase", was introduced to test the functioning of the EU-ETS system. Its implementation led to some economic distortions mainly due to the grandfathering of the emission allowances (Neuhoff et al., 2006a, 2006b; Reinaud, 2003, 2005) and to the consequent raise of "windfall profits" for the power sector (Sijm et al., 2006). Compared to the energy intensive industries involved in the EU-ETS, generators are able to pass through a high proportion of their carbon costs in electricity prices despite the fact that almost all CO_2 permits, needed to cover their emissions, are freely distributed. This happens because the current organization of electricity markets allows for pricing power at marginal production cost. The result is twofold: the EU-ETS causes both an increase of electricity prices and an intended raise of generators' profits. These two issues have been extensively discussed in literature and many studies confirm this outcome (see, for instance, Chen et al., 2008, Kara et al., 2008, Linares et al., 2008 and Lise et al., 2010, Oggioni and Smeers, 2009).

In order to remedy to this situation, the Directive 2009/29/EC, regulating the third EU-ETS phase (2013-2020), has imposed a full auctioning system for the allocation of emission permits destined to the energy sector. For the industrial sectors, it foresees a progressive adoption of the auctioning system starting from a proportion of the 20% in 2013 and reaching a 70% level in

[1]See Autorità per l'Energia Elettrica e il Gas (AEEG), Relazione annuale sullo stato dei servizi e sull'attività svolta, 2011. Available at `http://www.autorita.energia.it/it/relaz_ann/11/11.htm`

[2]`http://ec.europa.eu/clima/policies/ets/index_en.htm`

2020[3]. Moreover, the revised EU-ETS will cover more industries and types of greenhouse gases and will encourage the development of renewables.

In this paper, we investigate the economic impacts of the EU-ETS on the Italian electricity market. In particular, taking into account the current organization of the Italian electricity market, we formulate a capacity expansion model, where generators are Cournot players. Indeed, imperfect competition models are often used to study electricity markets (see, for instance, Chen and Hobbs, 2005, Chen et al., 2006, Hobbs, 2001, Hobbs and Helman, 2004, Vespucci et al., 2009). An oligopolistic market can be described either by a Nash-Cournot or a Bertrand or a Supply Function Equilibrium models. Supply Function Equilibrium (see Anderson and Hu, 2008, Willems et al., 2009) and Cournot Equlibrium (for overviews see Tirole, 1988, Vives, 1999 and for review see Ventosa et al., 2005) are the most applied models to electricity markets. However, since the aim of the restructuring of the electricity market is to make it fully competitive, we also analyze the case where power producers operate in a perfectly competitive market. More specifically, we adopt a technological representation of the energy market and we assume that generators operate in different zones linked by inter-connectors with limited transfer capacity. The solution of the overall system is found by exploiting the mixed complementarity theoretical framework and solution algorithms.

The organization of this paper is as follows. In Section 2, we describe the market model where generators are Cournot competitors. Section 3 presents a perfectly competitive version of the model illustrated in Section 2. In Section 4 we discuss the results of our analysis. Finally, Section 5 is devoted to conclusions and final remarks.

2 The market model

We first describe a market where generators compete à la Cournot. Each generator maximizes its profits taking into account the decision taken by his competitors. Market energy balance is guaranteed by the Italian Market Operator which maximizes consumers' willingness to pay taking into account the transfer limits of the interconnections linking the different zones. We also model an emission market limited to the energy sector. We first list the notation used in this paper.

2.1 Notation

We here introduce all symbols of the model. They are classified on basis of their means and use.

Sets

- $i \in I$: Zones;
- $t \in T$: Time segment, we consider time horizon $t = 1, ..., 24$ hours;
- $p \in P$: Set of technologies (note that we respectively indicate with $p = h$ and $p = sh$ the hydro plants based on reservoir and on the pumped-storage technologies);

[3]The Article 10 ter of the Directive 2009/29/EC states that all industrial sectors that are exposed to the risk of carbon leakage will continue to receive free permits. See `http://ec.europa.eu/clima/policies/ets/leakage/index_en.htm`.

- $f \in F$: Generators;

Parameters

- $vc_{f,p,i}$: Hourly variable costs of new and existing plant of technology type p owned by generator f in zone i (€/MWh);
- $fc_{f,p,i}$: Hourly fixed costs of new plant of technology type p owned by generator f in zone i (€/MWh);
- $shc_{f,sh,i}$: Hourly costs of pumped-storage technology sh when pumping owned by generator f in zone i (€/MWh);
- $\overline{G}_{f,p,i}$: Total available capacity of technology plant p owned by generator f in zone i (MW);
- $\overline{TH}_{f,p,i}$: Total available capacity of hydro $p = h, sh$ technology owned by generator f in zone i (MW);
- $\underline{gh}_h, \overline{gh}_h$: Minimum and maximum capacity of hydro technology h (MW) owned by generator f in zone i;
- $\underline{sh}_{f,sh,i}, \overline{sh}_{f,sh,i}$: Minimum and maximum capacity of the technology pumping water in the upper basin in the pumped-storage technology sh (MW);
- $\underline{gsh}_{f,sh,i}, \overline{gsh}_{f,sh,i}$: Minimum and maximum capacity of pumped-storage technology sh (MW) owned by generator f in zone i;
- $\overline{R}_{f,p,i}$: Variance between maximum and minimum energy reserve of hydro technology h and sh (MW) owned by company f in zone i;
- e_p: Emission factor of technology p (ton/MWh);
- E: Total emission cap (ton);
- GE_f: Total amount of emission allowances grandfathered to generators f (ton);
- τ: 8760 (number of hours in one year);
- τ_t: 365 (number of days in one year);
- $a_{t,i}$: Intercept of consumers' affine demand functions at zone i in time segment t (€/MWh);
- $b_{t,i}$: Slope of consumers' affine demand functions at zone i in time segment t (€/MWh^2);
- $\rho_{f,sh,i}$: Performance of pumped-storage technology showned by generator f in zone i.
- $\overline{Flow}_{i,ii}$: Flow transfer limit from zone i to zone ii (MW).

Variables

- $g_{t,f,p,i}$: Power produced by generators f in zone i using existing technology p in time segment t (MWh) (In particular, $g_{t,f,h,i}$: power supplied by generators f in zone i using existing technology h in time segment t (MWh), $g_{t,f,sh,i}$: power supplied by generators f in zone i using existing technology sh in time segment t (MWh).);
- $gn_{t,f,p,i}$: Power produced by generators f to zone i using new technology p in time segment t (MWh);

- $sh_{t,f,sh,i}$: Power used by generator f in zone i to pump water in the upper reservoir of pumped-storage technology sh in time segment t (MWh);
- $R_{t,f,h,i}$: Hydro energy reserve of hydro technology h owned by generator f in zone i in time segment t (MWh);
- $I_{f,p,i}$: Investments in new capacity of technology type p operated by generators f in zone i (MW);
- $s_{t,f,i}$: Power supplied by generator f to zone i in time segment t (MWh);
- $d_{t,i}$: Electricity consumption in zone i in time segment t (MWh);
- $p_{t,i}$: Nodal electricity price in time segment t (€/MWh);
- $P_{t,i}(d_{t,i})$: Willingness to pay in zone i and in time segment t (€);
- $flow_{t,i,ii}$: Power transferred from zone i to zone ii in time segment t.

2.2 Generation expansion model

We model a zonal market where generators compete as Cournot players. They produce energy by running existing or new plants in which they invest. We assume that new plants are immediately disposable. Each plant is characterized by its own fixed[4], emission and fuel costs that influence their endogenously determined merit order. During the implementation phase, we consider a set of eight technologies composed of wind, photovoltaic, geothermal, run-on-river, coal, CCGT, gas and oil based technologies. These plants are endogenously put in merit order. In the theoretical formulation of the problem, we also model the use of reservoir and pumped-storage hydro plants[5]. Generators make their strategical investment and production choices by taking into account the environmental opportunity costs due to the CO_2 regulation.

Each generator f maximizes its objective function (1) subject to technological constraints (2)-(15). In (1), the term $s_{t,-f,i}$ stands for $\sum_{f'\neq f} s_{t,f',i}$. In particular, each generator maximizes his profit (1) by selling electricity at price $p_{t,i}(s_{t,-f,i} + s_{f,t,i} - \sum_{ii}(flow_{t,i,ii} - flow_{t,ii,i})$ that in the following we denote as $p_{t,i}$. The costs faced by generators are: the variable generation $(\sum_{p,i} vc_{f,p,i} \cdot (g_{t,f,p,i} + gn_{t,f,p,i}) \cdot \tau_t)$, the investment $(\sum_{p,i} fc_{f,p,i} \cdot I_{f,p,i} \cdot \tau)$ and the emission opportunity costs $(\varphi \cdot (GE_f - \sum_{t,p,i} e_p \cdot (g_{t,f,p,i} + gn_{t,f,p,i}) \cdot \tau_t))$ computed over a year. Moreover, for those generators who dispose of hydro pumped-storage technologies, we consider the cost of pumping water from the lower to the upper basin $(\sum_{i,t} shc_{f,sh,i} \cdot sh_{t,f,sh,i} \cdot \tau_t)$.

$$\begin{aligned}
\textbf{Max} \quad & \left\{ \sum_{t,i} \left[p_{t,i} \left(s_{t,-f,i} + s_{t,f,i} - \sum_{ii} (flow_{t,i,ii} - flow_{t,ii,i}) \right) \right] \cdot s_{t,f,i} \right\} \cdot \tau_t + \qquad (1) \\
& - \left\{ \sum_{t,p,i} vc_{f,p,i} \cdot (g_{t,f,p,i} + gn_{t,f,p,i}) + \sum_{t,i} shc_{f,sh,i} \cdot sh_{t,f,sh,i} \right\} \cdot \tau_t + \\
& + \left\{ \varphi \cdot \left[GE_f - \sum_{t,p,i} e_p \cdot (g_{t,f,p,i} + gn_{t,f,p,i}) \right] \right\} \cdot \tau_t +
\end{aligned}$$

[4]We only account for fixed costs of new generating units.

[5]Unfortunately, we do not dispose of the data related to these two hydro technologies.

$$-\sum_{p,i} fc_{f,p,i} \cdot I_{f,p,i} \cdot \tau$$

s.t.

$$\sum_p g_{t,f,p,i} + \sum_p gn_{t,f,p,i} = s_{t,f,i} \qquad (\alpha_{t,f,i}) \qquad \forall t,f,i \tag{2}$$

$$\overline{G}_{f,p,i} - g_{t,f,p,i} \geq 0 \qquad (\beta_{t,f,p,i} \geq 0) \qquad \forall t,f,p \neq h, p \neq sh, i \tag{3}$$

$$I_{f,p,i} - gn_{t,f,p,i} \geq 0 \qquad (\nu_{t,f,p,i} \geq 0) \qquad \forall t,f,p,i \tag{4}$$

$$\overline{TH}_{f,p,i} - g_{t,f,p,i} - R_{t,f,p,i} \geq 0 \qquad (\beta_{t,f,p=h,p=sh,i} \geq 0) \qquad \forall t,f,p=h,p=sh,i \tag{5}$$

$$R_{t,f,p,i} + \overline{R}_{f,p,i} \geq 0 \qquad (\overline{\xi}_{t,f,p,i} \geq 0) \qquad \forall t,f,p=h,p=sh,i \tag{6}$$

$$\overline{R}_{f,p,i} - R_{t,f,p,i} \geq 0 \qquad (\underline{\xi}_{t,f,p,i} \geq 0) \qquad \forall t,f,p=h,p=sh,i \tag{7}$$

$$g_{t,f,h,i} - \underline{gh}_{f,h,i} \geq 0 \qquad (\underline{\delta}_{t,f,h,i} \geq 0) \qquad \forall t,f,h,i \tag{8}$$

$$\overline{gh}_{f,h,i} - g_{t,f,h,i} \geq 0 \qquad (\overline{\delta}_{t,f,h,i} \geq 0) \qquad \forall t,f,h,i \tag{9}$$

$$\rho_{f,sh,i} \cdot sh_{t,f,sh,i} - g_{t,f,sh,i} \geq 0 \qquad (\eta_{t,f,sh,i} \geq 0) \qquad \forall t,f,sh,i \tag{10}$$

$$sh_{t,f,sh,i} - \underline{sh}_{f,sh,i} \geq 0 \qquad (\underline{\theta}_{t,f,sh,i} \geq 0) \qquad \forall t,f,sh,i \tag{11}$$

$$\overline{sh}_{f,sh,i} - sh_{t,f,sh,i} \geq 0 \qquad (\overline{\theta}_{t,f,sh,i} \geq 0) \qquad \forall t,f,sh,i \tag{12}$$

$$g_{t,f,sh,i} - \underline{gsh}_{f,sh,i} \geq 0 \qquad (\underline{\mu}_{t,f,sh,i} \geq 0) \qquad \forall t,f,sh,i \tag{13}$$

$$\overline{gsh}_{f,sh,i} - g_{t,f,sh,i} \geq 0 \qquad (\overline{\mu}_{t,f,sh,i} \geq 0) \qquad \forall t,f,sh,i \tag{14}$$

$$g_{t,f,p,i}; gn_{t,f,p,i}; I_{t,f,p,i}; s_{t,f,i} \geq 0 \qquad \forall t,f,p,i \tag{15}$$

Equation (2) defines a production balance between the total amount of electricity generated ($\sum_p g_{t,f,p,i} + \sum_p gn_{t,f,p,i}$) and sold ($s_{t,f,i}$) in zone i by generator f in each time segment t.

Constraints (3) and (4) impose generation capacity limits respectively for existing and new plants. These constraints hold for all technologies with the exception of pumped storage and hydro plants with reservoir. For these hydro technologies, we have specific capacity constraints (see (5)-(14)). Constraint (5) states that the total available capacity $\overline{TH}_{f,p,i}$ (with $p = h, sh$) has to be greater or equal to the sum of the quantity of electricity $g_{t,f,p,i}$ (with $p = h, sh$) generated by those hydro plants and the energy reserve $R_{t,f,p,i}$ of the recervoir. This reserve varies between a minimum ($-\overline{R}_{f,p,i}$) and a maximum ($\overline{R}_{f,p,i}$) level as indicated by constraints (6) and (7). Conditions (8), (9), (13) and (14) indicate the generation limits of the turbines of hydro (with reservoir) and pumped-storage technologies respectively.

Condition (10) defines that the energy needed to pump water from the lower to the upper reservoir is greater than the energy produced. The turbine used to pump water has capacity limits as indicated by inequalities (11) and (12) that respectively define a lower and an upper bound.

Finally, conditions (15) are the non-negativity constraints.

2.3 Market operator's model

Market Operator maximizes the consumers' willingness to pay (16) taking into account a zonal energy balance constraint (17)-(18) and transmission constraint (19) that defines the flow transfer limits among connected zones (more details are reported in Section 4.1).

$$\mathbf{Max}_{\mathbf{d_{t,i}}} \quad \sum_t \left[\int_0^{d_{t,i}} P_{t,i}(\xi) d\xi \right] \cdot \tau_t \tag{16}$$

s.t

$$\sum_f s_{t,f,i} - \sum_{ii} (flow_{t,i,ii} - flow_{t,ii,i}) - d_{t,i} = 0 \qquad (\psi_{t,i}) \qquad \forall t, i \tag{17}$$

$$d_{t,i} \geq 0 \qquad \forall t, i \tag{18}$$

$$0 \leq flow_{t,i,ii} \leq \overline{Flow}_{i,ii} \qquad (\sigma_{t,i,ii}) \qquad \forall t, i, ii \tag{19}$$

2.4 Emission market

Our model only considers the emissions of power plants. Since National Allocation Plans (NAPs) refer to annual targets, we impose one emission constraint, limited to the electricity market, which is associated with the dual variable φ, representing the allowance price. E indicates the annual CO_2 emission cap while $\sum_{t,f,p,i} e_p \cdot (g_{t,f,p,i} + gn_{t,f,p,i}) \cdot \tau_t$ are the annual emissions generated by electricity production.

$$E - \sum_{t,f,p,i} e_p \cdot ((g_{t,f,p,i} + gn_{t,f,p,i}) \cdot \tau_t) \geq 0 \qquad (\varphi \geq 0) \tag{20}$$

2.5 Mathematical structure

Let K be a nonempty, closed and convex subset of the n-dimensional Euclidean space $\mathbb{R}^n$, $F : K \to \mathbb{R}^n$ a continuous mapping. The variational inequality problem (VI for short) is the problem of finding a point $x^* \in K$ such that

$$\langle F(x), (x - x^*) \rangle \geq 0, \quad \forall\, x \in K. \tag{21}$$

The solution set of VI (21) is denoted by $SOL(K, F)$.

Most existence results of solutions for VIs are proved by using various fixed point theorems.

As shown by Hartmann & Stampacchia (1966), VI (21) has a solution if K is compact and F is continuous.

In general, VI can have more than one solution. We now recall one condition under which VI (21) has a unique solution, this result needs generalized monotonicity assumption.

Definition 1 *Let K be a convex set in $\mathbb{R}^n$. A mapping $F : K \subseteq \mathbb{R}^n \to \mathbb{R}^n$ is said to be*

- monotone *on K if $(F(x) - F(y))^T (x - y) \geqslant 0$, $\forall x, y \in K$;*
- strictly monotone *on K if $(F(x) - F(y))^T (x - y) > 0$, $\forall x, y \in K$ and $x \neq y$.*

Theorem 1 *(Harker & Pang 1990) If $F(x)$ is strictly monotone then VI (21) has at most one solution.*

In addition, we now recall the known monotonicity criteria for continuosly differentiable mappings.

Theorem 2 *(Ortega & Rheinboldt, 1970) Let K be an open convex set in $\mathbb{R}^n$ and let $F : K \subseteq \mathbb{R}^n \to \mathbb{R}^n$ be countinuously differentiable on K.*

- *F is monotone on K if and only if ∇F is positive semidefinite on K;*
- *F is strictly monotone on K if ∇F is positive definite on K.*

VIs are closely related with many problems of Nonlinear Analysis, such as complementarity, fixed point and optimization problems. In general, a complementarity problem (CP) is the problem of finding a point x such that:

$$0 \leq x \perp F(x) \geq 0 \tag{22}$$

where $F : \mathbb{R}^n_+ \to \mathbb{R}^n$. We recall that condition (23) can be alternatively defined as:

$$x \geq 0, \qquad F(x) \geq 0, \qquad F(x) \cdot x = 0. \tag{23}$$

We now consider a Nash Equilibrium problem with N players, each of whom has a certain cost function $\theta_i(x)$, where $x = (x^i : i = 1, ..., N)$, and a strategy set $K_i \subseteq \mathbb{R}^{n_i}$.
The problem of player i, given the other players' strategies $\widetilde{x^i} = (x^j : j \neq i)$, is to solve the cost minimization problem in the variable y^i:

$$\begin{aligned} \min \quad & \theta_i(y^i, \widetilde{x^i}) \\ \textit{sub to } & y^i \in K_i. \end{aligned} \tag{24}$$

The solution set of the problem is denoted by $\mathcal{S}_i(\widetilde{x^i})$.

Definition 2 *A* Nash Equilibrium *is a tuple of strategies $x = (x^i : i = 1, ..., N)$ such that for each i, $x^i \in \mathcal{S}_i(\widetilde{x^i})$.*

This problem can be transformed into an equivalent variational inequality or complementarity problem if for each fixed $\widetilde{x^i}$ the $\theta_i(y^i, \widetilde{x^i})$ function is convex in y^i. The following proposition gives the relationship between the solution of VI and the solution of a Nash Equilibrium (see Facchinei and Pang, 2003).

Proposition 1 *Let K_i be a close subset of $\mathbb{R}^{n_i}$. Assume that for each fixed tuple $\widetilde{x^i}$, the function $\theta_i(y^i, \widetilde{x^i})$ is convex and continuously differentiable in y^i.*
Then x is a Nash equilibrium if and only if $x \in SOL(K, F)$, where

$$K := K_1 \times K_2 \times ... \times K_N,$$

$$F(x) := (\nabla_{x^i}\theta_i(x)) \qquad i = 1, ..., N$$

and

$$\nabla_{x^i}\theta_i(x) = \left(\frac{\partial \theta_i(x)}{\partial x^{i1}}, ..., \frac{\partial \theta_i(x)}{\partial x^{iN}} \right).$$

It is easy to verify that our Cournot model presented in Section 2 can be formulated as a VI, where each function $\theta_i(y^i, \widetilde{x^i})$ is continuous and strictly convex in the variable y^i.The resulting function $F(x)$ that defines the VI of our Cournot problem is continuous and it has a Jacobian matrix positive definite on the bounded, convex and admissible set. Hence, on the basis of these considerations, we can conclude that our model has one solution.

In order to find this solution, we formulate our model in complementarity form that we here present.

$$0 \leq vc_{f,p,i} + \varphi \cdot e_p - \alpha_{t,f,i} + \beta_{t,f,p,i} \perp g_{t,f,p,i} \geq 0 \qquad \forall t, f, p, i \tag{25}$$

$$0 \leq vc_{f,p,i} + \varphi \cdot e_p - \alpha_{t,f,i} + \nu_{t,f,p,i} \perp gn_{t,f,p,i} \geq 0 \qquad \forall t, f, p, i \tag{26}$$

$$\begin{aligned} 0 \leq vc_{f,h,i} + \varphi \cdot e_h - \alpha_{t,f,i} + \beta_{t,f,h,i} - \underline{\delta}_{t,f,h,i} + \\ + \overline{\delta}_{t,f,h,i} \perp g_{t,f,h,i} \geq 0 \quad \forall t, f, h, i \end{aligned} \tag{27}$$

$$\begin{aligned} 0 \leq vc_{f,sh,i} + \varphi \cdot e_{sh} - \alpha_{t,f,i} + \beta_{t,f,sh,i} + \eta_{t,f,sh,i} \\ - \underline{\mu}_{t,f,sh,i} + \overline{\mu}_{t,f,sh,i} \perp g_{t,f,sh,i} \geq 0 \qquad \forall t, f, sh, i \end{aligned} \tag{28}$$

$$0 \leq \frac{-\partial p_{t,i}}{\partial s_{t,f,i}} \cdot s_{t,f,i} - p_{t,i} + \alpha_{t,f,i} \perp s_{f,p,i} \geq 0 \qquad \forall f, p, i \tag{29}$$

$$0 \leq shc_{f,sh,i} - \rho_{f,sh,i} \cdot \eta_{t,f,sh,i} - \underline{\theta}_{t,f,sh,i} + \overline{\theta}_{t,f,sh,i} \perp sh_{t,f,sh,i} \geq 0 \qquad \forall t, f, sh, i \tag{30}$$

$$0 \leq fc_{f,p,i} - \sum_t \frac{\tau_t}{\tau} \nu_{t,f,p,i} \perp I_{f,p,i} \geq 0 \qquad \forall f, p, i \tag{31}$$

$$\sum_p g_{t,f,p,i} + \sum_p gn_{t,f,p,i} - s_{t,f,i} = 0 \qquad (\alpha_{t,f,i}) \qquad \forall t, f, i \tag{32}$$

$$0 \leq \overline{G}_{f,p,i} - g_{t,f,p,i} \perp \beta_{t,f,p,i} \geq 0 \qquad \forall t, f, p \neq h, p \neq sh, i \tag{33}$$

$$0 \leq \overline{TH}_{f,p,i} - g_{t,f,p,i} - R_{t,f,p,i} \perp \gamma_{t,f,p,i} \geq 0 \qquad \forall t, f, p = h, p = sh, i \tag{34}$$

$$0 \leq g_{t,f,h,i} - \underline{gh}_{f,h,i} \perp \underline{\delta}_{t,f,h,i} \geq 0 \qquad \forall t, f, h, i \tag{35}$$

$$0 \leq \overline{gh}_{f,h,i} - g_{t,f,h,i} \perp \overline{\delta}_{t,f,h,i} \geq 0 \qquad \forall t, f, h, i \tag{36}$$

$$0 \leq R_{t,f,p,i} + \overline{R}_{f,p,i} \perp \overline{\xi}_{t,f,p,i} \geq 0 \qquad \forall t, f, p = h, p = sh, i \tag{37}$$

$$0 \leq \overline{R}_{f,p,i} - R_{t,f,p,i} \perp \underline{\xi}_{t,f,p,i} \geq 0 \qquad \forall t, f, p = h, p = sh, i \tag{38}$$

$$0 \leq \rho_{f,sh,i} \cdot sh_{t,f,sh,i} - g_{t,f,sh,i} \perp \eta_{t,f,sh,i} \geq 0 \qquad \forall t, f, sh, i \tag{39}$$

$$0 \leq sh_{t,f,sh,i} - \underline{sh}_{f,sh,i} \perp \underline{\theta}_{t,f,sh,i} \geq 0 \qquad \forall t, f, sh, i \tag{40}$$

$$0 \leq \overline{sh}_{f,sh,i} - sh_{t,f,sh,i} \perp \overline{\theta}_{t,f,sh,i} \geq 0 \qquad \forall t, f, sh, i \tag{41}$$

$$0 \leq g_{t,f,sh,i} - \underline{gsh}_{f,sh,i} \perp \underline{\mu}_{t,f,sh,i} \geq 0 \qquad \forall t, f, sh, i \tag{42}$$

$$0 \leq \overline{gsh}_{f,sh,i} - g_{t,f,sh,i} \perp \overline{\mu}_{t,f,sh,i} \geq 0 \qquad \forall t, f, sh, i \tag{43}$$

$$0 \le I_{f,p,i} - gn_{t,f,p,i} \perp \nu_{t,f,p,i} \ge 0 \qquad \forall t,f,p,i \tag{44}$$

$$\beta_{t,f,h,i} - \overline{\xi}_{t,f,h,i} + \underline{\xi}_{t,f,h,i} = 0 \qquad (R_{t,f,h,i}) \qquad \forall t,f,h,i \tag{45}$$

The complementarity conditions associated to the market operator' problem are as follows:

$$0 \le -a_{t,i} + b_{t,i} \cdot d_{t,i} + \psi_{t,i} \perp d_{t,i} \ge 0 \qquad \forall t,i \tag{46}$$

$$\sum_f s_{t,f,i} - \sum_{ii}(flow_{t,i,ii} - flow_{t,ii,i}) - d_{t,i} = 0 \qquad (\psi_{t,i}) \qquad \forall t,i \tag{47}$$

$$0 \le \overline{Flow}_{i,ii} - flow_{t,i,ii} \perp \sigma_{t,i,ii} \ge 0 \qquad \forall t,i,ii \tag{48}$$

$$0 \le \psi_{t,i} - \psi_{t,ii} + \sigma_{t,i,ii} - \sigma_{t,ii,i} \perp flow_{t,i,ii} \ge 0 \qquad \forall t,i,ii \tag{49}$$

The complementarity condition associated to the emission market's problem is as follows:

$$0 \le E - \sum_{t,f,p,i} e_p \cdot ((g_{t,f,p,i} + gn_{t,f,p,i}) \cdot \tau_t) \perp \varphi \ge 0 \tag{50}$$

3 Perfect competition model

We modify the model presented in Section 2 by assuming that generators operate in a perfectly competitive way. Under this assumption, generators are price takers and sell electricity at the zonal price $p_{t,i}$ defined by the market. This implies a slight modification of their objective function that becomes as reported in (51) below. The price $p_{t,i}$ is now the dual variable of the market clearing condition in the Market Operator's problem (see (52)).

All the remaining constraints are as in Section 2.

$$\mathbf{Max} \quad \left\{ \sum_{t,i} p_{t,i} \cdot s_{t,f,i} - \sum_{p,i} vc_{f,p,i} \cdot (g_{t,f,p,i} + gn_{t,f,p,i}) \right\} \cdot \tau_t + \tag{51}$$

$$+ \left\{ \varphi \cdot [GE_f - \sum_{t,p,i} e_p \cdot (g_{t,f,p,i} + gn_{t,f,p,i})] - \sum_{i,t} shc_{f,sh,i} \cdot sh_{t,f,sh,i} \right\} \cdot \tau_t +$$

$$- \sum_{p,i} fc_{f,p,i} \cdot I_{f,p,i} \cdot \tau$$

$$\sum_f s_{t,f,i} - \sum_{ii}(flow_{t,i,ii} - flow_{t,ii,i}) - d_{t,i} = 0 \qquad (p_{t,i}) \qquad \forall t,i \tag{52}$$

The complementarity conditions of the perfectly competitive market are the same of those of the Cournot model except for conditions (29), (46) and (47) that respectively become:

$$0 \le \ -p_{t,i} + \alpha_{t,i} \perp s_{t,f,i} \ge 0 \qquad \forall t,f,p,i \tag{53}$$

$$0 \leq -a_{t,i} + b_{t,i} \cdot d_{t,i} + p_{t,i} \perp d_{t,i} \geq 0 \qquad \forall t, i \tag{54}$$

$$\sum_f s_{t,f,i} - \sum_{ii} (flow_{t,i,ii} - flow_{t,ii,i}) - d_{t,i} = 0 \qquad (p_{t,i}) \qquad \forall t, i \tag{55}$$

4 Application to the Italian electricity market

4.1 Market description

We apply our models to a prototype of the Italian electricity market as depicted on Figure 1. This market is discretized into six geographical zones (North, Center-North, Center-South, South, Sicily, Sardinia) and five virtual poles (Monfalcone, Foggia, Brindisi, Rossano, Priolo) with limited production for a total of eleven zones. Our analysis is calibrated with 2009 data.

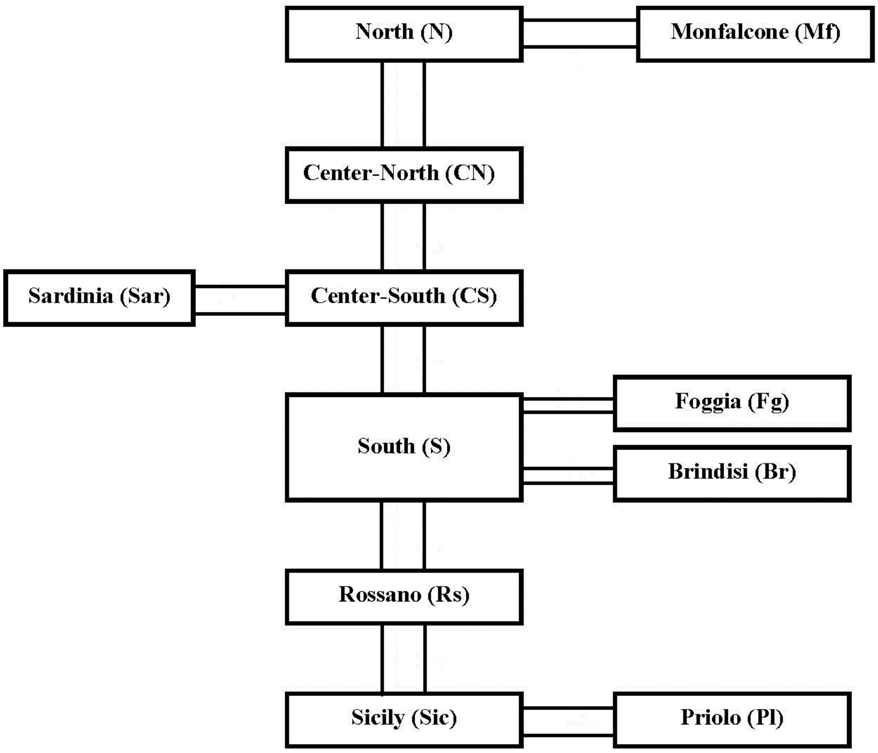

Figure 1: Italian Network

Following the network representation provided by Terna, the Italian Transmission System Operator (TSO), we assume that each zone is connected to the others by two connections with different limited transfer capacities that depend on the flow directions. The transfer limits are listed in Table 1[6] and are used to define the parameter $\overline{Flow}_{i,ii}$ in condition (19).

MW	N	CN	CS	S	Sic	Sar	Mf	Fg	Br	Rs	Pl
N	0	3450	0	0	0	0	10000	0	0	0	0
CN	1700	0	1750	0	0	0	0	0	0	0	0
CS	0	2250	0	10000	0	420	0	0	0	0	0
S	0	0	3700	0	0	0	0	10000	10000	10000	0
Sic	0	0	0	0	0	0	0	0	0	275	10000
Sar	0	0	450	0	0	0	0	0	0	0	0
Mf	1030	0	0	0	0	0	0	0	0	0	0
Fg	0	0	0	1200	0	0	0	0	0	0	0
Br	0	0	0	5200	0	0	0	0	0	0	0
Rs	0	0	0	1613	150	0	0	0	0	0	0
Pl	0	0	0	0	315	0	0	0	0	0	0

Table 1: $\overline{Flow}_{i,ii}$

A set of eight generators[7] produce electricity running wind, run-on-river (hydro), geothermal, photovoltaic, coal, CCGT, other gas and oil based power plants depending on their availability. Capacity data for all these technologies are taken from the annual reports of the considered power companies and from Terna[8]. Electricity is generated by existing and new power plants. In order to simplify both the database and the interpretation of the results, we assume that old and new capacity have identical variable costs. The models obviously allow one to change this assumption to apply different efficiency rates to new plants. Doing so in this prototype study would however mix fundamental economic phenomena and sometimes arbitrary data differentiations and hence cloud the interpretation of the results.

The time horizon of the model is divided into segments corresponding to the twenty-four hours of a day. We model electricity demand by using an affine inverse demand function depending on time and zones. Demand function is constructed taking an elasticity of 0.1 for all consumers; reference demand and price are taken from the Italian Market Operator website[9].

We develop and analyze a variety of scenarios in the framework of the two market forms previously analyzed. These scenarios allow us to evaluate the impact of the EU-ETS on electricity prices, investments and generators' profits in the different scenarios.

Scenarios are subdivided into two groups: in the first one we describe the situation of the Italian electricity market in 2009 (see Table 2), while in the other we provide an outlook of the 2020's situation (see Table 3) in order to study the new setting of the third EU-ETS phase. In

[6] See Terna, (2011). Valori dei limiti di transito tra le zone di mercato REV.14, Available at `http://www.terna.it/default/Home/SISTEMA_ELETTRICO/mercato_elettrico/Procedura_valutazione_limiti_e_limiti_transito.aspx`

[7] The considered companies are: Enel, Edison, Eni, Edipower, Eon, A2A, TirrenoPower, in addition to a fringe that collects all the remaining small power companies.

[8] See `http://www.terna.it/default/Home/SISTEMA_ELETTRICO/statistiche/dati_statistici.aspx`

[9] See Gestore Mercato Elettrico (GME) website at `http://www.mercatoelettrico.org/En/download/DownloadDati.aspx?val=MGP_PrezziConvenzionali`

all these scenarios, we assume that generators operate under the EU-ETS regime and always invest in new capacity.

Among the 2009 scenarios, we describe the setting of the current EU-ETS phase without ("ETS") and with ("ETS, inc") incentives in new renewable power plants. We apply these tests both to the "Cournot" and "Perfect" competition market organizations.

Scenario 2009	**Description**
Cournot, ETS	Oligopolistic competition with ETS regulation and investments
Cournot, ETS, inc	Oligopolistic competition with ETS regulation, investments and incentives in new renewable technologies
Perfect, ETS	Perfect competition with ETS regulation and investments
Perfect, ETS, inc	Perfect competition with ETS regulation, investments and incentives in new renewable technologies

Table 2: 2009 scenarios

For the 2020's prevision, we study scenarios with and without ("nodev") economic development. For both of them, we also consider the cases with and without incentives in renewables. To model economic development in 2020, we increase the 2009 reference electricity demand and prices by 22,4% and 14% respectively, while these increases are only of 14.3% and 11% in case of economic stagnation[10].

Scenario 2020	**Description**
Cournot, ETS	Oligopolistic competition with ETS regulation and investments
Cournot, ETS, inc	Oligopolistic competition with ETS regulation, investments and incentives in new renewable technologies
Cournot, ETS, nodev	Oligopolistic competition with ETS regulation and investments in the case of no economic development
Cournot, ETS, inc, nodev	Oligopolistic competition with ETS regulation, investments incentives in new renewable technologies in the case of no economic development
Perfect, ETS	Perfect competition with ETS regulation and investments
Perfect, ETS, inc	Perfect competition with ETS regulation, investments and incentives in new renewable technologies
Perfect, ETS, nodev	Perfect competition with ETS regulation and investments in the case of no economic development
Perfect, ETS, inc, nodev	Oligopolistic competition with ETS regulation, investments and incentives in new renewable technologies in the case of no economic development

Table 3: 2020 scenarios

The emission market that we model is limited to the Italian electricity market and we do not consider the CO_2 allowance trade with the other sectors involved in the EU-ETS. We introduce

[10]See Terna, 2006 and ICCF, 2005.

this restriction since we do no have any information about this trade, but we intend to overcome this limit in our future research. Given this restriction, the total emission cap E computed for the 2009 scenarios corresponds exactly to the sum of the NAPs of the electricity generating companies included in the simulation tests that we took from the European Commission website[11]. It amounts to about 94 Millions tons. This cap denotes the amount of emissions allowed in the power market. Considering the new disposal introduced by Directive 2009/29/EC, we compute the 2020 cap by reducing by 15% the 2009 cap[12].

Finally, our mixed complementarity problems are implemented in GAMS language using PATH as solver.

4.2 Results

In this section, we report the results of our analysis. In particular, we want to show the effects of the EU-ETS on electricity prices, investments and generators' profits in the different scenarios.

4.2.1 Impact on prices

Figures 2 and 3 define the trend of the national hourly electricity prices respectively in 2009 and 2020. For 2009, we consider all scenarios listed in Table 2, while for 2020, we select only four among the six cases proposed in Tables 3.

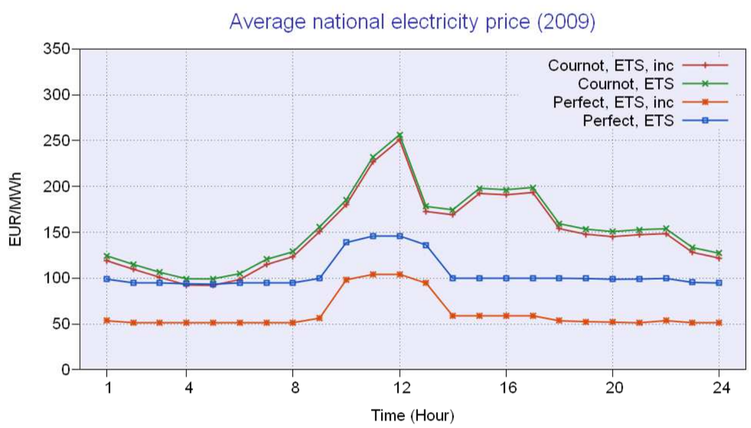

Figure 2: Average national electricity prices in 2009

Both in Figures 2 and 3, electricity prices are higher in the oligopolistic market organization than in perfect competition. The electricity prices are generally lower in presence of incentives in

[11]See `http://ec.europa.eu/clima/policies/ets/allocation/index_en.htm`

[12]The 15% cut corresponds to a yearly reduction of 1,74% of the 2009 cap as foreseen by the new ETS Directive.

renewables. This happens both in 2009 (see Figure 2) and 2020[13]. In fact, with incentives, there are more investments in less pollutant plants that imply a reduction of the CO_2 allowance price. This is particularly evident in the "Perfect, ETS, inc" of the 2009 setting, where the emission price decreases by 41% compared to its corresponding level without incentives ("Perfect, ETS"). This lower electricity price also implies a daily increase of about 102 GW in electricity demand compared to the "Perfect, ETS" value. We register the same phenomenon in the 2009 "Cournot, ETS, inc" case, but in a smaller proportion because the CO_2 price decreases only by 23.5% and the raise of the daily power consumption is just of 9 GW.

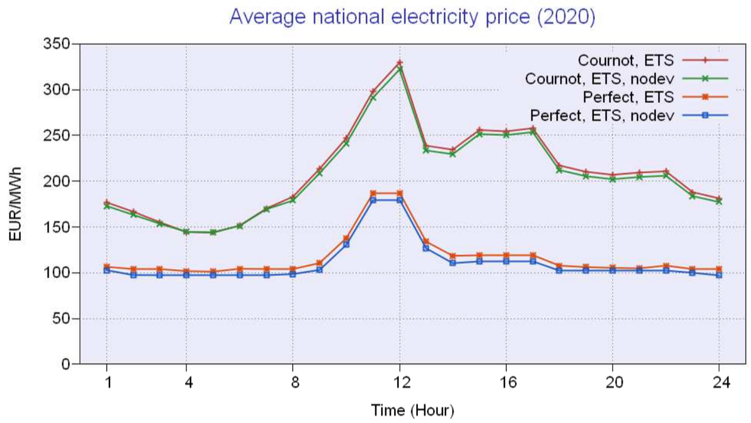

Figure 3: Average national electricity prices in 2020

Figure 3 depicts the electricity prices in 2020 in the case with and without economic development for both market organizations. The results confirm that power prices in 2020 are higher than in 2009. Since the difference between the total quantity of electricity produced in the cases of economic growth and stagnation is small, we obtain similar electricity prices in these two cases. This happens both in the Cournot and in the perfect competition market organizations[14].

4.2.2 Impact on investments

In this section, we describe how the market organization (Cournot vs perfect competition) and the EU-ETS can affect investment strategies. In our simulations, we assume that generators

[13] We do not report this case in Figure 3.

[14] In the "Perfect, ETS, nodev" electricity generation is only 7% lower than in the "Perfect, ETS". We have an identical reduction in the "Cournot, ETS, nodev" compared to "Cournot, ETS".

can only invest in the geographical zones[15] (namely North, Center-North, Center-South, South, Sicily and Sardinia). In Figure 4, we report the results of the 2009 scenarios "ETS", "ETS,

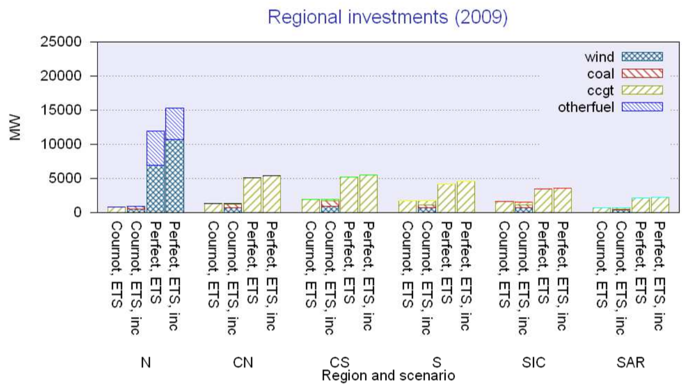

Figure 4: Zonal investment in 2009 by source of energy (MW)

inc" in the "Cournot and "Perfect" competition cases. A first result is that perfect competition enhances investments compared to the situation where generators are Cournot players. This happens both in the scenarios with and without incentives. Under the assumption of perfect competition, Figure 4 shows that generators take different investment decisions depending on the zones. In the North, there is a massive investment in wind in addition to other-gas based plants, while in the other zones power producers only invest in CCGT. These investment choices can be explained by the fact that, considering our input data, the North disposes of almost the 57% of the Italian available CCGT. This is an efficient technology both in terms of production and emission generation and it is not subject to intermittence problems (like wind). On the other hand, wind is the cheapest among the renewable technologies in terms of fixed costs, but it remains much more expensive compared to the other power units. Even in presence of incentives ("Perfect ETS, inc") investment strategies do not change. The incentives increase the wind investments in the North by 35%. Note that, besides these investments, generators use existing plants to produce electricity. In particular, both with and without incentives, they run all renewables[16] and CCGT technologies. While renewables are run at full capacity in almost all hours, existing CCGT is mainly used in the central hours (from 10 a.m to 5 p.m.).

When considering the Cournot scenarios in 2009 (see Figure 4), the investment choices are all oriented towards CCGT. With incentives in renewables, the investment mix changes and includes wind, CCGT and also a proportion of coal. Under Cournot assumptions, generators are able to impose higher electricity price and reduce their production and investment levels. In

[15]Note that we assume no investments in hydro plants since the hydroelectric resources are almost fully exploited in Italy.

[16]Wind, hydro, photovoltaic, geothermic.

this way, the emission constraint is still binding but the associated CO_2 is much lower than in all other 2009 considered scenarios[17]. This cut in emission price is due to the increased use of wind. On the other side, this situation makes coal plants competitive since they are relatively cheap both in terms of fixed and variable (fuel) costs.

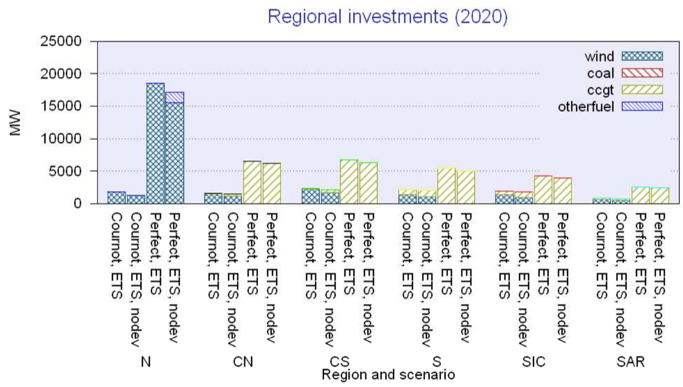

Figure 5: Zonal investment in 2020 by source of energy (MW)

In 2020, the overall investment level is higher than in 2009 both under the Cournot and the perfect competition assumptions. In Figure 5, we report the results of the 2020 scenarios in the case with and without economic development. Under perfect competition, generators' investment strategies remain almost unchanged at zonal level with respect to the 2009 situation (compare the scenarios reported in Figure 5 with the "Perfect, ETS" case in Figure 4). This is particularly true in the scenario of low economic growth (see "Perfect, ETS, nodev" in Figure 5) where in the North there are still investments in other-gas power plants (even though in a lower proportion compared to the 2009 case[18]). Recall again that due to the high concentration of CCGT plants in the North, generators prefer to invest in another type of fossil-fired technology, at least in this area, but in the other zones, they continue to invest in CCGT. These investments in other-gas plants disappear in presence of economic development. In fact, generators only build new wind stations. With incentives in renewables (these cases are not reported in Figure 5),

[17]It amounts to 39 €/MWh, while in the corresponding Cournot case without incentives allowance price is 51 €/MWh. Under perfect competition, CO_2 emission prices amount to 207 €/MWh and 112 €/MWh respectively in the cases without and with incentives. We know that these prices are not realistic, but they can be compatible with our model assumptions. In fact, we assume that the emission market involves the electricity market only and experience has shown that the power market has been always short in emission permits. This becomes particularly true in the case of the Italian electricity market because its production is mainly based on fossil-fired power plants. In fact, we have observed that an increase of the emission cap determines a decrease of the CO_2 allowance price.

[18]In 2009, investments in other-gas plants amount to 42% and 30% of the total investment level in the North respectively in the case without and with incentives. In 2020, this proportion drops to 9%.

investments increase both in the scenarios with and without economic development. In the North, only new wind plants appear, while in the other zones investments in CCGT persist.

Considering now the Cournot scenarios in Figure 5 and comparing them with the case "Cournot, ETS" in Figure 4, one can see that generators reduce their global investments in CCGT in favor of wind in all zones. This is particularly evident in the North. This change of tendency can be considered as a direct effect of the compulsory auctioning system imposed by Directive 2009/29/EC on energy sector during the third EU-ETS phase. Since the aim of oligopolistic generators is to maximize their profits, they try to reduce their emission costs by investing in renewables. This happens both with and without economic developments.

In presence of incentives in renewables[19], investments in wind almost double in the "Cournot, ETS, inc" and triple in the "Cournot, ETS, inc, nodev" with respect to the corresponding cases without incentives (see Figure 5). However, incentives induce generators to build new coal plant both with and without economic development. The reasoning, illustrated for the 2009 scenarios with incentives, also holds for these 2020 cases.

4.2.3 Impact on generators' profits

Tables 4 and 5 respectively report the profit analysis in the 2009 and 2020 scenarios. In particular, they list the "Generation Revenues", the "Generation Costs", the "Emission Revenues" and the "Emission Costs". The first two terms indicate the profits and the (fixed and variable) costs related to power production from new and existing plants, while the difference between the other two shows the emission opportunity costs. In 2020, the column "Emission Revenues" disappears since during the third EU-ETS phase the power sector will buy all needed permits. Note that, in our analysis, we do not consider the windfall profits problem that has been extensively discussed and proved in literature (see Chen et al., 2008, Kara et al., 2008, Linares et al., 2008, Lise et al., 2010, Sijm et al., 2006). Moreover, in our simulations we assume full auctioning of CO_2 allowances both in 2009 and 2020. The "Emission Revenues" in 2009 are simply given by the product between the endogenous allowance price and the grandfathered permits.

As expected, the generators' profits in an oligopolistic market are always higher than in perfect competition. This happens both in 2009 and 2020 scenarios, but it is particularly evident in 2020 when generators no longer receive permits for free. The comparison between the results in Tables 4 and 5 shows that the profits of oligopolistic ("Cournot") generators are higher in 2020 than in 2009. This is a direct consequence of the increase of the electricity prices that more than compensates the cost of emissions.

In the perfect competition cases, profits are lower in 2009 than in 2020 because they have to buy all needed permits.

In all scenarios, generators gain lower profits when receiving incentives on renewables because the subsidies to these technologies lead to lower electricity prices while maintaining relatively high investment costs. Finally, in the 2020 case with no economic developments, generators' profits are lower than in the corresponding cases with economic growth.

[19] Again, results are not reported in Figure 5.

Scenarios	Generation Revenues (M€)	Generation Costs (M€)	Emission Revenues (M€)	Emission Costs (M€)	Total Profits (M€)
Cournot, ETS	40,010	10,615	4,317	4,797	28,915
Cournot, ETS, inc	38,997	10,779	3,268	3,631	27,854
Perfect, ETS	38,366	11,149	17,387	19,319	25,284
Perfect, ETS, inc	25,293	10,144	9,405	10,450	14,104

Table 4: Generators' profits in 2009 scenarios

Scenarios	Generation Revenues (M€)	Generation Costs (M€)	Emission Costs (M€)	Total Profits (M€)
Cournot, ETS	62,817	21,698	8,086	33,034
Cournot, ETS, inc	53,665	17,920	2,578	33,166
Cournot, ETS, nodev	57,306	19,044	7,720	30,542
Cournot, ETS, inc, nodev	49,156	16,156	2,578	30,417
Perfect, ETS	52,076	24,231	19,583	8,262
Perfect, ETS, inc	36,162	17,761	13,169	5,231
Perfect, ETS, nodev	47,084	20,790	18,211	8,083
Perfect, ETS, inc, nodev	27,081	13,864	9,068	4,149

Table 5: Generators' profits in 2020 scenarios

5 Conclusion

The generation expansion models presented in Section 2 and Section 3 simulate and analyze the impact of the EU-ETS on the Italian electricity market. In particular, these models are used to measure the effects of the EU-ETS Directives on electricity prices and demand, investments and generators' profits both in an oligopolistic and in a perfectly competitive organization of the power market. For this reason, we consider several investment scenarios under the CO_2 regulation with and without incentives to renewables. The scenarios also include simulations on future effects of the third EU-ETS phase on the system.

Our analysis shows that perfect competition induces generators to invest more than in an oligopolistic framework, but in both market configurations, investments are mainly concentrated in fossil-fired plants (CCGT and coal), leaving a small proportion to new wind plants. This happens also in presence of incentives given to renewable technologies. We can thus conclude that investments in a secure and efficient technology like CCGT is preferable compared to those in renewables that cannot be used with continuity. The absence of nuclear plants in the Italian power market also influences the choice described above. This investment policy affects electricity prices that significantly increase in 2020 compared to their 2009 levels.

The raise of electricity prices in 2020 is particularly favorable for generators operating as Cournot players which are able to increase their profits compared to 2009, despite the full auctioning system foreseen for the allocation of CO_2 allowance to the power sector in the third EU-ETS phase. On the contrary, in a perfect competition organization, generators face a significant drop in their 2020 profits compared to 2009 caused by the increase of their emission costs.

In our future research, we intend to develop the current model by including a technological representation of industrial sectors covered by the EU-ETS. This will allow us to have a complete and more realistic representation of the emission market functioning.

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