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EUROPEAN ELECTRICITY DAY AHEAD MARKET

A MULTIPLE TIME SERIES APPROACH

Doctoral Dissertation

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Abstract

The energy market reform of the last decades is a complex restructuring process that first has opened up Member State electricity markets to competition and it gradually fosters them toward integration into the Single European Market. Even if national markets are still characterized by several differences in the production structures, regulation shapes a common market design at European level and voluntary measures have been adopted to promote market integration. The recent empirical literature highlights the presence of cointegration at least among the day ahead electricity markets of Central Western Europe. In this framework, Power Exchanges have taken a key role as shown by the growing volumes traded on their different segments and in recent years electricity price forecasting has become an interesting research field. However, up to now, most of the contributions on short term forecasting of day ahead electricity prices do not include the possibility of dynamic interactions between several interconnected electricity markets. After a primer on the economics of electricity markets and the analysis of the regulatory and market framework, the present work proposes a multiple time series approach for electricity price forecasting, joining the two strands of empirical literature on market integration and day ahead price forecasting. Accounting for the presence of market integration enlarges the model information set, so it may potentially improve the forecasting performance.

This thesis considers hourly day ahead electricity prices for eight European countries (Austria, Belgium, France, Germany, Italy, Netherlands, Slovenia and Switzerland) for the period May 2010–July 2013. Multiple time series models have been used to forecast electricity prices for all the markets and an in-depth comparison between their accuracy and the one of simple time series models has been provided. At present the implemented forecasting exercise does not allow stating that estimating multiple time series models, and especially including potential cointegration relationships between day ahead electricity prices, greatly improve their forecasting performances compared to simple time series models. The adoption of multiple time series may lead to better results only in some hours and in other hours, simple time series models outperform multiple time series ones (especially ramp- up hours in the morning).

Keywords: European electricity markets, electricity prices, forecasting, electricity market integration, multiple time series models

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List of abbreviations

ACER:	Agency for the Cooperation of Energy Regulators
ADF:	Augmented Dickey Fuller
AIC:	Akaike Information Criterion
AR:	Auto Regressive
ATC:	Available Transmission Capacity
BIC:	Schwarz Bayesian Information Criterion
BS:	Balancing Services
CACM:	Capacity Allocation Congestion Management
CBA:	Coordinated Balancing Area
CCGT:	Combined Cycle Gas Turbine
CEE area:	Central East Europe area
CEER:	Council of European Energy Regulators
CHP:	Combined Heat and Power plant
CSE area:	Central South Europe area
CWE area:	Central Western Europe area
DSO:	Distribution System Operator
EB FG:	Electricity Balancing Framework Guidelines
ENTSO-E:	European Network Transmission Operators –Electricity
EPC:	European Price Coupling
ERGEG:	European Regulators' Group for Electricity and Gas
ERI:	Electricity Regional Initiatives
FTR:	Financial Transmission Rights
FUI area:	France UK Ireland
GME:	Gestore del Mercato Elettrico
HQ:	Hannan Quinn
IEA:	International Energy Agency
ISO:	Independent System Operator
ITO:	Independent Transmission Operator
ITVC:	Interim Tight Volume Coupling
KPSS:	Kwiatkowsky Phillips Schmidt Shin
MAPE:	Mean Absolute Percentage Error
NC EB:	Network Code on Electricity Balancing
NRA:	National Regulatory Agency
NTC:	Net Transfer Capacity
OCGT:	Open Cycle Gas Turbine
PTR:	Physical Transmission Rights
PX:	Power Exchange
PP:	Phillips Perron
RES:	Renewable Energy Source
RMSE:	Root Mean Square Error
SMAPE:	Symmetric Mean Absolute Percentage Error

SO:	System Operator
SWE area:	South West Europe area
TPA:	Third Party Access
TSO:	Transmission System Operator
VAR:	Vector Autoregressive
VEC:	Vector Error Correction
VoLL:	Value of Lost Load

Introduction

Since the mid 1990s, the European Commission has been promoting an extensive reform process aimed at restructuring the Member States electricity supply industries, traditionally based on regulated vertically integrated natural monopolies. Several reasons have fostered this process, from the global trend toward the liberalization of the infrastructural services to technological change, that allowed overcoming the perception of monopoly as the natural solution for all the electricity supply chain segments. Two interrelated levels distinguish the European reform: on the one hand electricity markets Directives have fostered the liberalization process of the national electricity markets and, on the other hand, several initiatives have been promoted to improve cross border exchanges (Jamasb and Pollitt, 2005). Competition across Europe was viewed as a major pre-condition for the gradual integration into a single European electricity market. Hense, the First and the Second Electricity Directives mainly aimed to restructure the sector, moving toward a market based industry, while the Third Directive focused on the final target of the reform process, i.e. the creation of the Single European Energy market. Indeed, the Third Electricity Directive and the related Regulations support the bottom-up approach implemented by the Electricity Regional Initiatives from 2006 with a top-down approach for the integration of national electricity markets. The Agency for the Cooperation of Energy Regulators (ACER) and the European Network of Transmission System Operators for Electricity (ENTSO-E), established with the Third Package, have the task to develop framework guidelines and network codes that are legal instruments to enforce the Electricity Target Model across Europe in all timeframes relevant for electricity exchanges. It is a set of harmonized rules developed bringing together National Regulatory Authorities, Transmission System Operators, Power Exchanges and electricity market players in a voluntary bottom-up approach to the integration of national electricity markets into regional ones, as an intermediate step towards the completion of the single European electricity market. Up to now, it has already contributed to the creation of several regional wholesale electricity markets in Europe, but at present it needs to be adopted at European level as well. Therefore, in order to reach the goal of a Single European Market, four cross regional roadmaps have been identified, each dedicated to a peculiar aspect of the Electricity Target Model. Focusing on the day ahead timeframe, the Target Model envisages the implementation of a Single European Price Coupling, i.e. a simultaneous calculation of volumes and prices in all European day ahead market zones on the basis of the marginal pricing principle.

In the actual implementation of the Electricity Target Model and the creation of a single European wholesale electricity market, especially in the day ahead timeframe, Power Exchanges have taken a key role, as the growing volumes of electricity traded on their various segments also show. Accordingly, Power Exchanges prices forecasting and especially day ahead electricity market price forecasting has become increasingly important for market players, not only for long term capital budgeting but also for short term bidding optimization. The costs of adjust their position in the balancing markets are general so high that can heavily impact on the financial structure. Considering the extreme electricity price volatility, price forecasting both for short and for long term have become crucial for corporate portfolio strategies (Weron, 2014). Moreover, as reported by Kristiansen (2012), a key factor for market openness and participation in energy trading is the possibility for medium sized consumers to set up reliable and independent price forecasting.

In this contest, electricity price forecasting has become an interesting research field and a growing empirical literature has been developed since 2000. This is a challenging matter, due to the peculiar features of electricity that make it a unique commodity, both from an economic and a technical point of view. Looking at the demand side, electricity shows high variability over time and cannot be managed trough price mechanisms, since it is generally price inelastic, at least in the short term. Coming to the supply side, electricity cannot be stored at economic condition on large scale (it can be stored only through battery or storage hydro plants) and this implies that it must be generated in the same quantity and at the same time as it is consumed. From the technical point of view, the electricity sector is a network system, arranged by a set of power lines connecting different locations. Energy is fed into the grid by scattered generation plants in several points of the power lines and it is withdrawn by the final consumers as an integrated system, without being possible to determine the path followed by the power and the energy origin in each node. The network is built as a dense mesh to ensure system security, allowing electricity to follow alternative paths in case of line failure and due to this structure, technical constraints arise. First, power transmission on the grid requires accounting for the line capacity and when power flows originated by market transaction violate a network constraint, congestion arises. Second, frequency and potential differences must be always under control and cannot diverge from standard levels, in order to ensure generation plants security and service quality. Power flows in the network according to physical laws, implying that every time there is an injection or a withdrawal on a node, network externalities are generated on all the others agents connected to the same grid. All these features have required a particular market design for electricity and they contribute to make electricity price forecasting a quite complex issue.

Focusing on short term forecasting of day ahead electricity prices, the empirical literature has so far suggested to use a wide range of simple time series models, such as ARIMA models, structural models including variables on market fundamentals or possibly regime switching models and mean-reverting jump-diffusion models. However, most of the contributions on short term forecasting of day ahead electricity prices tackle this task without including in the estimation the possibility of dynamic interactions between several interconnected day ahead electricity markets.

The present work is aimed to propose an approach to forecast European electricity day ahead price including the evidence about market integration. In recent years, a growing empirical literature is indeed investigating whether or not European wholesale electricity markets and especially European day ahead electricity markets are cointegrated and, despite there is no a conclusive evidence at the European level, the presence of cointegration seems to emerge at least between the day ahead electricity markets of Central Western Europe, an area covering most of the countries analyzed in this work. Accounting for the presence of market integration enlarges the information set of the model, so it may potentially lead to better forecasting performances.

From a methodological point of view, multiple time series models are set up. Due to uncertainty about the stationarity properties of the electricity price series, verified through the implementation of both unit root and stationarity tests, a Vector Autoregressive Model has been fixed under the assumption of stationarity and a Vector Error Correction Model has been specified under the assumption of unit root. The inclusion in the VEC model of the cointegrating relationships allows the model to account for cointegration among national day ahead price time series.

The analysis has been carried over the period from May 11th, 2010 to July 29th, 2013 for the following eight European countries: Austria, Belgium, France, Germany, Italy, Slovenia, the Netherlands and Switzerland.

Each hour of the day has been modeled separately, in order to capture the day ahead electricity markets microstructure (Huisman et al., 2007). Indeed, day ahead negotiation results in one price for each hour of the day even when Power Exchange rules allow not only hourly offers, but also block orders, combining different hourly products. This approach is also consistent with some previous contributions showing that it leads to better forecasting performance (Cuaresma et al., 2004; Knittel and Roberts, 2005; Karakatsani and Bunn, 2008) and with a multi model specification for short term forecast adopted in the demand forecasting research (Weron and Misiorek, 2008).

VAR and VEC models have been estimated for each of the 24 hours of the day after grouping together all the countries involved so as to capture the possible presence of dynamic interactions and possible cointegration between their corresponding day ahead electricity markets.

These models have been implemented in order to obtain short term forecasts, so each model has been used to make one step ahead forecast. All the models have been estimated using a recursive scheme, meaning that the model structures are the same throughout all the forecasting period, but every day the model coefficients have been estimated again using all the previous values of the variables included. For a benchmark purpose, simple time series models are estimated separately for each of the 192 combinations between the 24 hours of the day and the 8 countries involved, both under the hypothesis of stationarity and the hypothesis of the presence of unit root in the day ahead electricity price time series. In such a way, the present work provides a comprehensive comparison between forecasts obtained through multiple time series models and simple time series models: three measures of forecast accuracy have been provided, Mean Absolute Percentage Error (MAPE), Symmetric Mean Absolute Percentage Error (SMAPE) and Root Mean Square Error (RMSE) loss functions.

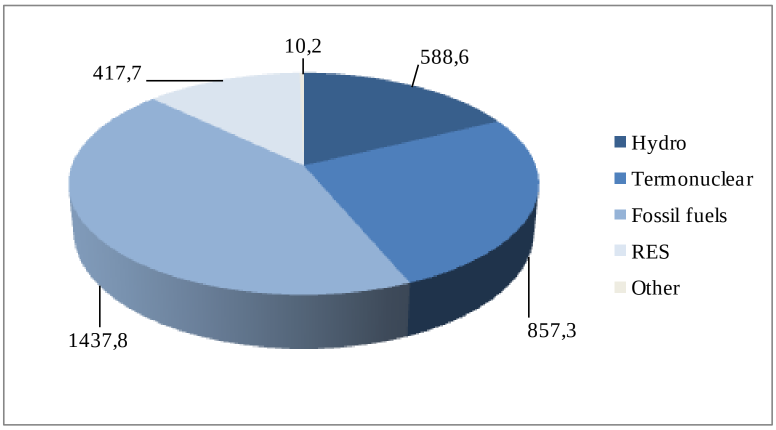
Moreover, the analysis has been extended in order to account for the presence of spikes. The electricity non storability at economic conditions eliminates the buffering effect and forces spot prices to depend widely on supply and demand condition in each moment and this increases the probability of sudden large price changes, named spikes, especially when demand is high (Huisman and Kiliç, 2013; De Jong, 2006). As an attempt to deal with this phenomenon, the same models have been estimated after spikes detection and substitution in the dataset through a filtering procedure.

The thesis is structured as follows. Chapter one provides a primer on the economics of the electricity market, describing electricity technical and economic features that make this commodity quite unique. These characteristics heavily affect market design, so an overview on the resulting market organization and energy transaction and system operation has been provided. The second chapter clarifies the regulatory framework, in order to describe the reform process that has interested Europe in the last two decades. After placing the European reform into the context of the liberalization era, Directives and Regulations aims have been investigated. Moreover, an overview on the main aspects of the Electricity Target Model, especially referring to day ahead timeframe is reported. The third chapter explores the national generation capacity mix and it provides an explorative analysis of wholesale electricity markets in terms of market liquidity and price convergence. Once investigated the complex set of transformation electricity markets have been facing both from a regulatory and a market point of view, chapter four introduces electricity price forecasting. A cross overview of the main contributions regarding time series model and a review of the recent empirical literature on market cointegration, so far developed independently, has been provided. In order to carry this study, hourly price and load data have been collected for eight European countries for the period May 11th, 2010 to July 29th, 2013; chapter five reports the dataset description. In the sixth chapter, the chosen methodology has been described. After an introduction on multiple time series models, stationarity properties of day ahead electricity price time series have been investigated through unit root and stationarity tests and models have been specified accordingly. In the last chapter, multiple time series models have been used for short term forecasting and the forecasting performances have been compared with the ones obtained using simple time series models. A recursive filter has been applied on the original dataset to detect and remove spikes that may affect forecast. Again, multiple time series model forecasting performances have been compared with simple time series ones. The last chapter discloses conclusive thoughts and further developments of the present work.

1 A primer on the economics of electricity market

The society development has experienced a growth in energy use, with more concentrate and versatile forms respect to the past (Smil, 2000). In particular, due to its versatility, electricity has taken a key role, with an intensive usage both for domestic consumers (e.g., heating, air conditioning, household electric appliance) and industrial activities. For an illustrative purpose, in order to provide the dimension of the sector, **Figure 1.1** shows electricity production by source in Europe in 2013, that amounts to 3330 TWh[1].

Figure 1.1: European Electricity Production (TWh) - 2013



Data source: ENTSO-E

A close relation between electricity consumption and GDP growth has been observed[2], and electricity related measures are used as indicators of industrial development or living standards (Laloux and River, 2013). IEA scenario for 2035 foresees that global demand for electricity still grows faster than any other energy form, even if with different rates across countries. In particular, non OECD countries are responsible of the higher growth and European demand will increase at a CAAGR 2010-2035 ranging from 0.5% to 1.1% according to different scenarios (**Table 1.1**). This is linked to the new uses for electricity that, at the moment, overcomes the substantial improvement in energy efficiency in developed countries.

[1] This is the total production for 2013 for all the countries registered in the ENTSO-E Country Packages.
[2] Starting from Kraft and Kraft (1978) that identified a uni-directional causal relationship between GNP and energy consumption a wide stream of literature analyzed the direction of this relationship with different conclusions.

Table 1.1: Electricity demand by region and scenario (TWh)

			New policies		Current policies		450 Scenario	
Region	**1990**	**2010**	**2035**	**CAAGR 2010-35**	**2035**	**CAAGR 2010-35**	**2035**	**CAAGR 2010-35**
OECD	6592	9618	11956	0,9%	12635	1,10%	11013	0,50%
Europe	2321	3232	3938	0,8%	4247	1,10%	3676	0,50%
Non-OECD	3494	8825	19903	3,3%	22254	3,80%	16931	2,60%
Word	**10086**	**18443**	**31859**	**2,2%**	**34889**	**2,60%**	**27944**	**1,70%**

Source: IEA World Energy Outlook, 2012, p.180

Since electricity is considered an essential service, it is necessary that the provision of electricity is ensured to all end users and at any time. Due to this, complex power systems have been set up and "electric power system are generally regarded to be the largest and most complex industrial system ever built." (Laloux and River, 2013, p.1). In the follow of this section, an overview of the electric power system structures has been provided, starting from a description of the electricity technical and economic features and how they affect market design.

1.1 Electricity technical and economic features

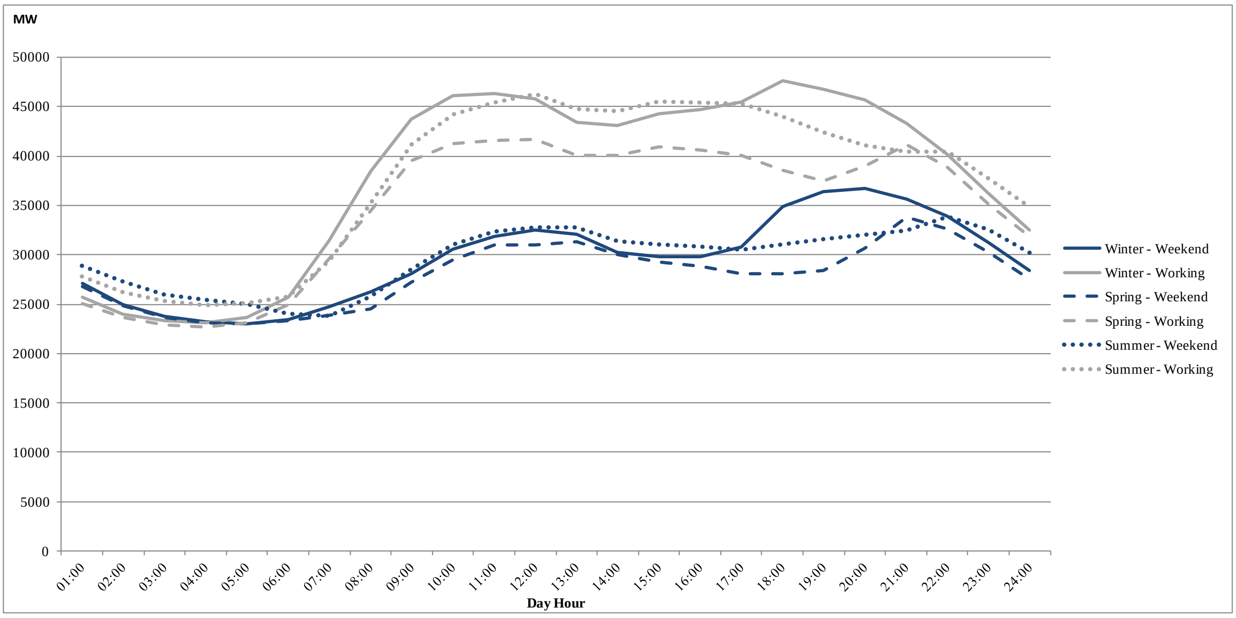
Power system is made up by production plants that convert primary energy into electricity, by transmission and distribution grids that transport power from the generation plants to final users and by consumption.

Electricity is a quite unique commodity due to several features, both from an economic perspective and a technical one.

Looking at the demand side, electricity shows high variability over time. Load curves, that are the sum of all individual consumption curves and represent power consumed as a function of time, indicate that electric demand varies significantly at daily, weekly and yearly level. In particular, higher demand is registered in some hours during the day (between 4th and 11th in the morning load almost doubles), moreover the load is larger in working day than in weekends and it increases in winter and summer because of heating and air conditioning. For an illustrative purpose, in **Figure 1.2** six hourly load curves[3] for Italy have been represented: the three upper curves (in grey) refer to working day (Monday) and the lower ones (in blue) to weekend (Sunday). Within each group, the lowest curve shows hourly load value for a Spring day (April). Moreover, a higher demand has been registered in hot hours in Summer due to air conditioning, and vice-versa in Winter due to heating.

[3] Load curves refer to the following days: Winter- weekend 12th January 2014; Winter- working 13th January 2014; Spring- weekend 6th April 2014; Spring- working 7th April 2014; Summer- weekend 22nd June 2014; Summer- working 23rd June 2014.

Figure 1.2: Hourly load values for Italy (MW)



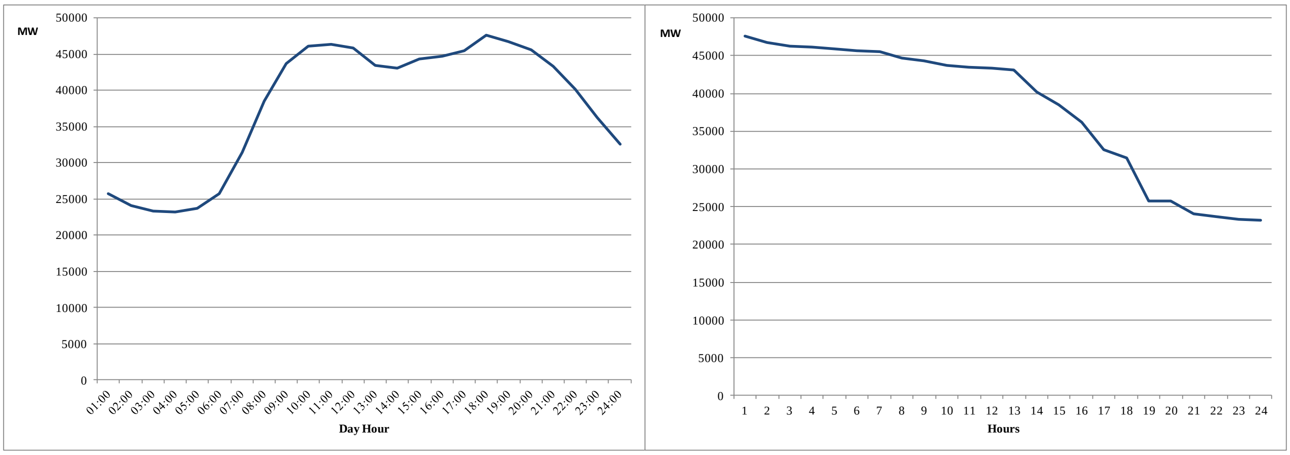
Data Source: ENTSO-E

Electricity demand cannot be managed through price mechanisms, since it is generally price inelastic, at least in the short term. Such feature is due to the absence of substitutes and to the consumers' inability to react to spot prices. Only in recent years, thanks to the progress in the information and communication technologies and the liberalization process, consumers could assume an active role in programming electric consumptions according to price signals, but demand side management is still a way to go, due to high transaction costs coming from monitoring spot prices and adapting the consumption inclinations (Laloux and Rivier, 2013). Furthermore, also the physical rationing is limited, because, generally speaking, it is not possible to interrupt the service on a consumer-by-consumer basis in real time. This option is feasible only for special customers that have subscripted a specific contract clause in return for a discount on power price.

Coming to the supply side, electricity cannot be stored at economic condition on large scale (it can be stored only through battery or storage hydro plants) and this implies that it must be generated in the same quantity and at the same time as it is consumed. This feature joint with the load variability heavily impacts on the supply. To ensure system adequacy, generation capacity has to be computed in order to cover peak load period, even if peak hours are limited. This need reduces plant load factor, but it is necessary to guarantee the service provision. Moreover, in the attempt of minimizing the cost of the service, economic principles suggest the opportunity of a generation mix composed by several technologies with different technical features and cost structures (**Figure 1.4**). Different technologies are usually characterized by an inverse relation between fixed and variable costs and therefore they can satisfy different demand segments, referring to the hour of functioning. High fixed costs technologies, such as nuclear power or coal plants, comparatively show low operating costs, being able to meet the base load (8760 hours in the year). On the opposite side, open cycle gas turbines that display higher operating costs, but low fixed costs, are available to meet peak requests. Combined cycle gas stations are in the middle (modulation plants).

Starting from the load duration curve, obtained by sorting in decreasing order the hourly load curve (**Figure 1.3**), it is possible to identify the optimal generation mix analyzing the relationship between demand requirement and plant cost structures.

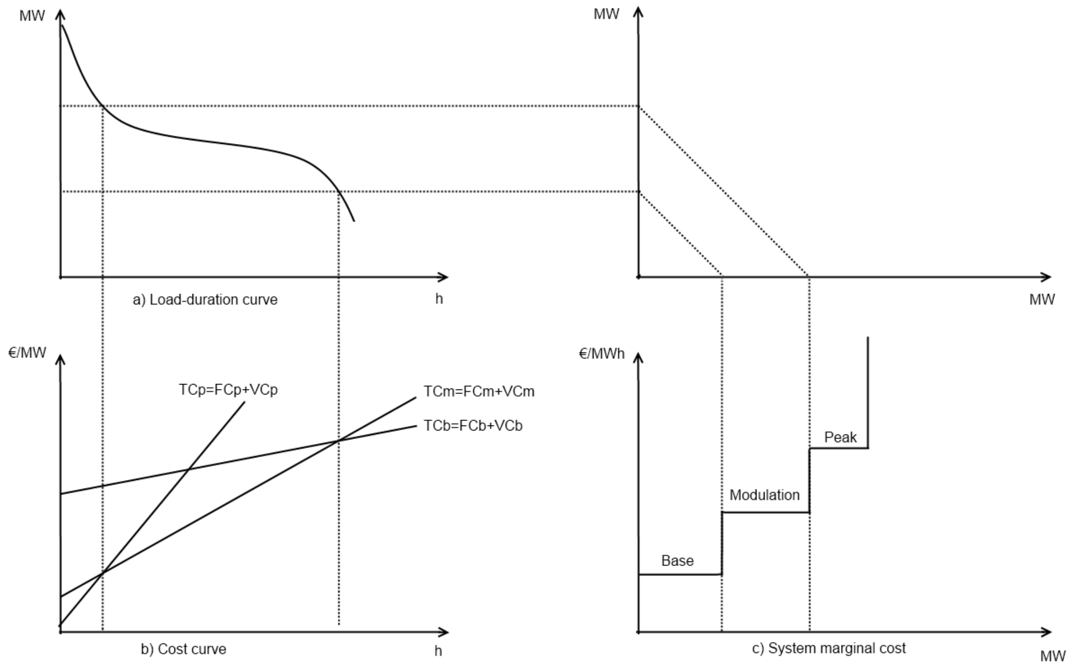
Figure 1.3: Hourly load (left) and Load duration curve (right)



Data Source: ENTSO-E

Figure 1.4 shows the optimal generation mix in the simplified case of three technologies. In the upper left corner, load duration curve is reported and corresponding to each part of it, part b) displays the different costs level for each technology. Total costs have been represented as straight lines, where the intercepts represent fix costs and the slopes identify variable costs. The subscript *b* identified base load plants, *m* the middle merit ones and *p* peak load technologies. The last picture displays the supply curve originated from the different technologies.

Figure 1.4: Optimal generation mix



Source: Campidoglio, 2011, p. 143

Plants also differ for technological features, such as the ramp rate constraints, that are related to the speed and the cost of changing the power supplied: base load plants cannot modify production quickly and at economic conditions, while peak load stations are able to do it. Furthermore, the co-existence of different technologies is also justified by political and environmental considerations, such as the need to diversify the energy sources in order to overcome international political and economic crises and the willingness to provide clean energy, fostering environmental sustainability.

Another peculiar feature of electricity deals with the technical grid structure. The electricity sector is a network system, composed by a set of power lines connecting different locations. Energy is fed into the grid by scattered generation plants in different points of the power lines called nodes and it is withdrawn by the final consumers as an integrated system, without being possible to determine the path followed by the power and the energy origin in each node. Transmission networks connect generation stations to demand hubs and, in order to optimize long distance transmission minimizing power line losses, high voltage grids have been implemented, where energy intensive users can connect directly. Some networks lie underground and submarine cables have been used to connect island and mainland. Scattered substations are transformation nodes that step the voltage down for local distribution networks (medium and low voltage) where small generators can feed their production (distributed generation).

Reliability is crucial for the power system, so the network has been structured as a dense mesh to ensure system security, allowing electricity to follow alternative paths in case of line failure. Given this structure, relevant technical constraints arise. First, power transmissions on the grid require accounting for the line transmission capacity i.e. the maximum power that the line can carry, imposed by the conductors' cross section. When power flows determined by market transactions violate a network constraint a congestion arises. Second, frequency and potential differences must be always under control and cannot differ from standard levels, in order to ensure generation plants security and service quality. Power flows in the network according to Kirchhoff rules. In each point of time, at any node, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node. Moreover, in a meshed network, power follows every available parallel path between the injection node and the delivery point, inversely proportional to the relative resistance, in order to minimize grid losses. These physical laws imply that every time there is an injection or a withdrawal on a node, network externalities are generated on all the others agents connected to the same grid.

1.2 Market design

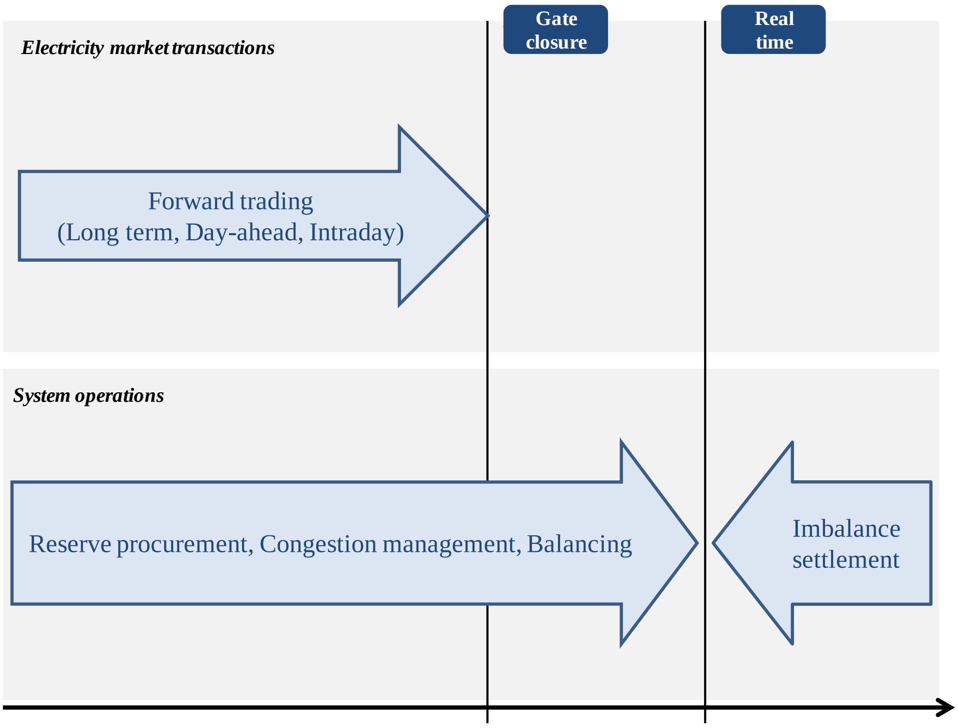
The electricity technical and economic features described above heavily impact on both the power market design and the industry structure.

Due to the complexity and the high coordination level required by the electric power system management, a central entity that guarantees the system security, matching production and consumption, ensuring the respect of the network constraints and providing sufficient generation and transmission spare capacity, is needed. This role is covered by the System Operator (TSO- Trasmission System Operator and DSO- Distribution System Operator[4]).

Moreover, electricity cannot be negotiated as the other commodities. Following the classification of Cervigni and Perekhodtsev, 2013, (**Figure 1.5**) it is possible to distinguish between electricity market transactions, that are all the operations dealing with energy trading, and other transactions related to system operations, carried by the SOs in order to ensure system security. The following paragraphs aim to illustrate this market design; all the descriptions mainly refer to the European model, but, also within this setting, several scheme can be found across countries.

[4] In the follow, the term SO is used without a clear distinction between TSO and DSO.

Figure 1.5: Timeline of electricity transactions



Source: Cervigni and Perekhodtsev, 2013, p.18

1.2.1 Energy transactions

All the transactions in electricity market are forward transactions, even when the expression "spot market" is used. This is because they take place before the time of the delivery, even if at different timeframes. According to the temporal dimension, the market sequence allows to distinguish amongst long term, day ahead and intraday market until the gate closure that is the last time to trade power for delivery at certain time.

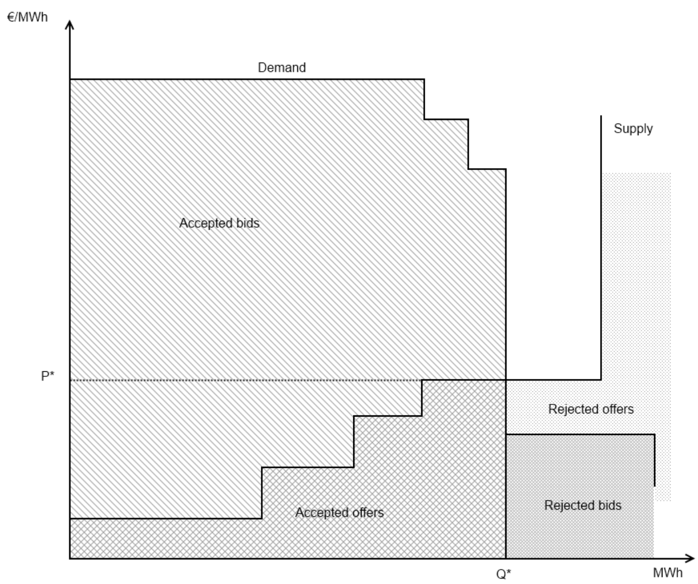
In the wholesale market a central role is covered by the day ahead markets that are heavily influenced by the peculiar features of electricity. Day ahead transactions can be organized as bilateral markets, exchange and pool markets.

In a bilateral model, buyers and sellers engage in an agreement for the delivery of energy without a central counterpart. Exchange markets are based on product standardization, considering the whole energy production of a certain time interval independently from the effective pattern followed during this period. For this purpose, the nature of commodity is essential, because it allows the determination of a single price for different electricity units and the perfect physical substitutability. In absence of standardization, the number of different products traded would be unmanageable. In this framework, market agents submit offers for buy and for sell to the trading platform and Power

Exchange (PX) clears the market. The presence of an efficient spot market minimizes transaction costs, it eliminates the counterparty risk and it guarantees a transparent price formation. Furthermore, PX improves efficiency, allowing the use of the most efficient available resources and the conclusion of all the feasible transactions (Campidoglio, 2011). In general, also in this model bilateral trading is allowed and the co-existence of both bilateral market and spot PX increases market flexibility, since market agents engaged in bilateral contracts may adjust their positions in the spot market. According to this scheme, the production and consumption scheduling is carried out after market clearing: after the gate closure, buyers and sellers notify the SO which unit will produce/consume the traded electricity (nomination). Once collected this information, the SO verifies the network condition and it ensures the feasibility and the system security through ancillary services.

An alternative scheme for day ahead negotiation is the electricity pool model that is a centralized market where the clearing algorithm provides also the unit scheduling for production and consumption, accounting for unit's technical capabilities and system security. This model is prevailing in the US, while in European markets a hybrid scheme based on Power Exchange and bilateral transactions mainly prevails.

Figure 1.6: Market clearing price



Source: Cervigni and Perekhodtsev, 2013, p.24

In day ahead trading, demand and supply match trough an auction mechanism. In the simple structure, for the following day market agents submit offers for buy and for sell, composed by quantity-price pairs for each trading interval. After the gate closure, a merit order is established ranking offers for buy by decreasing prices and offers for sell by increasing prices. In such a way, aggregate demand and supply curves are built and their interception determines market equilibrium (price and volumes). All the bids with a price higher than the equilibrium price are accepted such as all the offers specifying a lower price than the equilibrium one (**Figure 1.6**).

In principle, this mechanism maximizes the net social benefit in each trading interval. Due to the shape of the load curve and the generators' cost structure, the system marginal price can vary significantly during the day. For this reason, generally speaking, the electricity produced and consumed in different hours is traded as a different product. However choosing hours as trading interval can lead to an unfeasible or at least uneconomical plant scheduling, because in simple auction inter temporal plant technical constraints (such as start up cost, minimum technical output, maximum ramp rates, minimum up/down time) are not considered. So, for example, offers from one supplier can be accepted in non consecutive hours, but due to technical infeasibility real production cannot fit the market outcome and generators has to adjust their position through replacement power. In such a condition, the social benefit may not be maximized, because generating cost may not be minimized. Indeed, generators are exposed to risk, so they expect higher rates of return on their investment that imply higher electricity prices; moreover, since they internalize the adjustment costs, offers may not represent the actual costs, so production inefficiency may arise (Cervigni and Perekhodtsev, 2013; Batlle, 2013).

In order to overcome this issue, in a power exchange market structure, it's possible to allow market agents to adjust their position after day ahead market clearing in the intraday market. Moreover, some power exchanges, such as EPEX, have implemented semi-complex auction structures, that, for instance, allow for block-bids, i.e. market agents submit offers for produce/consume in a certain interval of consecutive hours at an average price, that can be completely accepted or rejected. Keeping in mind this issue, for sake of simplicity and without loss of generality in the follow only the case of simple auction is treated.

Market clearing algorithm comes up with an equilibrium price, but for a long time the actual remuneration for generating unit has been subject to a debate between the application of a discriminatory auction, according to which different units receive different payments equivalent to their bids (pay-as-you-bid) or a non discriminatory auction, according to which all market agents refer to the market clearing price. In general, day ahead PXs adopt system marginal price (single price auction) and generators and consumers receive/pay the market-clearing price, i.e. the offer price of the highest accepted bid. This system generates an inframarginal rent for the most efficient plants. Under the assumption of absence of market power, non discriminatory price rule fosters a competitive behavior, since producers bids reflect their marginal production costs and consumers offers represent the buyers' valuation of the good. In this contest the application of the single price rule has a number of benefits. For each trading interval, the gains from trade are maximized and the more efficient plants are selected for production (productive efficiency) and for each level of demand price is equal to marginal production cost (allocative efficiency). The system marginal cost can be decomposed in a short run marginal cost (equal to the marginal production cost) and in a rationing premium (positive only when demand and supply cross in a vertical trait of the supply curve).[5] Trough this system, consumers who withdraws electricity in peak load period face a higher price (long run marginal costs), that includes also capacity costs, according to the peak load pricing theory (Crew and Kleindorfen, 1976) (Campidoglio, 2011).

Once day ahead market has been closed, different demand and supply conditions may arise, due to plants outages, production requirements, modified weather conditions and so forth. Market position adjustments can be assessed in the intraday markets that allow transactions until few hours before real time. Intraday markets can be organized as non discriminatory auction, as in the Italian Mercato infragiornaliero[6] or with continuous trading. In the last model, each submitted bid price is compared with the offers not yet matched and transactions are concluded maximizing the net value. Intraday market with continuous trading operates in different countries, such as France, Belgium, Netherlands, Germany and in the Nordic countries (Cervigni and Perekhodtsev, 2013).

Long term markets include transactions concluded at different timeframe (years, months or weeks ahead the delivery). The main aim of long term transactions is to hedge market agents against short term prices in the liberalized contest, but also speculators may participate to this market. Long term contracts can be either physical (and in this case they influence the dispatch) or pure financial contracts that require only cash delivery on expiry. These contracts can be traded both in over the counter (OTC) markets and in organized Power Exchanges. In the OTC model, bilateral contracts are concluded and the counterparties directly negotiate outside an organized market. This market does not come out with a unique price and only indices, created by

[5] This premium is the consumers reserve price or, when demand is totally price inelastic, the VoLL i.e. the Value of Lost Load. This value is defined by regulators and it is the cost of the missing supply. For an in depth analysis, look at Cervigni and Perekhodtsev, 2013.

[6] This market is organized in four sections, two on the day ahead and two the same day of the delivery. (GME, 2014, website)

organization such as Platt’s, are available. In organized PX, it is possible to trade standardized derivative contracts, futures and options, and transactions are mainly financial.
All the electricity market transactions described in long term, day ahead and intraday markets stop at the gate closure, and market participants’ net positions are determined. Accordingly, the physical production/consumption scheduling is transmitted to the SO (nomination).

1.2.2 System Operations

As mentioned before, due to the complexity of power system, the SO assumes a key role. European Directive 2009/72/EC (article 12) states that TSOs are responsible for ensuring Transmission System Operational Security, with a high level of reliability and quality. System security means the absence of supply interruptions in the short term, while reliability refers to long term horizon and quality means maintaining voltage and frequency within certain margins (Batlle, 2013).
Real-time balance between injections and withdrawals on the network is essential for safeguarding system security, so the SO has to provide balancing services (BS). Moreover, SO has to guarantee efficiency that means supply electricity at the minimum costs. Several reasons may be responsible for imbalance in power systems, such as sudden accidental outage of a component of the electricity system, stochastic imbalance in plant operations and so on. In order to guarantee the security conditions, system operations includes different activities (such as reserve procurement, congestion management, balancing and imbalance settlement) that take place in different timeframes.

Ancillary services and balancing market

SO ensures the electricity delivery and system security through ancillary services. These services deal with production, transmission and distribution of electricity and can be classified in frequency control, reactive power for voltage regulation and black start capability (Batlle, 2013).

Production and consumption may not be perfectly balanced in real time and this implies frequency variations: negative imbalances cause a frequency reduction and the opposite happens in case of positive imbalances. Electric power system needs to keep frequency within a certain range around the standard value (50 Hz in Europe), so the SO has to conduct frequency controls, at three different levels, named primary, secondary and tertiary control.
Primary control is an automatic regulation that is provided by unit already operating, when frequency varies from its nominal value. The response time is within 30 seconds after the

disturbances and this control has a short duration, around 15 minutes. Due to the network structure, the automatic regulation influences power flows also between different areas.

Secondary control is an automatic control that signals special generating units to restore standard frequency value, replacing the primary reserve, according to the interchange flows between the control area and the adjacent areas. The response time ranges from 5 to 15 minutes and the regulation lasts for several minutes. While primary and secondary reserves face the contingency, SO attempts to compensate the imbalance through manual control (tertiary control), that once activated substitutes the automatic reserves.

Different payments are provided for frequency control services. Primary reserve capacity may be obtained mandatory (as in France, UK and Norway, where major generators have the obligation to provide the services) or on a commercial basis. In several countries (Austria, Italy, Spain, Norway, Netherlands, Switzerland and Slovenia) no explicit charges are imposed for this service, under the assumption that production variations from the scheduling will compensate each others. The secondary services are generally not mandatory[7] and are valued at predefined prices or at the same price of the tertiary reserves (Batlle, 2013; Cervigni and Perekhodtsev, 2013). The tertiary control is priced on the balancing market. In this market, some generators submit bids for increase their production (upward offer that contains the value they are willing to receive for the additional production) and others for decrease their production from a specific unit (downward offer that reports the price they are willing to pay for the production variation). In order to provide the services at minimum costs, according to the sign of the system imbalance in the control area, SO accepts the cheapest upward bid or the highest downward bid. In many European countries, the balancing market follows a price-as-bids mechanism, mainly due to the need of continuous operations in order to balance the system and account for network constraints (Cervigni and Perekhodtsev, 2013).

According to Milligan et al. (2010) “the real time power capability that can be given or taken in the operating timeframe to assist in generation and load balance and frequency control is defined as operating reserve” (Milligan et al., 2010, p.1). The presence of such operating reserves is crucial for the system functioning and several systems can be adopted to secure reserve capacity. First of all, many units are needed due to the different dynamic features (such as rump rates) required for the different operating reserves. Suppliers of primary and secondary reserves have to make capacity available in real time to respond to the automatic control; for tertiary reserves, suppliers bid on the balancing markets. Generators offering up/downward regulation have to program the energy

[7] France constitutes an exception because “large” generators are required to provide it (Batlle, 2013).

scheduling in order to provide capacity headroom or foot room respectively. The cost of providing these reserves is the opportunity cost arising from the missed negotiations on the spot market. In order to guarantee the presence of unloaded capacity, the operating reserves can be secured before gate closure, in day ahead, month ahead and year ahead markets. Another approach is used in some countries, where operating reserves are procured after the gate closure, as in the Italian MSD-ex ante market (Cervigni and Perekhodtsev, 2013).

In very recent years, the role of the balancing market has increased due to the penetration of electricity coming from renewable energy sources that for their very nature display limited predictability.

Other ancillary services include the provision of reactive power for voltage regulation and black start capability. Voltage reactive power regulation is needed to maintain the voltage within certain range in the network nodes. This regulation is carried on at three levels, with an automatic primary and secondary regulation correcting the voltage level instantaneously or in few seconds. Tertiary regulation is manual and centralized and it requires more computational time.
Black start capability services allow generators to restart production after an outage and it is generally provided by hydropower plants.

Imbalance settlement

At the time of delivery, actual consumed and produced electricity can differ from the notified quantities. In real time, these discrepancies (imbalances) are valued through a financial mechanism named imbalance settlement. The SO calculates the imbalance volumes as the difference between the nominated volumes and the metered electricity. The imbalance is positive when there is an excess of energy (higher production or lower consumption) that is sold to the SO; in the opposite case, a negative imbalance implies that electricity is bought from the SO. There are several imbalance pricing schemes. Under a “single price” scheme, the imbalance volumes are valued at the balancing price independently from the sign of the imbalance. However, this pricing mechanism may provide incentives to voluntary deviate from the scheduled programs, according to the expected difference between day ahead and balancing prices. In order to overcome this issue, most European power systems (for instance, France, Belgium and Italy) adopt a “dual imbalance pricing system”, that prices negative and positive imbalance volumes differently. When system balance is negative, the SO has to buy electricity, therefore balancing price is likely to be higher than day ahead prices. The opposite situation happens when the system balance is positive. Imbalances of the same sign of the system imbalance are valued at the balancing market price, while day ahead price is applied to the imbalance of the opposite sign. In this way, the market agents that reduce the system imbalance obtain the same profits they would gain operating in the day ahead markets. Dual system imbalance avoids generators' voluntary deviations from the notified volumes with speculative aim. At the same time, it induces system costs. Moreover, as reported by Vandezande et al., 2010, this scheme no longer guarantees a zero sum game, so a surplus for the TSO emerges, that generally results in lower transmission tariffs. Dual pricing scheme may lead to small generators discrimination, when the volume imbalance is assessed at portfolio level. In such a condition, firms with many generators can compensate their imbalance position intra-firm, adjusting the production plan among their plants. Even if a balance is reached intra-firm, the system faces costs resulting from units' injections and withdrawals different from the nominated ones. In the European markets imbalances are computed with different granularities, for instance, German, Austrian, Belgian, French and Dutch systems use a portfolio level, Italian market assesses imbalances at unit level for large generators and at plant level for large customers, but it nets the position of small market agents (Cervigni and Perekhodtsev, 2013, p.47).

Network Congestion Management

Physical limits on grid components and reliability standard can cause network congestions. Several approaches can be adopted to face congestion management, but here only the zonal approach is treated; for further analysis on this topic see Perekhodtsev and Cervigni, 2013.

The zonal approach proposes a simplified network scheme, grouping nodes in zone. Each zone has inside generators and consumers and it is connected to the other zones trough a network, that has a defined transmission capacity i.e. the amount of power that can be carried on that line. Congestions may arise both at intra zonal level and a cross border level. In the first case, they happen within different control area with a single price. The SO has to manage these congestions, and market agents do not consider transmission constraints in the negotiations. Cross border congestions deals with capacity allocation mechanism for cross border trade. In the follow, only cross border congestions are considered. In Europe the zonal approach is used to model cross border power transfers, considering each country as a market zone. The connection between market zones allows exchanging energy between the two countries, defining import and export flows. According to Regulation 1228/2003/EC (art. 2.2c) "congestion means a situation in which an interconnection linking national transmission networks, cannot accommodate all physical flows resulting from international trade requested by market participants, because of a lack of capacity of the interconnectors and/or the national transmission systems concerned”. Congestion must be managed by SO ensuring system security and the efficient use of the transmission capacity. In order to reach this goal, the available transmission capacity has to be maximized and correctly valuated, providing adequate incentives for network and generation capacity investments.

Several methodologies have been applied for cross border allocation in Europe. Broadly speaking it is possible to distinguish between market based and non market based methods. Non market based methods are arbitrary and they do not provide economic correct signals, promote efficient operations and ensure the minimization of welfare losses. This class includes access limitation, “first come, first served” criterion where capacity is allocated on the basis of the requests order until the depletion of the available transmission capacity, or “pro-rata” criterion, where the rationing of the exceeding capacity is shared between applicants in proportion to requests (Kristiansen, 2007).

Gradually market based allocation mechanisms, such as explicit or implicit auctions, have been introduced, also thanks to the development of liberalized and stable electricity markets. Market based methods are non discriminatory and transparent and they are able to provide correct economic signals.

In case of explicit auction, energy market and capacity allocation procedures are separated. Periodically (e.g. one year ahead, one month ahead) the SO determines the Net Transfer Capacity (NTC)[8] and runs auctions in order to set the transmission rights. The transmission capacity, with a positive value due to its scarcity, is priced according to the auction equilibrium price. The congestion rent, if any, is used by SO for reducing operating costs or for network development. Through explicit auctions, the capacity price derives from market agents’ expectations about electricity price that can be failed, so neither the formation of a correct value for transmission capacity nor its efficient use is guaranteed.

In implicit auction mechanism, energy market and transmission capacity allocation procedures are not independent and the right to use the network is implicitly allocated in the spot market, as a part of the market clearing process. As long as there is sufficient transmission capacity, the cheapest available units in both areas are used to match demand and only one system price exits. Power flows according to price differential until the congestion occurs, when market splits and two different zonal prices arise. The capacity is valued as the price difference between the two zones, and the congestion rent can be used for network expansion or for reducing transmission tariffs.

[8] The NTC values represent an ex-ante estimation of the seasonal transmission capacities of the joint interconnections on a border between neighboring countries. The NTCs constitute the maximum foreseen magnitudes of exchange programs that can be operated between two areas respecting the N-1 security conditions of the involved areas, taking into account the uncertainties on the assumptions of NTC assessment (ENTSO-E, 2014a)

In the previous discussion, the central issue is how to allocate the transmission capacity, but the determination of the available transmission capacity is ignored. Actually, this issue is crucial and the approach using to model real network heavily impacts the determination of the transmission capacity and consequently market results. Traditionally in Europe Net Transfer Capacity approach has been used, but recently the implementation of the flow based approach has been increasing. In the NTC model, the capacity limits are set considering bilateral transmission between each pair or connected countries, without accounting for the exchanges amongst the other zones. Within this model, the feasible transactions may be not able to cover the entire security domain, i.e. "the combination of all injections and withdrawals that do not violate any security constraints" (Perekhodtsev and Cervigni, 2013, p. 120). On the other hand, the flow based model allows setting a limit on each critical part of the network where congestion occurs, considering the flows coming from all the other zones. This method allows a more efficient network use compared with the NTC, because it covers the entire security domain making feasible a larger volume of cross border trade. This solution, that requires a high coordination level between SOs, has been implemented both for the allocation of implicit or explicit transmission rights, and it is the preferred solution especially in highly meshed grids in the European reform.

2 The regulatory Framework

2.1 The electricity liberalization era

Traditionally the electricity industry has been structured as a vertically integrated monopoly. Several reasons can be provided to explain this setting. First of all, electricity is a network industry, transmission and distribution activities are natural monopolies and consequently, due to the subadditivity of the cost function, it is less costly to concentrate production in a single firm. Historical reasons may explain the vertical integrated structure, since the beginning, electricity companies carried out all the electricity supply chain steps: generators also provided the distribution network and they directly sold electricity to final consumers in a local dimension (La Cognata, 2011). The vertical integrated structure has allowed the extension of the monopolistic regime also to the stages that cannot be considered as natural monopoly. Moreover, the commodity complexity, discussed in the previous section, and the presence of network externalities added the perception that a monopolistic structure should be preferred. In addition, electricity is considered a universal service, so its provision has to be ensured to all the consumers. Public intervention has been required to guarantee the security of supply and to contribute to the huge investments needed to build large scale power plants and the national transmission grid to face the growing electricity demand (Pollitt, 2012). State ownership or regulation is also necessary to avoid the inefficiency coming from unregulated monopolistic regime (Batlle and Ocaña, 2013). Due to all these considerations, in the last fifty years of the twentieth century the electricity industry was organized as vertically integrated monopoly mainly public-owned in Europe or privately-owned but regulated in US.

This industry organization remained almost the same until the 80s, when an intensive reform process has involved most of the infrastructural services, starting from the US with the Public Utility Policies Act (1978). This process reached Europe in the 80s, first in the UK, with the Thatcher period marking the beginning of the so called “liberalization era”, that involved many industries from telecoms to airlines. Some scholars identified in the willingness of the government to withdraw from the industry and in the search of increasing efficiency the main motivations underlying the liberalization and privatization program (Pollitt, 2012).

The liberalization “standard textbook model” generally implemented in several countries for the electricity sector re-organization is based on a number of interrelated main steps, as explained by Joskow, 2008. Even if not all the reform processes include all the described stages, they represent generic measures useful to build up a market oriented industry (**Figure 2.1**).

Figure 2.1: Main Steps in Electricity Reform

Restructuring	-Vertical unbundling of generation, transmission, distribution, and retail supply activities - Horizontal splitting of generation and retail supply
Competition and Markets	- Wholesale market and retail competition - Allowing new entry into generation and retail supply
Regulation	- Establishing an independent regulator - Provision of third-party network access - Incentive regulation of transmission and distribution networks
Ownership	-Allowing new private actors - Privatising the existing publicly owned business

Source: Jamasb and Pollitt, 2005, p. 2

The restructuring of the sector is a key element, through the separation of the different segment of the vertically integrated firm named unbundling. This implies the separation of the potentially competitive businesses from the segments that cannot be open up to competition due to their very nature of natural monopolies. As mentioned above, transmission and distribution activities are natural monopolies, but generation, marketing and retail supply are competitive activities. Unbundling is crucial because of the conflict of interest of a monopolist also operating in the competitive segment of the market. In such conditions, the incumbent has the incentive and the opportunity to behave in an anticompetitive manner. For instance, the monopolist may implement cross subsidies, using the earnings coming from the regulated activity to subside the competitive activities setting price lower than the ones of competitors. Moreover, the monopolist can implement discriminatory policies, affecting the third party access to the grid (Batlle and Ocaña, 2013). Another important component of the restructuring process is the reduction of the horizontal concentration of generation activities, in order to mitigate market power and pursue an effective competition (Jamasb and Pollitt, 2005).

Opening the market through the introduction of competitive wholesale and retail market is another step in electricity reform. The market has to be designed in order to account for the special features of electricity and the technical system requirements. A sufficient liquidity level is also needed in order to allow participation and efficiency in the market (Jamasb and Pollitt, 2005).

Privatization of the state owned monopolies is another step in the industry transformation. It origins from the belief that private entities are able to improve firm performance guarantying efficient management and cost saving (Jamasb and Pollitt, 2005). Moreover, private property removes the chance for the state to exploit this firm for political purposes (Joskow, 2008). However, privatization is not a mandatory requirement for a reform process, as shown by the experiences in

the Nordic countries, where a full privatization has not been implemented (Nepal and Jamasb, 2013).
Furthermore, the institution of an independent regulatory body is one of the most underlined point of the restructuring process. The agency must have good information about the industry in order to defend public interest, foster competition and effectively control the monopolistic segments, ensuring network access and regulating network charges (Joskow, 2008; Nepal and Jamasb, 2013).
As it will be explained later, even within this general framework, the European market reform does not present all the features of the textbook models, for instance, there is no an explicit requirement to privatize the firms, that is considered a sovereign matter (Pollitt, 2009b; Nepal and Jamasb, 2013).

2.2 The European electricity reform

On this path, several factors have fostered European electricity sector reform. Historically, as already mentioned, the global trend toward liberalization and the diffusion of the neoliberal ideas undermined the strong belief that a monopolistic structure was the only way to organize this sector. The international experiences such as electricity reform in Chile (1982) and UK (1990) strengthened this vision and supported the reform process in other countries (Pollitt, 2012). Moreover, there was a general perception of decreasing strategic and geopolitical concerns over energy supply security, thanks to the end of the cold war (Jamasb and Pollitt, 2005).
Technologically, the development of the combined cycle gas turbine (CCGT) and the combined heat and power plant (CHP) has allowed the reduction of the minimum efficient scale, lowering the entry barriers in generation activities. Indeed, these plants do not require long building time and huge capital, so smaller generators can entry the market. Moreover, progress in the ITC allows calculating the dispatch in a timely manner reaching a high level of coordination even in absence of vertical integration (Campidoglio, 2011).

In this framework, the European electricity reform began in the 90s and it represented and still represents the broadest electricity reform process, involving different national power systems (Jamasb and Pollitt, 2005).
The main goal of the reform is to introduce competition in electricity markets through an intensive process of restructuring and liberalization with the final aim of the creation of a single European electricity market.
The theoretical proposition at the roots of the reform is the theory of competitive market, according to which this process leads to improve social welfare, increase efficiency and service quality (Nepal and Jamasb, 2013).

Two interrelated levels distinguish the European reform: on the one hand electricity markets Directives have fostered the liberalization process of the national electricity market and, on the other hand, several initiatives have been promoted for the improvement of the cross border exchanges (Jamasb and Pollitt, 2005). Competition in the national electricity markets across Europe was indeed viewed as a major pre-condition for their gradual integration into a single European electricity market.

2.2.1 Toward a market based industry

Despite a pioneering attempt to create a single European electricity market can be traced back to the liberalization of the electricity transits between high-voltage transmission networks (Directive 90/547/EEC, the so called "common transit directive"), the first legal step towards restructuring of Member States electricity supply industries was the First Electricity Directive of December 1996 (Directive 96/92/EC). Under this Directive, Member States were required to vertically separate potentially competitive electricity generation and supply from natural monopoly electricity transmission and distribution, by introducing an accounting and management unbundling regime for transmission and an accounting unbundling regime only for distribution. In case of accounting separation the activities are carried by the same company, but separate accounting is required for each of them. In addition, management unbundling also requires separate management, such that the bundled firm provides the same information about the regulated business to all the competitors (Batlle and Ocaña, 2013). In order to ensure access to transmission and distribution networks, Member States were allowed to select between a negotiated Third Party Access (TPA) system based on indicative prices, a regulated TPA system based on published tariffs or a Single Buyer system. Furthermore, they were obliged to introduce authorization and tendering procedures to open up to competition the electricity generation, to designate Transmission System Operators (TSOs) and Distribution System Operators (DSOs) responsible for operating, maintaining and developing transmission and distribution networks respectively, and to take measures to gradually open up to competition the electricity supply at least at the wholesale level by defining large non-household customers as eligible customers able to freely choose their supply companies.

However, the First Electricity Directive resulted in diverging levels of market opening between countries and no single European electricity market could emerge, due to the large degrees of freedom and long term deadlines left to Member States within the transposition process into national legislations (Meeus and Belmans, 2008).

In order to ensure a more level playing field between Member States and speed up the national electricity supply industries restructuring across Europe, the European Commission then issued a

Second Electricity Directive in June 2003 (Directive 2003/54/EC). It required Member States to introduce a stricter vertical separation of potentially competitive electricity generation and supply from natural monopoly electricity transmission and distribution, by legally unbundling these activities from other businesses not relating to transmission and distribution respectively. With this separation monopolistic and competitive activities are carried by different companies, i.e. different legal entities, even if they can be part of the same group (Batlle and Ocaña, 2013). Moreover, Member States were left only the option of the regulated TPA system based on published tariffs to ensure access to transmission and distribution networks. Member States were also constrained to use only authorization procedures to allow new market players to enter the electricity generation, while tendering procedures were left only for situations where the electricity generating capacity built through the authorization procedures could not ensure security of supply. More detailed tasks were attributed to TSOs and DSOs. A TSO is responsible for ensuring the long term adequacy of the system, system reliability and security of supply and for managing energy flows on the system, also at cross border level, providing the other SOs sufficient information. A DSO is responsible for maintaining a secure, reliable and efficient electricity distribution system in its area, without discriminate between system users and providing them all the information for efficient access to the system.[9] At an early stage (from 1st July 2004) Member States were also obliged to identify all non-household customers and then all household and non-household customers (from 1st July 2007) as eligible customers able to freely change their supply companies. Finally, they were required to designate independent National Regulatory Authorities (NRAs) mainly responsible for monitoring national electricity markets and approving transmission and distribution tariffs prior of their entry in force. For this aspect, the EU reform does not accomplished to the "textebook liberalization model" that calls for the creation of the regulatory authority as a necessary first step in the reform process (Jamasb and Pollitt, 2005).

The European Commission created more favorable conditions for cross-border electricity trading (Regulation 1228/2003) with the aim to increase competition within the emerging single European electricity market. For this purpose, harmonized rules were introduced regarding the compensation mechanisms between TSOs for costs resulting from electricity flows, the calculation of cross-border transmission charges that could no longer be distance-related and the allocation of the available cross-border transmission capacity through market-based mechanisms.

After a few years from the Second Electricity Directive the DG Competition of the European Commission published an Energy Sector Inquiry which detected "serious competition concerns" in

[9] For the complete list of the tasks see Directive 2003/54/CE art. 9 for TSO and art.14 for DSO.

the national electricity markets and lack of electricity market integration in Europe, resulting from limited and inefficient allocation of cross-border transmission capacity between national power systems, week incentives to develop new cross-border interconnections and diverging market design between national electricity markets (Meeus and Belmans, 2008).

In light of these findings, the European Commission introduced a Third Electricity Directive in July 2009 (Directive 2009/72/EC). It further strengthened the vertical separation for transmission, by allowing Member States to choose between the ownership unbundling regime, the Independent System Operator (ISO) model or the Independent Transmission Operator (ITO) model, when the first two options were not already implemented at the time the Directive entered in force.

Ownership unbundling represents the higher degree of separation, since different companies with different owners operate in the monopolistic and liberalized business. This solution represents a “structural remedy” to the conflict of interest, because it eliminates the incentive to discriminate and not only reduce the opportunity to do it, as in all the other unbundling forms, the so called “behavioral remedies” (Batlle and Ocaña, 2013). Even if the ownership unbundling is the preferred option, ISO and ITO models are allowed.

The ISO model permits the vertical integrated firms to maintain network ownership and to designate an independent system operator; this designation is subject to approval of the Commission that verifies the candidate operator adequacy to all the requirements of art. 14.2. In this case, a legal unbundling is required between the transmission and non transmission activities. The Directive indicates the tasks both for the ISO and the network owner. The former is responsible for operating and maintaining the transmission system, and for granting and managing third-party access. Moreover, it is responsible for network developing, in details, planning, construction and commissioning of the new infrastructure. Instead, the transmission system owner’s tasks are mainly related to the financing of the investment planned by ISO: network owner is required to directly finance them (once approved by the Regulatory Authority) or give its agreement to financing by a third party and to provide guarantees to facilitate financing any network expansions.

The third model, the ITO model, has derived from the agreement between the Commission and some Member States, such as France and Germany, that would maintain transmission ownership and management in vertical integrated national firms. This model allows the ITO to remain part of the vertically integrated firms, but, at the same time, it fixes detailed rules in order to ensure effective unbundling and envisages an important intervention of the Regulatory Authority. The rules set deals with governance and the investment plan. The ITO has to be autonomous, so the overall management structure shall ensure effective independence, also trough the institution of

"Chinese wall", a set of informative and administrative barriers between the transmission system operator and the firm. Moreover, a Supervisory Body has to be set up: it cannot interfere with the day to day activity, but it has to monitor the decisions that can affect the assets value. Furthermore, ITO must establish and implement a compliance program, approved by the Regulatory Authority, in order to avoid discriminatory conduct. In addition, regarding investment decisions, every year, ITO shall submit to the Authority a ten-year network development plan, able to ensure the adequacy of the system and the security of supply.

Generally speaking, the higher is the degree of unbundling implemented, the lower the intervention of Regulatory Authority.

Referring to the other activities, the legal unbundling regime for distribution and the regulated TPA system based on published tariffs to ensure access to transmission and distribution networks, both set out in the Second Electricity Directive, were confirmed. Furthermore, the Third Electricity Directive left largely unchanged the provisions of the previous Directive concerning the electricity generation and supply, but significantly widened the tasks and powers of NRAs and also required Member States to ensure their independence not only from the electricity supply industry but also from governments and any other public entities.

2.2.2 Toward the Single European Market

As already mentioned, the final aim of the reform process is the creation of the Single European Energy market. This goal has been in the policy agenda of the European Union for long time, and it has been pursued with different degrees of commitment starting from the Treaty of Rome (1957) until the Single European Act (1986) that has further fostered this process. Moreover, in the last two decades this process has been in line with the general trend toward the creation of regional electricity markets that has been involving several regions from Central America (with the Mercado Regional de Electricitad, MER) to Australia (Australian National Electricity Market, NEM) (Olmos and Pérez-Arriaga, 2013).

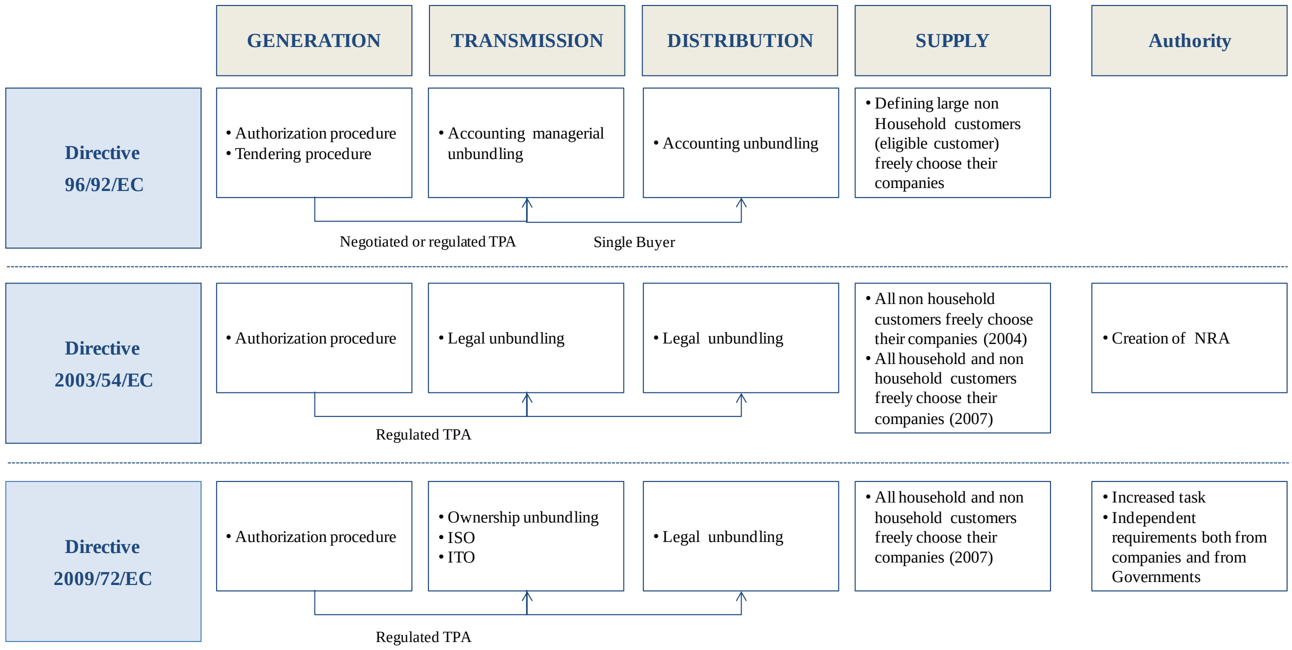
The creation of the internal market in the electricity industry is "particularly important in order to increase efficiency in the production, transmission and distribution of this product, while reinforcing security of supply and the competitiveness of the European economy and respecting environmental protection" (Directive 96/92/CE, p.1, 4).

In general, several benefits can come from regional integration, as discussed in Olmos and Pérez-Arriaga, 2013. Mainly, market integration permits to satisfy the demand at minimum cost, using the most efficient production plants available in the entire region. This can lower system operation costs and allow the exploitation of the weather conditions or load curve differences across the regions. Moreover, the presence of many market agents fosters competition in wholesale and retail markets, arguably leading to lower prices. Even before this tendency local electric system were interconnected, not for efficiency reasons, but to ensure reliability. Indeed, the presence of many plants with different technologies and the diversification of the primary energy sources lead to an increased security of supply for the whole system. Finally, the regional dimension allows fostering the diffusion of renewable generation, crucial to meet the environmental target, because it is possible to share the risk coming from their unpredictability.

If on the one hand many benefits can derive from the creation of a regional market, also challenges are related to this process. First of all, it is necessary to define a common market design and a set of harmonized rules that allow the creation of the single market. Moreover, an efficient management of the interconnection capacities is required. As previous discussed, the presence of competitive markets is an important step toward market integration. For this reason, the First and the Second Electricity Directives were mainly focused on opening the market, asking each Member Country to make progress toward liberalization of the national electricity industry within certain time-milestones. With the last Directive, the European Commission has focused more on market integration.

Indeed, in order to accelerate the completion of the single European electricity market, with the Third Electricity Directive, the European Commission not only improved the regulatory framework at European level by establishing an independent Agency for the Cooperation of Energy Regulators (ACER) with Regulation 713/2009, but also promoted the optimal management and evolution of transmission networks and the cross-border electricity exchanges by establishing a European Network of Transmission System Operators for Electricity (ENTSO-E) with Regulation 714/2009. ACER was attributed the task of coordinating and, where necessary, supplementing the NRAs' regulatory functions, promoting the cooperation between NRAs at regional and European level, developing framework guidelines to provide harmonized rules for cross-border electricity exchanges and monitoring the functioning of the market and especially of wholesale electricity trading. The main duties of ENTSO-E are instead the definition of European network codes on cross-border network issues and market integration issues consistent with the principles laid down in the framework guidelines developed by ACER and to define non-binding ten-year network development plans at European level every two years to ensure sufficient information about the electricity transmission network and support investment decisions at regional and European level.

Figure 2.2: EU Electricity Directives



In such a way the Third Electricity Directive and the related Regulations largely strengthened the legally binding top-down approach to the integration of national electricity markets into a single European electricity market. The ACER framework guidelines and the ENTSO-E network codes are indeed legal instruments through which common rules for cross-border capacity allocation can be enforced across Europe in all timeframes relevant for electricity exchanges. Such common rules (the Electricity Target Model) are the outcome of a long cooperation and coordination effort within the seven Electricity Regional Initiatives (ERI)[10] launched in 2006 by the European Regulators Group for Electricity and Gas (ERGEG) set up in 2003 by the European Commission (Decision 2003/796/EC). The aim of the ERIs, whose progress has been presented yearly within the European Electricity Regulatory Forum (Florence Forum), was to bring together NRAs, TSOs, Power Exchanges (PXs) and electricity market players in a voluntary bottom-up approach to the integration of national electricity markets into regional electricity markets, as an intermediate step towards the completion of the single European electricity market. The common rules for cross-border capacity allocation developed within the Electricity Regional Initiatives have already contributed to the creation of several regional wholesale electricity markets in Europe, but now

[10] The seven identified areas are: Baltic area including Estonia, Latvia and Lithuania; Central East area (CEE) including Austria, Czech Republic, Germany, Hungary, Poland, Slovakia and Slovenia; Central South area (CSE) including Austria, France, Germany, Greece, Italy and Slovenia; Central West (CWE) area including Belgium, France, Germany, Luxembourg and Netherlands; Northen area including Denmark, Finland, Germany, Norway, Poland and Sweden; South West (SWE) area including France, Portugal and Spain; France-Ireland-United Kingdom area (CEER, 2014 website).

need to be adopted at European level as well, as on February 2011 the European Council stated that the single European electricity market should be completed by 2014 (EUCO 2/11).

2.3 The Electricity Target Model

The Electricity Target Model is a set of harmonized rules to achieve real market integration. In order to reach the goal of a Single European Market, four cross regional roadmaps have been identified, each focusing on a peculiar aspect of the Electricity Target Model. Indeed, the Target Model envisages among other things a single European platform for allocation of transmission rights in the forward timeframe, a single European Price Coupling in the day ahead timeframe, a single continuous trading platform in the intraday timeframe and a strong coordination between TSOs to optimize the dimensioning of balancing reserves and the activation of balancing energy in the real-time timeframe.

2.3.1 Day ahead market coupling

Focusing on the day ahead timeframe, the Single European Price Coupling implies a simultaneous calculation of volumes and prices in all European day ahead market zones on the basis of the marginal pricing principle. More specifically, the European Price Coupling (EPC) envisages an implicit auctioning of the day ahead cross-border capacity between all European day ahead market zones, by making it available with electricity transactions on the PXs. Market agents offer energy bids for buy and for sell in their areas and the different PXs match the bids implicitly allocating the available cross-border transmission capacity in order to minimize the price difference between areas (ACER, 2012a). The implementation of such a solution requires an agreement between PXs and TSOs, both for the pre-coupling part (for instance the creation of a common governance or the decision about the amount of transmission capacity available for the market), for the coupling solution (the development of the algorithm that can satisfy TSO requirement in terms of efficient allocation) and for the post coupling part (the financial settlement between PXs and between PXs and TSOs) (ACER, 2012b; ACER, 2013a; ACER, 2014a).

The adoption of market coupling mechanism is expected to provide several benefits. First of all, the allocation and use of day ahead cross-border capacity is optimized at European level compared with the allocation and use resulting from an explicit auctioning process. Through implicit auctioning of the day ahead cross-border capacity indeed electricity flows are always directed from the low-price surplus areas towards the high-price deficit areas, favoring also an electricity prices convergence between market zones. Furthermore, the market value of the day ahead cross-border capacity is exactly identical to day ahead price differences between day ahead market zones. Conversely, the explicit auctioning of the day ahead cross-border capacity may result in frequent adverse electricity flows i.e. electricity flows from high-price deficit areas towards low-price surplus areas. Moreover, EPC leads to price convergence and it reduces price volatility. This mechanism enhances security of supply and economic efficiency, maximizing the social welfare and providing correct price signal for infrastructural investment (ACER, 2012a).

Since several years some regional market coupling projects are already operational. In detail, since 2007 market splitting (similar to market coupling, but with only one Power Exchange managing the process) has been operating between Portugal and Spain (MIBEL) and in the Nordic market. This last market included Norway and Sweden, starting from 1996 and later in 1998 and 2000 has been broaden to Finland and Denmark respectively. Moreover, Estonia (from 2010), Lithuania (from 2012) e Latvia (from 2013) became bidding areas in the Nord Pool. Poland has joined the coupling mechanism through the SwePol cable from 2010. Furthermore, a Trilateral Market Coupling was launched in November 2006 in order to integrate the Belgian, French and Dutch day ahead electricity markets. Since November 2010 this mechanism has been extended to Germany as well, through the Central Western Europe Market Coupling project. Moreover, from 2011 a market coupling exists between the Italian and Slovenian day ahead electricity market. Such market mechanism has been operating between Czech Republic and Slovakia from 2009 and in 2012 it has been extended to Hungary. Interconnection mechanisms are also implemented across different regions. From 2011 UK and the CWE area have been coupled through the BritNed cable; from November 2010, Nordic Market and CWE area have been linked through the Interim Tight Volume Coupling (ITVC) between Denmark and Germany. ITVC is a temporary solution and according to this system the volumes traded between countries are computed on the basis of all relevant information, as in the price coupling system, but prices are set by single PX. (TenneT, 2013). In detail, the PXs send to the central coupler complete data about the bids they receive and the central operator computes the optimal flows across the region and communicates them to the PXs that define price considering this quantity as inelastic offers within their systems. The Nordic market and CWE are linked through two connections: the NordNed Cable between the Netherlands and Norway (from 2011) and the Baltic Cable between Sweden and Germany (from 2010) (ACER, 2012a; ACER, 2012b).

In order to better address the efforts toward the creation of the Single European Market, ACER enhanced its coordination role adopting a more project-oriented approach for ERI, focusing on common projects, essential for the completion of the internal market (ACER, 2012a).

In this light, a growing attention has been put on the NWE coupling project. On February 4th 2014 the European Price Coupling was successfully launched in the North Western Europe (Belgium, Denmark, Estonia, Finland, France, Germany/Austria, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Sweden and the United Kingdom). This is an important milestone in the implementation of the EPC and the attention has been put on extending this mechanism to the other regions. In the South Western Europe (France, Portugal and Spain) price coupling was initially implemented without offering any cross-border capacity at the French-Spanish border, so explicit auctions on that border still existed. Since May, 13th 2014 the European Price Coupling was fully launched also in the South Western Europe and, following operations in North Western Europe and South Western Europe, it is expected to be adopted also at the northern Italian borders by mid December 2014 (ACER, 2014a).[11]

2.3.2 Target Model for intraday, forward and real time timeframes

The Electricity Target Model also refers to other timeframes, so harmonized rules have been proposed also for intraday, forward e real-time horizons.[12]

For the intraday timeframes, the Electricity Target Model envisages the Single European Continuous Implicit Mechanism for cross-border exchanges. In the intraday market operators can adjust their position modifying the programs defined in the day ahead markets. The Target Model aims to ensure intraday negotiations between different areas, requiring cross border capacity allocation, can be carried on as if they belong to the same area. This simplification appears increasingly important in the context of growing penetration of renewable generation being characterized by high unpredictability. Coupling the various national intraday markets will increase intraday liquidity and security of supply. The selected solution is “an evolution of continuous intraday trading, to include intraday capacity recalculation, capacity pricing reflecting congestion and the capability to trade sophisticated products” (ACER, 2014, website). The model envisages the construction of a common European platform (the Shared Order Book Function) that collects the orders for buy and for sell from all the national markets until cross border capacity is available, as reported in the European database Capacity Management Module. Due to the continuous based

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[11] A central issue closely related to the implementation of market coupling is the capacity calculation method. One of the cross border roadmap is specifically dedicated to this issue. The Target Model, defined by the CACM Framework Guidelines, specifies that TSOs need to apply an Available Transfer Capacity (ATC) or a Flow-Based (FB) method, preferring the second methodology in highly meshed grids. Whatever the model chosen, coordination among the TSOs is crucial for optimizing the utilization of the infrastructure. The Northern, SWE, CSE and FUI regions continue to apply the ATC method while CWE Market Coupling adopts a flow based method (for further information refer to ACER CACM Framework Guidelines).

[12] This section is based on ACER Framework Guidelines (ACER, 2011; ACER, 2012c) and ENTSO-E Network Codes (ENTSO-E, 2014b).

negotiations, as soon as two opposite orders for buy and for sell are submitted by the local platforms to the European platform, the algorithm matches them, adjusting in real time the transmission capacity, that is implicitly allocated with a first-come-first-served criterion. Initially the deadline for the implementation of the Intraday Target Model has been set at the end of 2014, but the project has been delayed until 2016. The implementation follows a phased approach, where the first step involves the NWE region (plus Austria and Switzerland). A single model is used for implicit capacity allocation, but, as interim solution, the possibility of explicit allocation of intraday capacity at certain borders is allowed. The second step requires the implementation of only implicit allocation at European level (ACER, 2014a; Elia, 2014 website).

As we already discuss, transmission capacity is allocated implicitly in the day ahead timeframe and it is valued at the difference between electricity prices in the national markets. Due to high price volatility, also the capacity value is subject to volatility. In order to face this risk, long term transmission rights can be negotiated in the forward market.

The Target Model offers market agents an opportunity to hedge themselves against congestion costs and day ahead congestion pricing, through an harmonized set of rules for long term transmission rights (ACER, 2014).

The Model requires the creation of a single allocation platform at European level and an harmonization of allocation rules, even if for different borders different rules are applied. Indeed, there are borders where physical transmission rights (PTR) are applied, subject to the use-it-or-sell-it clause, that allows the holder to realize energy exchanges or sell the rights on the market. For other borders, financial transmission rights (FTR) are applied and they can be treated as obligation or option. In the case of obligations, the holder receives a payment equal to the difference in price if it is positive or makes a payment in the opposite situation, while in option only a positive difference generates a payment. Furthermore, the Target Model requires the harmonization of the nomination rules, deadlines and processes. In January 2014, ENTSO-E presented its plan for drafting an harmonized set of rules applicable from early 2016 onwards (ACER, 2014a).

Real time horizon is crucial for the electricity market functioning, since through balancing market demand and supply differences are ensured to be balanced. At present, most balancing is carried out on a national level and the Target Model requires greater integration, coordination and harmonization amongst the electricity balancing markets at a pan-European level. In such a way, it will be possible to improve the exploiting of different resources across Europe, lower the costs and enhance security of supply (Network Codes:EU, 2014 website). Market integration to guarantee the optimal use of balancing energy and the correct sizing of balancing reserves requires strong coordination amongst TSOs (ACER, 2014a). In December 2013, ENTSO-E delivered the Network Code on Electricity Balancing (NC EB) to ACER, which provided its remarks in March 2014 leading to a new version of the Code published on September 16th, 2014. The NC EB envisages the creation of Coordinated Balancing Area (CBA) with two or more TSOs operating in different Member States. In CBA, TSOs will use the Exchange of Balancing Energy from at least one Standard Product and exchange standard product for Frequency Restoration Process with automatic activation or for Frequency Restoration Process with manual activation or for Reserve Replacement Process within the CBA. The Network Code indicates the schedule for the implementation of the defined models. Within two years and six months after the entry into force of the Network Code all TSOs shall implement the regional integration model for the Replacement Reserves and within four years the regional integration model for Frequency Restoration Reserves with both manual and automatic activation. Within four years TSOs can jointly propose a modification of the European model, supported by cost benefit analyses, and within five years all TSOs shall jointly develop a proposal for the implementation of the European integration models (ENTSO-E, 2014b). According to the provisions of the Framework Guidelines on Electricity Balancing (EBFG), these models consist of a single CBA, where a multilateral TSO-TSO model is applied with Common Merit Order List to share and exchange all Balancing Energy bids for Replacement Reserves and for the manually and automatic activated Frequency Restoration Reserves (ENTSO-E, 2014b).

3 The market framework

The present work is focused on eight European countries: Austria, Belgium, France, Germany, Italy, the Netherlands, Slovenia and Switzerland. The analyzed countries belong to different regions and several market coupling projects have involved some of these markets, such as the Central Western Europe Market Coupling project, among Belgian, French, German and Dutch markets or the market coupling project between Italy and Slovenia. As previous described, coupling projects envisage the cooperation of TSOs and PXs.

Different TSOs, all ENTSO-E members, operate in all the considered countries. In Austria the network is managed by Austrian Power Grid (APG), that is the national transmission grid operator, in cooperation with Vorarlberger Übertragungsnetz GmbH (VUEN), operating only in the area of Vorarlberg that however is under the APG control area; in Belgium the TSO is Elia System Operator SA (Elia); in France, Réseau de Transport d'Electricité (RTE); in Germany there are four TSOs, covering different control areas TransnetBW GmbH, TenneT TSO GmbH, Amprion GmbH, 50Hertz Transmission GmbH; in Italy the network is managed by Terna Rete Elettrica Nazionale Spa; in Slovenia by Eles and in Switzerland by SwissGrid.

3.1 National electricity generation capacity

Despite the regulatory push towards the integration of national markets, also pursued through the imposition of a common market design, there are still relevant differences amongst the physical systems, as shown by the different countries size and mix of electricity generation.

In order to explore this issue, each country generating capacity has been analyzed, based on data published by ENTSO-E, from 2008.

Net generating capacity has been calculated as the sum of net generating capacity of individual plants connected to the transmission or distribution network (ENTSO-E, 2014a). The net generating capacity of a plant is defined as the maximum net amount of energy that can be produced continuously from that plant operating in normal conditions (ENTSO-E, 2014a). “Net” means that the auxiliary equipments’ load and the losses in the main transformers of the power station have already been netted, “normal conditions” means for thermal plants average external conditions (e.g. in terms of weather condition, climate and so on) and full availability of fuels and for hydro and wind units the usual maximum availability of primary energy (ENTSO-E, 2014a).

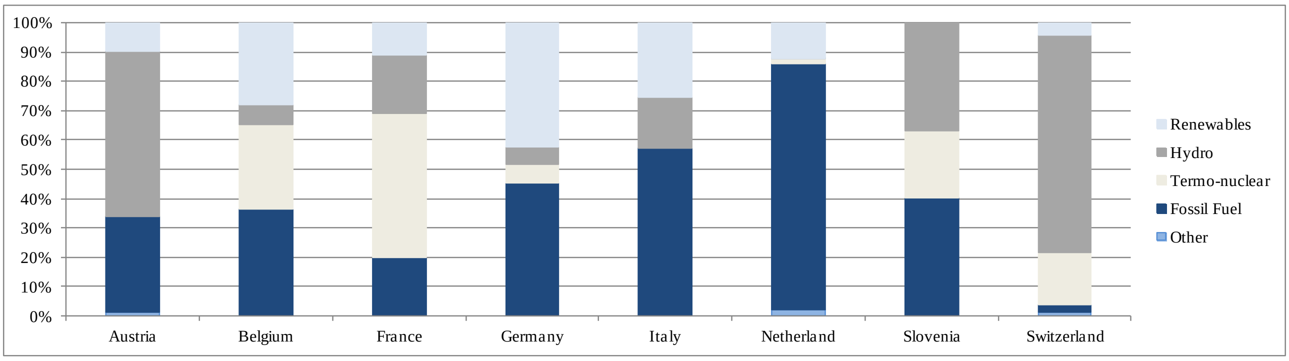
Table 3.1: Net generating capacity (MW)

	2008	2009	2010	2011	2012	2013
Austria	n.a.	20733	21085	22628	23164	23823
Belgium	16719	17663	18693	20027	20813	20596
France	117653	120235	123510	126814	128673	128289
Germany	134700	139500	152200	145019	175713	183099
Italy	98625	101447	106489	118443	124234	124750
Netherland	25260	26450	25465	24130	26422	31844
Slovenia	2894	2894	3041	3041	3074	3064,3
Switzerland	17590	17561	17727	18101	18209	18557

Data Source: ENTSO-E, 2014

First of all, **Table 3.1** displays the difference in terms of size of the generating structure of each countries, where Germany has the highest electricity installed capacity (more than 183 GW in 2013), followed by France and Italy (more than 128 GW and 124 GW respectively) and Slovenia the lowest (3 GW). Exploring the generation mix, it's possible to find a wide variation across countries. Data are aggregated by source used in production. The heading "hydroelectric plants" collects all plants deriving electricity from the potential and kinetic energy of water masses, therefore, this item includes run of the river systems[13], storage hydro plants and pumped storages[14]. In addition, other items include thermo-nuclear power plants, renewable sources (RES) plants (i.e. wind, solar, geothermal, tidal and so on) and power stations that use fossil fuels. **Figure 3.1** shows the net generating capacity mix for the analyzed countries for 2013.

Figure 3.1: Net generating capacity mix - 2013



Data Source: ENTSO-E, 2014

[13] A plant that exploits the cumulative flow continuously (ENTSO-E, 2014a).

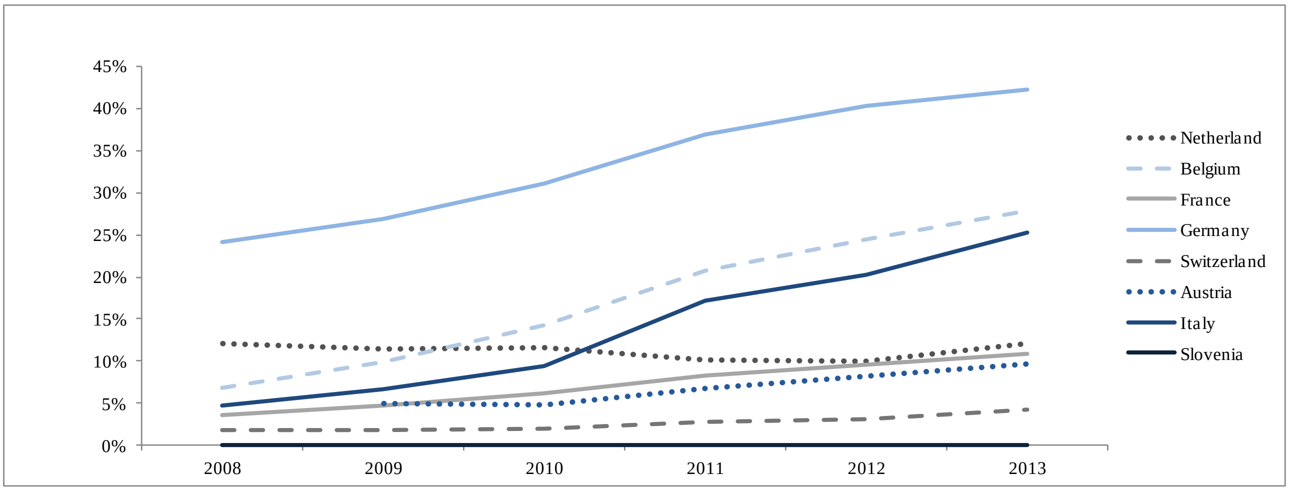
[14] A pumped storage is an hydro unit in which water can be raised trough pumps and stored to be used later for the generation of electrical energy. It can be classified as pure and mixed pumped storage, according to the absence or the presence of natural cumulative flow into the upper reservoir respectively (ENTSO-E, 2014a).

Austrian generating capacity mostly consists of hydro power plants (56% of the capacity), while the remaining is made up of fossil fuels plants (33%) and renewable sources (about 10%).
Switzerland has a production structure mainly composed by hydroelectric plants, which account for 74% of generation capacity, while the 18% is made up of nuclear power plants. However, this share is likely to decrease, due to the ongoing process of nuclear power phasing out. Indeed, in March 2011, after the reactor accident in Fukushima, the Swiss Federal Council and Parliament have decided to set up a new energy policy (2050 Energy Strategy), gradually withdrawing from nuclear power by decommissioning the five nuclear power plants currently operating at the end of their useful life, without replace them with other nuclear installations (SFOE , 2014, website).
Instead, France depends heavily on the nuclear power, which accounts for more than 49% of the installed capacity. The rest of the generating capacity is made up by fossil fuels plants and hydro (each amounting at 20%), while the share of renewable sources generation is around 11%.
Looking at the German generating capacity mix, renewable sources are very significant, covering more than the 40% of the generation capacity, while the 45% is represented by fossil fuel plants. The process of nuclear power phase-out has led to halving the weight of this source in the German generating structure, from a share of 15% in 2009 to 7% in 2013. The amendment of the Atomic Energy Act, which entered into force in August 2011, led to the decommissioning of the seven more obsolete German nuclear power plants and of the Krümmel plant[15], entailing a reduction of 8400 MW of capacity.
Italian generating structure is mainly characterized by fossil fuel plants (57% of the capacity), of which the majority are natural gas-fired power plants. A significant part of the capacity consists of hydroelectric plants, which account for almost the 18% of the total. These shares are decreasing compared to previous years, while the amount of renewable energy plants have significantly risen, reaching the 25% of the generating capacity.
In Slovenia, the generating capacity mix has not changed significantly over the last few years: it is mostly based on fossil fuels (40%), followed by hydro (almost 37%) while the remaining capacity is provided by nuclear plants (23%).
Finally, fossil fuel plants are dominant in Belgium and in the Netherlands, where account for 37% and 84% of the generating capacity respectively. Belgium has seen the growth of renewable energy plants that in 2013 account for 28% of the installed capacity, while the share of these plants is almost stable in the Dutch mix (12%). Furthermore, nuclear power plants cover almost the 29% of the capacity in Belgium.

[15] In 2007 and 2009 two accidents happened to this plant leading in March 2011 to the decision of definitively shut down the plant.

At a global level, it is possible to observe a reduction of the nuclear component in the European generating capacity mix, due to the energy policy strategies adopted by some of the countries considered that has decided to phase out nuclear plants. On the other hand, a substantial increase in power stations using renewable energy sources is registered, as shown by **Figure 3.2**. This growth has been particularly significant in Italy and Belgium, where the weight of renewable energy has increased more than fourfold and almost fivefold respectively. In Germany, the country with the highest percentage of RES plants, the share of renewable energy generation capacity has little less than doubled from 2008 to 2013.

Figure 3.2: RES plant evolution in net generating capacity mix (%)



Data Sources: ENTSO-E, 2014

The heterogeneity of production structures, together with the relevant regulatory, political and economic progress outlines a complex and rapidly evolving framework for the electricity sector. These features require monitoring of an increasing number of variables and the need to adopt an integrated European-wide approach to analyze these markets.

3.2 Explorative analysis of wholesale markets

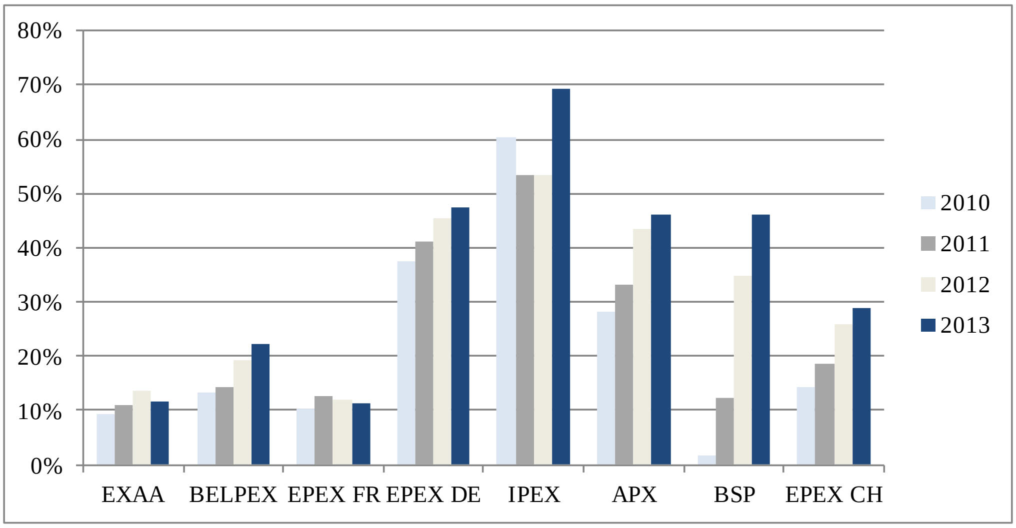
Organized markets are necessary to facilitate short term trading and to provide a transparent price for electricity negotiations. In Europe these organized markets have been set as Power Exchanges, generally based on private initiatives. In the present work, eight European PXs, listing hourly prices for day ahead electricity markets, are considered: EXAA for Austria, Belpex for Belgium, EPEX Spot for France, Germany and Switzerland, IPEX for Italy, BSP for Slovenia and APX for the Netherlands. The distinction between the Austrian and German day ahead electricity prices is not as clear as it is for the other six countries. The EXAA day ahead electricity market allows electricity to be physically delivered not only in the Austrian control area, but also in the four German control areas. Similarly, the German segment at the EPEX Spot day ahead electricity market allows electricity to be physically delivered both in the four German TSOs control areas and in the Austrian TSO control area.

3.2.1 Market liquidity

The creation of a wholesale liquid market is one of the step envisaged by the European reform process. A liquid wholesale electricity market simplifies transactions, fosters further market agents to entry in the market and leads to transparent electricity prices. So, in the present framework, especially in the day ahead timeframe, PXs have taken a key role, as shown by the growing volumes of electricity traded on their various segments.

However, participation in the day ahead electricity markets is generally not mandatory, so the liquidity levels of these markets are significantly different amongst the analyzed countries.

Figure 3.3: Wholesale market liquidity (%)



Data Sources: National PXs and ENTSO-E, 2014

Liquidity levels have been calculated using a proxy, equal to the ratio of total yearly electricity volumes traded on a particular day ahead electricity market to total yearly electricity consumption of the corresponding country. Total yearly electricity volumes traded on day ahead electricity markets have been calculated from the hourly electricity volumes data published by each PX. For Italy, electricity volumes traded through bilateral contracts registered on the day ahead electricity market for physical delivery have been excluded. Instead, yearly electricity consumptions have been calculated from consumption data published in the ENTSO-E Country Packages.

As **Figure 3.3** shows, liquidity varies across countries; it is higher in the Italian, German and Dutch market, while the less liquid markets are the French and Austrian ones. Between May 2010 and July 2013 on IPEX the yearly average liquidity level was never below 50%. On the other hand, on the French segment of the EPEX Spot day ahead electricity market the yearly average liquidity level barely exceeded 10% as on the Austrian EXAA.

However, in most of the countries analyzed the liquidity level has increased over time. During the first seven months of 2013, the liquidity level reached almost 50% in the German segment of the EPEX Spot day ahead electricity market, APX and BSP. Also on the Swiss segment of the EPEX Spot market and on BELPEX an upward trend in yearly average market liquidity has been registered, even if it has been equal to 22% and 29% respectively in the first months of 2013.

Even in countries where over-the-counter electricity trades are prevailing and the liquidity level of day ahead electricity markets is low, prices of day ahead electricity markets are anyway an important reference for over-the-counter electricity trades as well.

3.2.2 Price convergence

The data collected from the PXs of the eight countries considered have also been analyzed in order to have a measure of the convergence of wholesale prices.

For each of the possible pairs of day ahead electricity markets considered, the level of convergence is defined as the percentage of hours on the total hours of the sample in which equal prices are recorded[16].

As reported in **Table 3.2**, this analysis shows the highest level of convergence in the CWE area. Between 2010 and 2012 the prices listed on the Belgian and Dutch PXs have been equal for more than 70% of the time; Belgian and French day ahead prices have been equal for more than 80% of the hours and the French and Dutch ones for more than 50% of the cases. From 2011 there is a clear evidence of the extension to Germany of the market coupling mechanism, which began in November 2010. Indeed, wholesale price convergence between German and the other coupled markets has increased considerably in 2011, rising from just under 12% to around 88% in the case of the Netherlands, from about 8% to over 60% in the case of Belgium and from just under 8% to around 65 % in the case of France.

[16] The same methodology is applied by ACER in its Annual Report on the Results of Monitoring the Internal Electricity Market, 2013; an analogous methodology has been applied by Nitsche, Ockenfels, Röller, Wiethaus, 2010.

Table 3.2: Wholesale price convergence 2010-2013

Country	Year	Belgium	France	Germany	Italy	Netherland	Slovenia	Switzerland
Austria	2010	0,96%	0,72%	0,10%	0,05%	1,29%	0,32%	0,23%
	2011	0,15%	0,15%	0,19%	0,02%	0,18%	0,56%	0,38%
	2012	0,11%	0,13%	0,15%	0,02%	0,10%	1,46%	0,20%
	2013	0,07%	0,12%	0,14%	0,02%	0,07%	1,47%	0,07%
Belgium	2010		82,44%	8,21%	0,05%	72,36%	0,12%	0,15%
	2011		94,54%	67,17%	0,01%	71,29%	0,11%	0,05%
	2012		81,14%	59,20%	0,01%	72,47%	0,07%	0,13%
	2013		51,82%	15,58%	0,05%	67,56%	0,09%	0,02%
France	2010			7,61%	0,06%	57,48%	0,12%	0,16%
	2011			64,71%	0,01%	67,84%	0,11%	0,05%
	2012			61,22%	0,00%	56,61%	0,06%	0,11%
	2013			41,21%	0,09%	29,97%	0,12%	0,07%
Germany	2010				0,01%	11,88%	0,09%	0,09%
	2011				0,01%	87,87%	0,10%	0,07%
	2012				0,00%	55,18%	0,07%	0,10%
	2013				0,14%	13,63%	0,21%	0,09%
Italy	2010					0,03%	0,00%	0,07%
	2011					0,01%	2,31%	0,03%
	2012					0,01%	1,12%	0,01%
	2013					0,02%	0,44%	0,05%
Netherland	2010						0,21%	0,26%
	2011						0,10%	0,07%
	2012						0,14%	0,09%
	2013						0,07%	0,02%
Slovenia	2010							0,07%
	2011							0,09%
	2012							0,22%
	2013							0,05%

Instead, day ahead electricity price on EXAA and on the Swiss segment of EPEX Spot have been significantly different from the ones registered in all the other countries.

Price convergence between Italian[17] and Slovenian markets has been registered for the 20% of the hours both in 2011 and 2012, even if from 2011 a market coupling mechanism has been operating between the two countries. Generally speaking, market coupling does not allow to fill the gap between two different market prices when system generating cost structures diverge. Furthermore, even if volumes allocated through market coupling mechanism have largely increased in 2012, about 5% of capacity is still allocated through explicit auctions (GME, 2013).

However, in 2013 a strong reduction in the convergence levels between pairs of day ahead electricity prices, mainly in the CWE area, has emerged. This evidence may be related to the presence of renewable energy sources in Germany. ACER Annual Report 2013 highlighted the relation between wind production in Germany and price divergence in the CWE area for 2012 and

[17] For compute price convergence between these two zones, as reported by the GME statistics, the Slovenian price listed on BSP is compared with the price registred in the North zone on IPEX.

ACER Annual Report 2014 shows the contribution of solar production to price divergence in the CWE area for 2013. The reduction of convergence between German and Dutch electricity prices can be also related to fuel prices movements combined to national generation mix: the fossil generation capacity in the Netherlands is mainly composed by gas plants, while in Germany coal-fired plants prevail. The spread between gas and coal prices (the former increased and the latter decreased) may further exacerbate electricity price divergence between the two countries (ACER, 2014b, p.111). Moreover, a reduction of nuclear power generation in France and Belgium for 2012 may have further influenced price divergence from the German low price (ACER, 2013a, p.61).

Possible price convergence of national day ahead electricity prices may be linked to production structures similarities, but the presence of market coupling generally fosters price convergence.

This analysis can be considered only as an explorative and preliminary step, on the path of that carried by ACER in its Annual Report, in the study of the integration of national market, since price convergence can be considered only as an indicator of this process. Indeed, the final goal of market integration do not necessary requires full price convergence.

4 Literature review

4.1 Forecasting electricity prices

Fostered by the electricity reform process and all the sector transformation already described, Power Exchanges have assumed an important role in the electricity market. PXs prices forecasting and especially day ahead price forecasting has therefore become essential for electricity market players, not only for long term capital budgeting but also for short term bidding optimization. The costs to adjust their position in the balancing markets are so high that can heavily impact on the financial structure. Considering extreme electricity price volatility, price forecasting both for the short and for long term have become crucial for corporate portfolio strategies (Weron, 2014). Moreover, as reported by Kristiansen (2012), a key factor for market openness and participation in energy trading is the possibility for medium sized consumers to set up reliable and independent price forecasting.

In this framework, electricity prices forecasting has become an interesting research field and since 2000 a growing empirical literature has been developed. Electricity price forecasting is challenging due to the peculiar features of this commodity. On the one hand it cannot be stored economically, on the other hand the physical system requires a constant balance between production and consumption. Moreover, the inelastic nature of demand over short period, its dependence from business cycle and weather and the steeply and discontinuous shape of the supply function due to the presence of different production structures, contribute to define electricity as a unique commodity (Aggarwal et al., 2009; Weron, 2009; Karakatsani and Bunn, 2008). These characteristics lead to non constant mean and variance, multiple seasonality, time varying volatility and spikes, since the non storability nature of electricity eliminates the buffering effect (Huisman and Kiliç, 2013; De Jong, 2006).

Several methodologies have been applied in electricity price forecasting and according to Aggarwal et al. (2009) it is possible to classify them in three main classes, even if some solutions implemented in literature are hybrid approaches, since they combine techniques coming from different classes. The first one includes game theory models, where price is determined solving games in oligopolistic markets, while simulation models represent the second typology. Through this last technique using mathematical algorithms it is possible to determine optimal energy flows in the system, complying with safety requirements. These models need detailed information and they are quite complex, but their diffusion is increasing, while a game theory approach becomes less popular (Weron, 2014). The third class consists of time series models, that, considering the dependent variable past behavior, are one of the most important approach (Weron and Misiorek, 2008). According to Aggarwal et al. (2009) within the time series class further three different modeling techniques can be identified. The first includes the classical structural models using the relationship between economic and physical factors known or that can be estimated and the electricity prices (dependent variable). The second technique adopts an artificial intelligence-based approach using neural network and fuzzy logic. Moreover, the application of non-parametric models allows mapping the input-output relationship, without analytically analyzing all the processes that cannot be successfully represented by conventional model (Weron and Misiorek, 2005; Aggarwal et al., 2009). Stochastic models represent the third class of techniques. They are inspired by the financial literature and aim to replicate the statistic properties of the electricity price time series, in order to provide forecasting. The present work is focused only on time series models, and especially on the statistic ones, for a complete review of the state of the art see Weron (2014) or Aggarwal et al. (2009). Several time series models have been applied to capture the main features of electricity prices. In the following, a cross overview of the main contributions in literature has been provided, organized for principal issues discussed in electricity forecasting (**Figure 4.1**).

Figure 4.1: Empirical literature on price forecasting

Author	Country	Period	Level	Model
Cuaresma et al. (2004)	Germany	June 16, 2000 - October 15, 2001	Hourly	AR (1), ARMA, Jump diffusion
Knittel and Roberts (2005)	California	April 1, 1998 - April 30, 2000 May 1, 2000 - August 31, 2000	Hourly	AR, ARMA,ARMAX, Jump Diffusion, EGARCH
Weron and Misiorek (2005)	California	July, 5 1999 – April, 2 2000	Hourly	AR and ARX
Koopman et al. (2007)	Norway, Germany, France and Netherland	January 4, 1993 - April, 10 2005	Daily average	Reg-ARFIMA-GARCH and Reg-ARFIMAX-GARCH
Karakatsani and Bunn (2008)	UK	June 6, 2001 - April 1, 2002	Half hour	Fundamental price models, time varying parameter regression, regime switching
Weron and Misiorek (2008)	California, Scandinavia	July 5, 1999 – April 2, 2000 (California) 1998-1999 (Scandinavia) 2003-2004 (Scandinavia)	Hourly	AR; p-AR; TAR; MRJD; IHMAR;SNAR;ARX; p-ARX; TARX; MRJDX; IHMARX; SNARX
Weron (2009)	California	July 5, 1999 – April 2,2000	Hourly	ARX;ARX- GARCH; ARX-N , ARX-S , ARX-NP
Bisaglia et al. (2010)	France, Spain and Austria	November 27, 2001 - April 21, 2009 (France) , November 1, 2001 - October 30, 2009 (Spain) and March 22, 2002 - November 30, 2009	Hourly	AR-GARCH, SUR-GARCH, VAR-GARCH and Markov Switching
Gianfreda and Grossi (2012)	Italy	January 1, 2005 - December 31, 2008	Daily average	ARFIMA-GARCH with exogenous variables

Regarding the level of the analysis, Cuaresma et al. (2004), comparing the forecasting performance of a battery of linear models for univariate time series using hourly electricity prices of the German LPX market for the period 2000-2001, show that when hours are treated separately, each model provides better forecasting performance than the ones obtained by the corresponding model estimated considering the data as a whole time series, both considering Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE). On the same path, among others Weron and Misiorek (2005 and 2008), Knittel and Roberts (2005) and Bisaglia et al. (2010) adopt a specification where each hour is modeled separately.

Considering the temporal properties, electricity prices display a statistically significant autocorrelation even at large lags and seasonality. The former feature is modeled through autoregressive model, widely adopted in different specifications (AR), moving average (MA), combination of the two, ARMA or ARIMA when the series are integrated (e.g. Conejo et al., 2005). Knittel and Roberts (2005), using California hourly day ahead electricity prices for two periods with different volatility (April 1, 1998 – April 30, 2000 more stable and May 1, 2000 – August 31, 2000, characterized by higher volatility), show that forecasting performance is significantly improved accounting for high autocorrelation of day ahead electricity prices. Moreover, they highlight that ARMA models outperform AR(1) models, but contradictory evidence is provided by Cuaresma et al. (2004) that find the best model of ARMA class performs worse than the best of AR(1) models. Seasonality is captured incorporating dummy variables, for time of the day, weekday and seasonal effects (e.g. Weron and Misiorek, 2008) or through periodic seasonal model, as in Koopman et al. (2007), that analyze daily day ahead electricity price of Nord Pool (Norway), EEX, PowerNext and APX from 1993 to 2005 using a periodic seasonal Reg-ARFIMA-GARCH model.

Some models have been extended introducing fundamental variables. Different scholars have chosen several variables, since there is not a general consensus on the factors that can significantly influence electricity prices. For instance, researchers included: electricity demand (expressed as load or load variations) due to the close relationship with prices; reserve margin, which can affect price variation when there is scarcity and so the possibility of exercising market power emerges; temperatures; fuel prices, that impact on the generators offers pricing; generators market concentration indices, that signal the presence of market power and so on (Aggarwal et al., 2009). Knittel and Roberts (2005) show that the inclusion of temperature slightly improves forecasting performances in stable period, but worsens them in the higher volatility periods; Weron and Misiorek (2008) using data from Nord Pool for two different periods (1998-1999 and 2003-2004) find out that the inclusion of temperature leads to higher forecasting accuracy only in Spring and Fall when the price-temperature relationship is stronger. Considering the dependence of Nord Pool prices from water reservoir levels and daily electricity consumptions, Koopman et al. (2007) incorporate these explanatory variables, but the extension does not significantly change the final results. Weron and Misiorek (2005 and 2008) introduce load as fundamental variable in forecasting

California prices for the period 1999-2000. This choice, also due to the linear dependence between the two variables, leads to better forecast. Analyzing the Italian zonal prices from 2005 to 2008, Gianfreda and Grossi (2012) obtain an improvement in the forecasting accuracy by including in the ARFIMA GARCH model different exogenous variables, such as volume, generation technology, market concentration and the congestion state.

Moreover, in order to account for heteroskedasticity some scholars have generalized models including GARCH component (Koopman et al., 2007, Weron, 2009, Bisaglia et al., 2010). Knittel and Roberts (2005) implement EGARCH models that highlight the presence of an inverse leverage effect, since positive shocks amplify volatility more than negative shocks. They show that EGARCH models provide the best forecasting performance for the high volatility period and the worst in the other cases, suggesting that including volatility is most important when the market is supply constrained.

As an attempt to capture the leptokurtosis of electricity price time series, some authors propose jump diffusion models, with contradictory evidence. Cuaresma et al. (2004) show that jump inclusion improves forecasting performance for all the models where hours are modeled separately, but this result is not confirmed for the model with time varying mean when prices are considered as a whole time series. Knittel and Roberts (2005) find that this model lead to better forecast compared with mean reverting model for the high volatility period, but it is worse when prices are more stable. This issue is partially solved allowing the jump intensity varying over time. Weron and Misiorek (2008) show that mean reverting jump diffusion models provide the worst forecast for the Nord Pool market, compared with the other models implemented, even if they improve a little in the volatile weeks.

Using an approach derived from the electrical engineering price forecasting literature, Weron and Misiorek (2008) set a spike preprocessed model where spikes are substituted with the mean plus three standard deviations of the price and find that this model outperforms the others in low volatility period for the California market.

Other specifications seem lead to better performance when volatility is high. Trying to capture irregular values, Karakatsani and Bunn (2008) considering half hour spot price of the UK PX markets for the period 2001-2002, and Weron and Misiorek (2008) proposed a regime switching mechanisms, while Weron and Misiorek (2008) e Weron (2009) implement a semiparametric extension where no specific form for the errors distribution is assumed.

Generally speaking, the empirical literature highlights that modeling each hour separately, considering higher number of auto regressive terms and incorporating exogenous variables can improve the forecasting performance. The inclusion of GARCH effects and jump diffusion process allows capturing heteroskedasticity and leptokurtosis of electricity price time series, leading to more accurate forecast in high volatility period.

At present, many contributions address day ahead electricity prices forecasting without including in the proposed models the possibility of co-movements between interconnected markets. Recently, a large body of empirical literature has investigated whether or not EU wholesale electricity markets are cointegrated, and despite there is no conclusive evidence at the EU level the presence of partial cointegration seems to emerge between day ahead electricity prices of Central-West European countries.

4.2 Electricity markets integration in Europe

The electricity market reforms[18] foster a growing literature on the restructuring process and especially market integration has been treated by scholars from several perspectives[19]; in the following a brief overview of the studies that investigate the presence of market integration has been provided.

Several approaches have been implemented for analyzing market integration. Using an explorative data approach, Armstrong and Galli (2005) study the convergence of hourly day ahead electricity prices from 2002 to 2004 of Germany, France, Spain and the Netherlands, comparing the prices of neighboring countries. Their analysis shows that during 2004 the mean and the median of the difference between pair of prices were diminishing with reference to the previous years. Focusing on Nordic countries, Amundsen and Bergman (2007) analyze the integration of wholesale markets between 1996 and 2004, looking at the differences between system price and national prices: the Nordic electricity market appears to be reasonably close to a single market. Zachmann (2008) analyzed day ahead electricity wholesale prices from eleven European countries, between 2002 and 2006, measuring the level of market integration and price convergence. Principal Component Analysis provides evidence that full integration has not been achieved in 2006, but national price can increasingly be explained by a common European pattern. Applying different methodology, Robinson (2007) analyzes annual prices from 1978 to 2003 of nine European countries using

[18] Market reforms similar to the European one have been conducted in US and Australia, where a stream of literature has been developed on this topic. In US McCullough (1996) and Woo et al. (1997) are the first studies on the US market, followed, between others by De Vany and Walls (1999) et Park et al. (2006); in Australia, Worthington et al. (2005) and Higgs (2009) have investigated the interrelations between Australian regions.

[19] For instance, some scholars conducted the analysis of market integration effects in terms of welfare (e.g. Pellini, 2012a; de Nooij, 2011) or the relation with market power (e.g. Hobbs et al., 2005; Fridolfsson and Tangeras, 2009; Bunn and Zachmann, 2010).

absolute β convergence[20] and a time series approach, both suggesting convergence of electricity prices.

Pinho and Madaleno (2011) analyze comovements between daily average prices from six European markets (Nord Pool, Spain, The Netherlands, Germany, France and Austria) collected from 2000 to 2009. Confirming evidence of Zachmann (2008) and Bosco et al. (2010), they cannot confirm full market integration and they explain price divergence by limited cross border capacity, different generation mix and different level of market power. They highlight that behavior changes after 2003, evolving with the implementation of the European Directives, and that some regions, especially CWE area, are converging. Confirming Bunn and Gianfreda (2010) results, Lindström and Regland (2012) analyze data from six European markets using independent spike model with three regimes, from 2005 to 2010. They compute the conditional probability for a market to experience spikes when another market has registered these phenomena, finding that Nord Pool market shows a very little dependence from the other markets, German and French markets are strongly affected by the other markets, but UK and the Netherlands do not show high dependence between each other.

Focusing on scholars adopting the concept of cointegration (**Figure 4.2**), among the first studies in Europe, Bower (2002) considers mean day ahead electricity prices data from Scandinavia, England, Spain, The Netherlands and Germany, collected for 2001 and shows prices cointegration across all the markets, except Spain, even where there is no physical interconnections.

The possibility of market integration in absence of geographical proximity is recently confirmed by other scholars. Analyzing Germany, France, The Netherlands, Spain and UK spot (average day ahead prices) and forward prices from July 2001 to July 2005, through correlation analysis and Granger causality test, Bunn and Gianfreda (2010) confirm that all market are positively related, and Germany, Spain, Netherlands and UK are interdependent, even without direct physical connections. Pellini (2012b), applying fractional cointegration analysis between 15 European Power Exchanges, until January 2012, shows that the null hypothesis of perfect integration cannot be rejected only for France and Spain and five cases of non boundary countries (the Netherlands-UK, Germany-Portugal, France-Austria, Austria-Portugal, Austria- Spain).

Several scholars find evidences of market integration especially between Central West countries. Considering UK, France, Germany, Netherlands, Nordic countries and Spain daily average prices for 2002 and Platts index as a reference for bilateral prices, Boisseleau (2004) reveals the presence

[20] "a variable β converges if countries with low level of this variable register faster growth rate in this variable than the other countries in the sample" (Robinson, 2007, p.474).

of two supra national markets, the Nord Pool and the France-Germany one. Bosco et al. (2010) analyzing data from 1999 to 2007 for six European wholesale markets (APX, EEX, EXAA, Nord Pool, Omel and Powernext) conduct a robust multivariate dynamic analysis of weekly median of hourly prices and verify that, even if the null hypothesis of strong integration cannot be rejected only for EEX and Powernext, APX, EEX, EXAA and Powernext share a common trend. Pellini (2012b) through a state space model finds clear evidence of ongoing convergence between 20 market pairs in the CWE and CEE area. Bollino et al. (2013) analyzing data from Austria, Germany, France and Italy for the years 2004-2010 find three long run relations that can be interpreted as convergence pattern between each national electricity price and the German one. Houllier and de Menezes (2013) analyzing Powernext, EPEX, APX-NL, APX-UK and NordPool hourly electricity spot prices between 2009 and 2011 with Engle and Granger methodology find evidences of cointegration between France and Germany, Germany and The Netherlands and in one sample, cointegration between The Netherlands and France, The Netherlands and UK and between France and Switzerland.

Figure 4.2: Empirical literature on European market integration (cointegration)

Authors	Market	Period	Level	Methods
Bower (2002)	Scandinavian countries, UK, Spain, Netherland, Germany	2001	Daily averages	Correlation and cointegration analysis (Engle and Granger)
Boisselau (2004)	France, Germany, Netherlands, Scandinavian countries, Spain and UK	January 1, 2002 - December 31, 2002	Daily averages	Correlation analysis and standard regression for each pair of country (OLS)
Bosco et al. (2010)	Austria, France, Germany and Netherlands	January 1, 1999 - March 12, 2007	Weekday medians	Cointegration analysis with parametric and semi parametric test
Bunn and Gianfreda (2010)	France, Germany, Netherland, Spain, UK	July 15, 2001 - July 15, 2005	Daily averages	Correlation and cointegration analysis (Johansen)
Haldrup et al. (2010)	Scandinavian countries	January 3, 2000 - October 25, 2003	Hourly	Regime switching VAR
Pellini (2012b)	Austria, Belgium, Czecch Republic, France, Germany, Greece, Ireland, Italy, Poland, Portugal, Scandinavia, Spain, Switzerland, Netherland, UK	to January 31, 2012	Daily averages	Fractional cointegration analysis (Engle e Granger)
Bollino et al. (2013)	Austria, Germany, France, Italy	2004- 2010	Hourly daily change	Cointegration analysis (Johansen)
Houllier e de Menezes (2013)	France, Germany, Netherland, Scandinavia, Spain, Switzerland, UK	January 1, 2009 - April 30, 2011	Hourly	Fractional cointegration analysis (Engle e Granger)

Despite evidence of an ongoing process of market integration (Bunn and Gianfreda, 2010; Pellini, 2012b), up to now the possibility of cointegration between electricity price time series has not yet been included in the forecasting literature, even if such an inclusion enlarges the information set and may lead to better forecasting performance of the models.

In the present work a multiple time series approach is used to model day ahead electricity price, in the attempt to capture the presence of complex price interdependencies and the possible cointegration among European electricity markets.

5 Dataset description

The dataset used for the empirical analysis of the present work includes the hourly day ahead electricity prices and the hourly electricity load levels of the period from May 11th, 2010 to July 29th, 2013 for the following eight European countries: Austria, Belgium, France, Germany, Italy, Slovenia, The Netherlands and Switzerland. More specifically, the hourly day ahead electricity prices are exactly those listed on EXAA for Austria, Belpex for Belgium, EPEX Spot for France, Germany and Switzerland, IPEX for Italy, BSP for Slovenia and APX for The Netherlands.

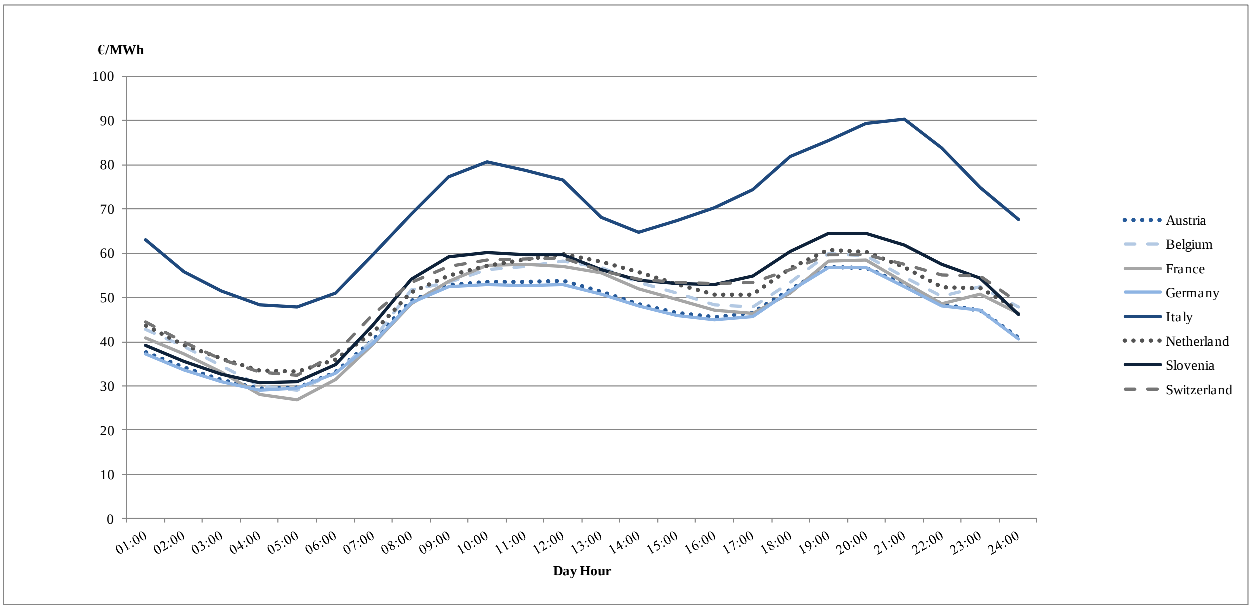
The liquidity levels of day ahead electricity markets are significantly different between the countries analyzed (see section 3.2.1) since participation in the day ahead electricity markets is generally not mandatory. However, even in countries where OTC trades are prevailing, with low liquidity level on PXs, prices of day ahead electricity markets are anyway an important reference for over-the-counter electricity trades as well.

The hourly day ahead electricity prices have not been subject to any log transformation, given the possible presence of negative values attributable to the operational rules of some day ahead electricity markets under analysis allowing market participants to submit negative price offers.[21] A pre-treatment was needed only for the days when a clock change takes place and for the EXAA hourly day ahead electricity prices of November 13th, 2012. For the last Sunday in March, when the clock goes forward, one hour of missing prices was replaced with the average price of the preceding and following hours, while for the last Sunday in October, when the clock goes back one hour, the prices of the 25th hour were deleted. In addition, EXAA was not able to run the day ahead auctions for delivery on November 13th, 2012 due to technical issues at the data processing center, so for each hour of this day the missing prices were calculated as the average prices of the corresponding hours in the preceding and following days. The empirical analysis has been carried out separately for each of the 24 hours of the day, so the hourly day ahead electricity prices series were rearranged into 192 daily series, one for each combination of country and hour of the day. Given the extension of the dataset, each daily series consists of 1176 observations. An identical rearrangement has also been applied to the hourly electricity loads series.

[21] Negative prices occur when low demand meets a high inflexible power generation. Such situation can be due to the impossibility of shut down inflexible power sources in a quick and cost-efficient manner or exceptional slumps in demand. This price sends a signal to generators to reduce output to avoid overloading the grid: producers compute their opportunity cost, comparing the costs of stopping and restarting the plants with the costs of selling their energy at a negative price (which means paying instead of receiving money). (Fanone et al., 2013; EPEX Spot, 2014)

Simple summary statistics show that in the period between May 11th, 2010 and July 29th, 2013 the Italian day ahead electricity market was characterized by the highest average price in all hours of the day (around 65.3 €/MWh in off-peak hours and 74.5 €/MWh in peak-load hours[22]), while the German day ahead electricity market has presented the lowest average prices (around 39.9 €/MWh in off-peak hours and 50.3 €/MWh in peak-load hours) as reported in **Figure 5.1**.

Figure 5.1: Average price by countries (May, 11th 2010 – July, 29th 2013)



Data Sources: National Power Exchanges

By comparing minimum prices, the possible formation of negative prices was confirmed for the period analyzed in the Belgian, French, German and Dutch markets, with the lowest price even below -200 €/MWh in off-peak hours in Belgium, France and Germany. There are no negative prices instead in the series for Austria, Italy, Slovenia and Switzerland. In these countries indeed the operational rules of day ahead electricity markets did not allow market participants to submit negative price offers in the period between May 11th, 2010 and July 29th, 2013. This option was introduced on the Austrian day ahead electricity market only from October 15th, 2013, while on the Swiss segment at the EPEX Spot market from January 1st, 2014.

A comparison of maximum prices shows the presence of particularly marked spikes both in the daily prices series of the 8th hour in Belgium (2999 €/MWh) and in the daily prices series of the hours between the 8th and the 13th in France. Negative prices as well as marked price spikes have an impact on the dispersion degree of the 192 daily prices series around their averages. For example,

[22] In the present work peak load hours are considered from 8th to 19th

the German day ahead electricity market exhibits the highest standard deviation of daily prices in nearly all off-peak hours in the morning, while the highest standard deviation of daily prices in off-peak hours in the evening is shown by the Slovenian day ahead electricity market. The French, Belgian and Slovenian day ahead electricity market display instead the highest standard deviation of daily prices in peak-load hours.

Table 5.1: Descriptive statistics EPEX France price

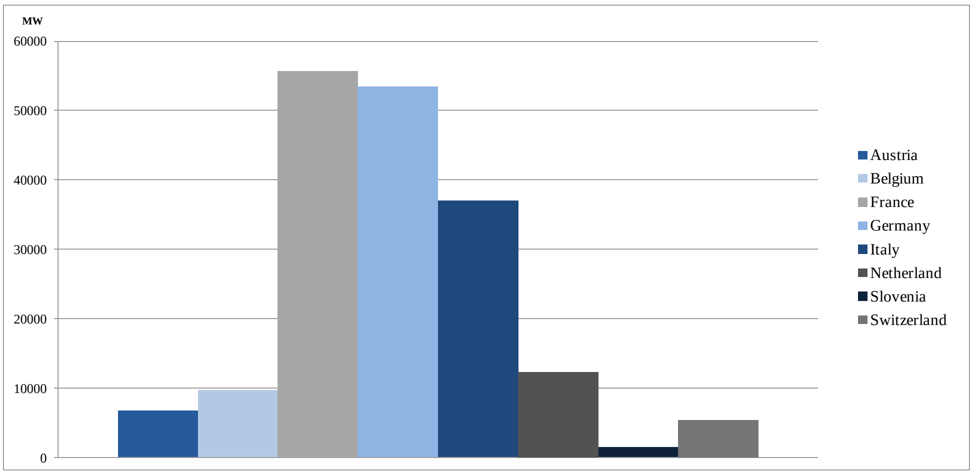
Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	40,74	7,94	108,88	12,33	0,06	5,01	0,966***
2	37,24	1,01	118,15	12,84	0,24	5,29	0,969***
3	33,12	0,00	106,96	12,84	0,14	3,88	0,980***
4	28,12	-58,67	81,93	12,72	-0,17	4,26	0,967***
5	26,88	-154,02	72,05	13,24	-2,11	31,34	0,881***
6	31,53	-200,00	84,99	14,47	-3,55	57,58	0,836***
7	39,31	-200,00	139,99	17,22	-2,26	35,14	0,863***
8	48,50	-200,00	236,70	21,69	-0,35	26,06	0,848***
9	53,70	-5,00	966,90	32,74	18,48	516,05	0,415***
10	57,18	0,09	1785,17	56,15	25,65	772,02	0,180***
11	57,59	-0,03	1938,50	58,78	28,17	894,55	0,148***
12	57,09	1,00	999,97	31,86	22,07	653,65	0,322***
13	55,60	6,06	456,70	18,52	8,66	191,11	0,634***
14	51,96	-29,00	142,51	14,78	-0,40	6,65	0,933***
15	49,60	-100,03	165,15	16,02	-0,51	13,38	0,902***
16	47,04	-100,00	148,49	15,61	-0,58	12,91	0,906***
17	46,35	-44,00	126,61	15,03	-0,33	5,78	0,951***
18	50,95	4,87	151,88	17,16	0,49	6,29	0,947***
19	58,33	9,57	500,00	26,13	6,22	88,12	0,673***
20	58,48	9,60	233,97	19,48	1,75	15,46	0,891***
21	53,29	9,89	143,02	14,46	0,10	6,42	0,950***
22	48,60	8,82	94,89	11,42	-0,59	5,00	0,950***
23	50,76	9,74	105,24	10,15	0,16	7,20	0,934***
24	46,47	10,19	89,66	10,05	-0,03	5,15	0,964***

Finally, nearly all the 192 daily prices series display distributions with non-zero skewness and kurtosis greater than 3 thereby suggesting non-normality. The Shapiro-Wilk W test (Shapiro and Wilk, 1965) statistically confirms the presence of non-normality in nearly all daily prices series distribution. Out of 192 daily prices series the null hypothesis of normality in their distribution in fact can be rejected in 184 cases at the 1% significance level, in 3 cases (Italian day ahead electricity prices of the 1st hour and 3rd hours and Swiss day ahead electricity prices of the 6th hours) at the 5% significance level. Only in the remaining 5 cases (Swiss day ahead electricity prices of the

2nd, 3rd, 4th and 5th hours and Italian day ahead electricity prices of the 6th hour) the null hypothesis of normal distribution cannot be rejected.
For illustrative purposes, **Table 5.1** displays summary statistics for the French day ahead market.

For all the countries under empirical analysis, the hourly electricity load levels were collected from the ENTSO-E Country Packages. Hourly electricity load levels indicate the hourly average active power absorbed by all the installations connected to either the transmission network or the distribution network and so include network losses, but exclude consumption from pumped-storage power plants and generating auxiliaries. In the case of Austria, hourly load levels are only referred to the public network, thereby excluding the self-production of the industrial sector, while in the case of France hourly load levels exclude Corsica. The German hourly load levels exclude not only the self-production of the industrial sector, but also part of the German railway network and thus cover only 91% of total load. Finally, also for Switzerland the hourly load values are not fully representative of the country's total load.

Figure 5.2: Average hourly load by countries in 2012 (MW)



Data source: ENTSO-E

Like in the case of the hourly day ahead electricity prices, even the hourly load levels have not been pre-treated with logarithmic transformations and, only for the last Sunday in March, when the clock goes forward one hour, a pre-treatment was needed and missing loads were replaced with the average loads of the preceding and following hours.

Bearing in mind these warnings, simple summary statistics show that over the considered period France and Germany have registered the highest average load in all hours of the day (about 52.7 GW in off-peak hours and 58.5 GW in peak-load hours for France and about 48.7 GW and

59.6 GW in off-peak hours and peak-load hours respectively for Germany), while in Slovenia hourly load is on average only 3% of the levels observed in France or Germany (**Figure 5.2**)[23].

Even if France and Germany have similar average load in all hours of the day, minimum and maximum load values indicate that the French electricity load is much more variable than the German one. More specifically, the difference between the maximum and the minimum load is larger in France than in Germany due to a more marked seasonality. In fact, in France electricity load values reach extremely high peaks in winter as heating uses mainly electricity, but German electricity load values slightly exceed the French ones in summer especially in peak-load hours.

[23] Figure 5.2 displays the average hourly load by country for year 2012 since it is the last year with complete data in the collected sample.

Appendix A

The following tables display summary statistics for all the day ahead electricity price of the market analyzed and for country load. Prices have been expressed in €/MWh, load in MW.

Table A.1: Descriptive statistics EXAA price

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	37,62	0,01	57,58	8,89	-0,84	4,47	0,963***
2	34,23	0,01	53,21	9,48	-0,81	3,88	0,963***
3	31,34	0,00	51,31	10,07	-0,73	3,42	0,963***
4	29,37	0,01	50,00	10,33	-0,58	2,99	0,973***
5	29,62	0,01	50,00	10,44	-0,61	3,04	0,971***
6	33,06	0,01	52,70	10,47	-0,87	3,61	0,950***
7	40,46	0,01	65,60	12,80	-1,00	3,74	0,932***
8	49,14	0,01	130,00	16,47	-0,48	4,24	0,955***
9	52,73	0,01	135,30	16,40	-0,27	4,83	0,957***
10	53,49	0,01	122,88	14,35	-0,34	4,87	0,964***
11	53,40	5,02	114,47	13,41	-0,31	4,56	0,971***
12	53,66	5,77	102,00	13,32	-0,44	3,92	0,980***
13	51,33	2,43	94,18	13,15	-0,63	3,73	0,974***
14	48,57	0,01	87,00	13,77	-0,67	3,54	0,973***
15	46,42	0,01	85,00	13,81	-0,69	3,50	0,972***
16	45,54	0,01	87,80	13,40	-0,65	3,57	0,973***
17	46,45	0,01	95,11	13,45	-0,38	3,87	0,982***
18	51,82	5,10	125,65	15,42	0,64	5,65	0,959***
19	56,79	13,53	175,74	16,14	1,46	9,91	0,918***
20	56,67	20,08	147,67	12,91	0,71	6,24	0,971***
21	52,99	1,52	105,00	10,04	-0,06	4,41	0,988***
22	48,48	0,01	83,90	8,32	-0,44	5,03	0,981***
23	47,00	0,01	70,40	7,70	-0,69	5,35	0,973***
24	40,94	0,01	60,60	7,91	-0,76	4,45	0,972***

Table A.2: Descriptive statistics Belpex price

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	42,71	9,28	120,00	12,20	0,28	6,48	0,950***
2	38,81	3,02	118,15	12,28	0,17	5,41	0,966***
3	34,64	0,00	80,77	12,18	-0,21	3,16	0,983***
4	29,98	-58,67	81,93	12,53	-0,42	4,50	0,962***
5	28,93	-154,02	67,44	13,13	-2,43	33,73	0,873***
6	32,99	-200,00	80,55	14,00	-4,16	67,02	0,813***
7	40,30	-200,00	121,94	16,51	-2,78	41,24	0,851***
8	51,80	-200,00	2999,00	88,40	31,54	1052,37	0,096***
9	53,47	-5,00	156,00	17,99	-0,05	5,26	0,954***
10	56,30	0,09	154,99	16,74	0,24	6,75	0,936***
11	57,12	-0,03	130,00	15,15	-0,21	5,74	0,946***
12	58,15	1,00	141,63	14,70	-0,23	6,04	0,945***
13	56,67	6,06	128,00	13,00	-0,56	6,20	0,932***
14	53,41	-29,00	128,00	13,90	-0,78	5,97	0,936***
15	50,91	-100,03	165,15	15,07	-0,84	15,68	0,890***
16	48,37	-100,00	148,49	14,61	-1,07	14,92	0,893***
17	47,81	-44,00	126,61	14,08	-0,64	6,25	0,937***
18	53,35	4,87	151,88	16,64	0,42	6,29	0,949***
19	59,86	9,57	252,11	20,77	2,44	20,13	0,840***
20	59,41	9,60	169,90	17,02	0,86	7,23	0,940***
21	54,68	9,89	136,03	12,99	-0,07	6,23	0,954***
22	50,36	8,82	94,89	10,48	-0,60	5,67	0,947***
23	52,37	0,02	120,00	9,14	0,46	9,21	0,928***
24	47,93	0,00	120,00	9,56	0,37	8,35	0,943***

Table A.3: Descriptive statistics EPEX Germany price

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	37,17	-149,90	57,32	11,73	-5,18	71,83	0,756***
2	33,72	-200,00	54,03	13,89	-7,31	113,01	0,658***
3	31,03	-221,99	52,05	14,73	-7,17	109,73	0,661***
4	28,98	-221,94	51,08	15,28	-6,94	101,05	0,657***
5	29,49	-199,89	52,07	14,36	-6,35	91,07	0,692***
6	32,78	-199,00	53,46	14,27	-6,54	95,88	0,682***
7	39,73	-199,94	73,31	17,16	-5,28	64,80	0,715***
8	48,80	-156,92	183,49	18,66	-1,35	18,45	0,897***
9	52,50	-5,95	175,55	17,06	0,14	7,01	0,951***
10	52,88	-0,03	128,14	14,85	-0,23	5,18	0,964***
11	52,56	-0,03	133,88	14,29	-0,31	4,78	0,968***
12	52,99	1,00	124,96	14,19	-0,40	4,27	0,975***
13	50,65	-0,07	113,00	13,94	-0,56	3,90	0,970***
14	47,98	-29,00	108,87	14,60	-0,65	4,19	0,969***
15	45,81	-100,03	103,65	15,24	-1,38	11,34	0,933***
16	44,99	-100,00	105,51	14,56	-1,34	11,67	0,934***
17	45,78	-44,00	121,12	13,95	-0,49	5,72	0,964***
18	51,55	3,60	151,88	15,70	0,75	7,14	0,945***
19	56,79	10,33	210,00	16,83	1,74	13,45	0,899***
20	56,88	13,70	169,90	14,20	1,01	8,37	0,950***
21	52,54	10,15	136,03	11,03	0,21	6,13	0,978***
22	48,06	8,82	94,89	9,08	-0,25	4,56	0,985***
23	47,20	9,74	79,71	8,28	-0,60	4,59	0,976***
24	40,72	-90,98	60,35	9,74	-3,17	34,86	0,843***

Table A.4: Descriptive statistics IPEX price

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	63,07	30,74	102,63	11,75	0,16	2,90	0,997**
2	55,84	23,57	96,56	12,11	0,21	3,05	0,996***
3	51,47	0,00	92,04	12,39	0,13	3,17	0,997**
4	48,35	10,00	87,00	12,60	0,17	2,78	0,996***
5	47,85	10,00	85,65	12,56	0,17	2,74	0,996***
6	50,99	10,00	86,83	12,23	-0,09	2,96	0,998
7	59,78	16,13	85,53	12,67	-0,79	3,59	0,961***
8	68,72	13,17	145,10	14,56	-0,28	5,95	0,955***
9	77,19	14,99	188,77	16,82	0,48	7,98	0,948***
10	80,58	15,00	207,04	17,16	0,87	10,90	0,913***
11	78,82	10,77	207,08	17,91	0,99	10,61	0,902***
12	76,66	7,35	206,49	18,62	0,73	8,65	0,909***
13	68,04	1,19	143,94	13,94	-0,88	7,73	0,908***
14	64,80	0,00	122,04	14,84	-1,07	6,64	0,905***
15	67,47	0,00	144,53	16,77	-0,59	6,38	0,923***
16	70,22	2,01	163,71	16,71	-0,31	7,29	0,925***
17	74,30	6,71	186,58	17,35	0,30	8,50	0,926***
18	81,80	11,45	196,55	22,24	1,31	6,39	0,897***
19	85,54	26,11	222,25	20,94	1,60	7,89	0,895***
20	89,41	49,63	211,87	20,04	1,32	6,07	0,921***
21	90,32	57,58	324,20	19,02	2,44	22,56	0,861***
22	83,87	55,16	156,31	14,76	1,20	5,20	0,922***
23	74,94	51,99	144,41	10,37	0,90	5,01	0,959***
24	67,64	35,78	101,68	9,18	0,48	3,74	0,985***

Table A.5: Descriptive statistics APX price

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	43,68	10,64	94,47	8,23	0,18	6,37	0,966***
2	39,26	8,52	74,71	8,06	-0,44	4,41	0,978***
3	36,22	0,00	63,18	8,70	-0,65	4,02	0,972***
4	33,53	0,86	59,94	9,24	-0,61	3,43	0,973***
5	33,20	0,01	58,12	9,26	-0,69	3,53	0,969***
6	35,95	1,71	59,96	9,13	-0,95	4,30	0,948***
7	42,29	-0,01	70,00	10,98	-0,91	4,51	0,951***
8	51,08	-0,08	120,03	14,53	-0,25	4,39	0,976***
9	54,86	0,00	156,00	14,70	0,36	7,23	0,956***
10	57,12	10,11	124,96	12,78	0,27	5,89	0,966***
11	58,57	15,40	124,96	11,52	0,23	5,15	0,977***
12	59,75	21,27	124,96	11,01	0,23	5,01	0,981***
13	58,12	26,00	113,00	9,46	0,17	4,82	0,983***
14	55,76	24,84	250,00	11,37	4,29	74,96	0,822***
15	53,08	23,48	192,99	10,63	1,98	28,64	0,905***
16	50,64	19,91	105,51	9,60	0,09	4,57	0,986***
17	50,68	17,36	121,12	9,80	0,61	6,57	0,966***
18	56,64	23,00	151,88	12,91	1,64	9,38	0,904***
19	60,70	27,00	210,00	14,74	2,36	16,89	0,859***
20	60,18	29,41	169,90	13,05	1,65	10,29	0,907***
21	56,79	24,26	136,03	9,20	1,08	8,91	0,951***
22	52,40	22,63	94,89	7,64	0,76	5,20	0,968***
23	52,03	30,25	84,93	6,67	0,64	4,53	0,973***
24	47,35	0,00	84,11	6,50	-0,36	8,80	0,955***

Table A.6: Descriptive statistics BSP price

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	39,23	0,00	85,00	11,50	0,10	4,91	0,971***
2	35,56	0,00	84,12	11,51	-0,01	4,65	0,975***
3	32,65	0,00	84,06	11,51	-0,17	4,20	0,977***
4	30,70	0,00	84,06	11,52	-0,08	3,93	0,981***
5	31,04	0,00	84,05	11,45	-0,11	3,86	0,982***
6	34,77	0,00	84,06	12,12	-0,22	3,94	0,977***
7	43,71	0,00	91,97	14,90	-0,27	3,60	0,980***
8	54,04	0,00	168,44	18,87	0,03	5,15	0,972***
9	59,10	0,00	204,01	20,53	0,68	7,76	0,956***
10	60,19	0,00	217,00	20,16	1,30	11,23	0,926***
11	59,62	0,00	217,00	19,00	1,30	12,52	0,925***
12	59,56	0,00	217,01	18,15	1,09	12,02	0,933***
13	56,40	0,00	150,01	15,56	-0,23	5,31	0,970***
14	53,99	0,00	132,59	16,22	-0,31	4,07	0,982***
15	53,08	0,00	153,39	18,00	0,12	4,65	0,985***
16	52,91	0,00	170,01	18,86	0,44	5,38	0,978***
17	54,76	0,00	195,80	20,41	0,97	7,23	0,952***
18	60,45	0,00	206,02	24,62	1,63	7,86	0,886***
19	64,41	0,00	224,00	23,61	1,85	10,09	0,879***
20	64,60	0,00	220,00	20,69	1,47	8,96	0,919***
21	61,94	0,00	160,00	18,54	1,03	5,56	0,936***
22	57,50	0,00	149,36	16,45	0,80	4,43	0,936***
23	54,25	0,00	119,30	14,35	0,51	3,94	0,950***
24	46,19	0,00	89,00	13,13	0,60	4,16	0,953***

Table A.7: Descriptive statistics EPEX Switzerland price

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	44,53	0,00	81,78	12,86	-0,04	3,06	0,996***
2	39,88	0,00	80,13	12,73	-0,04	3,13	0,998
3	35,95	0,00	80,10	12,71	-0,01	3,11	0,998
4	33,10	0,00	77,33	12,78	0,05	2,97	0,998
5	32,46	0,00	77,07	12,54	-0,02	2,99	0,998
6	37,26	0,00	80,87	13,40	-0,14	3,06	0,997**
7	46,13	0,00	95,02	16,58	-0,43	2,88	0,981***
8	53,31	0,00	210,36	18,94	0,22	8,10	0,932***
9	57,13	0,00	300,01	20,33	1,90	25,19	0,862***
10	58,54	1,43	300,04	19,71	2,34	28,78	0,840***
11	58,58	3,33	299,59	18,56	2,61	34,50	0,822***
12	58,84	3,12	210,25	16,88	1,12	15,96	0,875***
13	56,12	0,30	189,52	14,77	0,25	11,69	0,899***
14	54,08	5,13	137,59	15,11	-0,49	4,98	0,939***
15	53,49	0,18	188,25	16,74	0,03	7,80	0,931***
16	53,07	0,28	211,10	17,32	0,34	10,01	0,927***
17	53,51	4,77	220,07	17,72	0,84	12,57	0,919***
18	56,25	0,98	230,01	18,70	1,46	14,47	0,908***
19	59,77	0,99	243,02	19,96	2,25	17,91	0,860***
20	59,72	9,52	269,89	17,47	2,27	24,55	0,880***
21	57,41	5,52	160,33	13,84	0,33	6,67	0,962***
22	55,14	5,66	105,89	12,49	-0,30	3,34	0,990***
23	54,87	8,28	93,13	11,70	-0,33	3,54	0,991***
24	48,73	0,00	83,66	12,04	-0,14	3,15	0,995***

Table A.8: Descriptive statistics Austrian Load

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis
1	5684,9124	4373,00	7713,00	652,25	0,56	2,68
2	5369,4014	4087,00	7375,00	661,69	0,59	2,69
3	5221,0179	3957,00	7208,00	649,77	0,60	2,68
4	5059,5094	3766,00	7001,00	641,71	0,54	2,62
5	5127,6003	3715,00	7090,00	669,99	0,40	2,54
6	5565,2126	3757,00	7593,00	817,64	0,10	2,45
7	6307,9736	3870,00	8502,00	1082,10	-0,26	2,25
8	7017,2619	4118,00	9390,00	1239,82	-0,37	2,29
9	7399,8027	4649,00	9682,00	1198,39	-0,46	2,42
10	7592,642	4975,00	9854,00	1102,80	-0,46	2,59
11	7759,4464	5259,00	9985,00	1045,76	-0,46	2,62
12	7871,4974	5421,00	10040,00	994,45	-0,51	2,62
13	7634,3886	5220,00	9822,00	995,38	-0,50	2,58
14	7515,2789	5010,00	9709,00	1052,81	-0,49	2,50
15	7383,6216	4870,00	9670,00	1081,71	-0,47	2,46
16	7301,0825	4775,00	9578,00	1088,72	-0,41	2,47
17	7300,7321	4772,00	9746,00	1115,52	-0,23	2,55
18	7417,3002	4880,00	10005,00	1163,31	-0,01	2,51
19	7440,6497	5041,00	9973,00	1152,17	0,06	2,34
20	7272,983	5066,00	9557,00	1032,31	0,01	2,25
21	6983,9099	5030,00	8946,00	840,56	0,01	2,34
22	6588,3605	5036,00	8397,00	682,58	0,13	2,50
23	6497,5315	5079,00	8368,00	684,49	0,37	2,55
24	6002,8146	4624,00	7991,00	668,86	0,46	2,58

Table A.9: Descriptive statistics Belgian Load

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis
1	9091,8639	6955,00	12561,00	1083,78	0,60	2,79
2	8609,5196	6652,00	12067,00	1031,62	0,73	3,00
3	8264,6012	6467,00	11565,00	984,80	0,78	3,16
4	8099,676	6344,00	11274,00	930,65	0,74	3,17
5	8105,7866	6254,00	11068,00	911,37	0,59	2,92
6	8358,0587	6235,00	11311,00	1002,07	0,36	2,61
7	9041,1539	6136,00	12420,00	1315,60	0,10	2,32
8	9746,7551	6352,00	13212,00	1532,54	-0,04	2,17
9	10197,591	6650,00	13652,00	1445,98	-0,17	2,28
10	10562,913	6909,00	13766,00	1328,82	-0,23	2,44
11	10742,553	7202,00	13845,00	1237,30	-0,23	2,58
12	10924,593	7434,00	13874,00	1204,86	-0,24	2,62
13	10773,91	7451,00	13550,00	1118,11	-0,15	2,78
14	10648,154	7213,00	13553,00	1197,55	-0,18	2,68
15	10498,765	6898,00	13443,00	1232,72	-0,22	2,66
16	10411,032	6819,00	13486,00	1259,56	-0,21	2,62
17	10364,043	6889,00	13684,00	1263,52	-0,14	2,69
18	10588,141	7048,00	14274,00	1379,66	0,14	2,77
19	10665,713	7353,00	14191,00	1417,47	0,27	2,56
20	10487,905	7456,00	13793,00	1334,30	0,26	2,36
21	10160,651	7481,00	13231,00	1188,94	0,20	2,41
22	9859,9073	7526,00	12676,00	1001,37	0,25	2,62
23	10012,663	7870,00	13024,00	996,92	0,43	2,79
24	9787,9422	7530,00	13124,00	1104,87	0,50	2,75

Table A.10: Descriptive statistics French Load

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis
1	51839,173	36754,00	88828,00	10893,67	0,87	2,83
2	51057,111	35713,00	91216,00	11380,94	0,91	2,94
3	48792,771	33551,00	89645,00	11472,30	0,91	2,94
4	46795,995	32161,00	87082,00	11266,58	0,92	2,97
5	46711,904	31815,00	86910,00	11283,39	0,90	2,94
6	48928,57	31560,00	90412,00	12059,88	0,79	2,76
7	53005,488	30826,00	96327,00	13598,57	0,59	2,52
8	56421,562	31971,00	99204,00	14200,51	0,51	2,49
9	58449,475	34564,00	99776,00	13417,67	0,51	2,58
10	59782,641	37093,00	100000,00	12715,87	0,56	2,68
11	60178,611	38902,00	99724,00	12113,44	0,61	2,77
12	60834,202	40154,00	99862,00	11760,29	0,65	2,84
13	61094,043	41935,00	99160,00	11198,94	0,75	2,94
14	59169,1	39305,00	97052,00	11276,21	0,67	2,93
15	57633,348	37864,00	94727,00	10987,11	0,64	2,99
16	56182,765	36534,00	92965,00	11028,60	0,65	3,01
17	55586,823	35836,00	92907,00	11472,59	0,70	2,96
18	57058,384	36397,00	95642,00	12939,85	0,75	2,73
19	59810,053	38259,00	102000,00	13939,93	0,70	2,51
20	59151,533	39312,00	99872,00	13161,40	0,65	2,43
21	56828,508	39234,00	95132,00	11997,84	0,71	2,58
22	55025,057	40333,00	90964,00	10676,29	0,86	2,87
23	57905,998	43437,00	93728,00	10432,28	0,91	2,96
24	56461,266	41672,00	92410,00	10573,96	0,88	2,88

Table A.11: Descriptive statistics German Load

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis
1	45244,516	32758,00	64802,00	4967,73	0,44	3,29
2	43378,912	30271,00	62466,00	4980,23	0,43	3,33
3	42428,762	29278,00	60656,00	4955,08	0,36	3,24
4	42483,166	29201,00	59149,00	4971,28	0,23	3,04
5	43340,835	29845,00	59278,00	5105,83	0,07	2,86
6	45303,166	29932,00	61049,00	5821,94	-0,24	2,65
7	50389,466	29537,00	67297,00	8430,87	-0,54	2,20
8	55345,997	29644,00	73955,00	10103,90	-0,61	2,15
9	58315,039	30414,00	75300,00	9679,01	-0,71	2,28
10	59811,577	32596,00	75352,00	8641,94	-0,77	2,45
11	61318,629	35215,00	75678,00	8185,21	-0,78	2,46
12	62680,495	38327,00	76812,00	7823,71	-0,74	2,37
13	62022,272	39713,00	77057,00	7829,59	-0,71	2,32
14	60835,416	39428,00	77204,00	8321,33	-0,69	2,24
15	59520,299	38129,00	76379,00	8493,30	-0,66	2,19
16	58625,131	37528,00	76500,00	8477,24	-0,61	2,21
17	58056,807	37098,00	77999,00	8280,93	-0,47	2,36
18	59043,309	37778,00	79884,00	8320,22	-0,25	2,51
19	59691,282	38192,00	79019,00	7970,68	-0,20	2,42
20	59223,625	38335,00	77265,00	7636,65	-0,23	2,30
21	56896,169	40017,00	74666,00	6880,68	-0,25	2,25
22	54755,233	39695,00	71772,00	6040,26	-0,20	2,35
23	52726,247	39352,00	69945,00	5366,19	0,06	2,67
24	48546,184	37101,00	67054,00	5058,77	0,30	2,99

Table A.12: Descriptive statistics Italian Load

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis
1	30877,624	23485,00	40942,00	2890,79	0,29	3,51
2	29085,257	22117,00	38563,00	2767,93	0,25	3,42
3	28099,694	21243,00	47913,00	2741,16	0,47	5,36
4	27634,558	20904,00	36265,00	2630,39	0,10	3,19
5	27668,888	20925,00	35939,00	2581,57	0,02	3,08
6	28485,491	21073,00	35910,00	2635,45	-0,26	2,77
7	31399,505	20582,00	38654,00	3879,22	-0,59	2,40
8	35699,597	21370,00	45195,00	5575,27	-0,67	2,33
9	39660,808	23214,00	50139,00	6625,20	-0,74	2,34
10	41656,6	24694,00	53708,00	6635,70	-0,71	2,41
11	42121,56	24862,00	55385,00	6477,99	-0,62	2,41
12	42132,704	24737,00	56426,00	6406,69	-0,53	2,38
13	40391,006	24564,00	55180,00	5675,39	-0,37	2,56
14	39602,756	22076,00	55056,00	6066,21	-0,38	2,47
15	40060,671	21127,00	55775,00	6685,38	-0,45	2,31
16	40297,328	21268,00	55791,00	6852,60	-0,47	2,26
17	40756,05	21444,00	55660,00	6904,07	-0,47	2,27
18	41288,825	22000,00	54999,00	6658,71	-0,37	2,39
19	41523,731	23146,00	53790,00	6081,19	-0,37	2,46
20	41805,216	25114,00	52147,00	5311,32	-0,48	2,50
21	41220,623	28428,00	50057,00	4336,78	-0,49	2,38
22	39611,82	28818,00	50095,00	3793,14	-0,30	2,51
23	36565,361	27444,00	47503,00	3342,37	0,05	3,02
24	33571,829	25440,00	44589,00	3084,93	0,27	3,43

Table A.13: Descriptive statistic Dutch Load

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis
1	10311,688	8654,00	11926,00	582,06	-0,10	2,85
2	9644,8997	8122,00	11210,00	526,29	-0,06	2,93
3	9319,3424	7894,00	10910,00	507,51	-0,04	2,95
4	9188,2706	7688,00	10827,00	512,75	-0,03	2,97
5	9187,3547	7643,00	10870,00	536,13	-0,04	2,95
6	9393,1249	7349,00	11225,00	667,42	-0,15	2,75
7	10275,125	7382,00	12641,00	1110,86	-0,31	2,32
8	11818,13	7738,00	15023,00	1789,46	-0,37	2,11
9	13087,091	8383,68	16634,00	2031,65	-0,52	2,21
10	13832,104	8975,74	17237,00	1934,71	-0,63	2,42
11	14131,898	9426,09	17403,00	1797,01	-0,64	2,53
12	14263,927	9657,22	17522,00	1737,74	-0,64	2,52
13	14167,606	9784,00	17468,00	1645,58	-0,61	2,52
14	14149,507	9632,00	17505,00	1707,74	-0,62	2,44
15	14008,461	9404,00	17515,00	1743,11	-0,62	2,41
16	13849,971	9286,00	17516,00	1758,93	-0,59	2,39
17	13876,869	9340,00	17945,00	1777,56	-0,43	2,49
18	14150,333	9895,00	18390,00	1820,68	-0,05	2,58
19	13847,082	10020,00	17856,00	1689,61	0,16	2,40
20	13630,466	9930,00	17457,00	1643,36	0,08	2,20
21	13222,548	9804,00	16587,00	1447,09	-0,04	2,22
22	12707,153	9559,00	15429,00	1163,96	-0,13	2,47
23	12068,119	9764,00	14331,00	792,51	-0,03	2,81
24	11267,483	9444,00	13072,00	683,16	-0,09	2,76

Table A.14: Descriptive statistics Slovenian Load

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis
1	1229,3418	849,00	1538,00	137,78	-0,12	2,47
2	1196,2789	797,00	1491,00	125,24	-0,25	2,64
3	1183,2674	832,00	1458,00	118,28	-0,21	2,61
4	1179,4396	817,00	1463,00	119,01	-0,19	2,55
5	1191,9447	784,00	1479,00	122,85	-0,19	2,59
6	1239,1743	797,00	1611,00	145,40	-0,16	2,63
7	1390,0672	806,00	1851,00	191,94	-0,32	2,60
8	1516,7696	900,00	2027,00	213,46	-0,45	2,46
9	1570,2177	977,00	2070,00	198,09	-0,46	2,69
10	1566,2355	992,00	2056,00	179,80	-0,32	2,86
11	1559,7415	894,00	2053,00	168,04	-0,24	3,08
12	1581,7789	882,00	2061,00	165,77	-0,32	3,17
13	1575,2194	960,00	2071,00	169,88	-0,39	2,97
14	1545,9328	947,00	2019,00	181,32	-0,37	2,76
15	1517,7951	903,00	1986,00	179,81	-0,39	2,71
16	1495,5808	906,00	1967,00	178,95	-0,36	2,71
17	1508,5476	890,00	2000,00	192,12	-0,22	2,61
18	1521,7891	926,00	2063,00	213,47	-0,01	2,57
19	1558,5102	947,00	2099,00	219,07	-0,09	2,46
20	1587,6233	1012,00	2065,00	205,36	-0,22	2,44
21	1559,5918	1067,00	2003,00	168,71	-0,31	2,49
22	1473,4515	1091,00	1849,00	133,52	-0,33	2,70
23	1378,3019	1011,00	1743,00	126,64	-0,13	3,02
24	1282,2024	939,00	1646,00	131,95	0,10	2,91

Table A.15: Descriptive Statistics Swiss Load

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis
1	5172,3697	3479,00	7606,00	911,22	0,40	2,14
2	5164,7808	3431,00	7631,00	932,53	0,39	2,12
3	5104,3992	3342,00	7521,00	955,80	0,39	2,06
4	5049,8093	3223,00	7548,00	986,05	0,39	2,06
5	4917,0642	3136,00	7441,00	1010,05	0,35	1,94
6	5079,9449	3157,00	7375,00	1011,76	0,23	1,88
7	5247,6324	2863,00	7741,00	1053,71	0,15	1,98
8	5516,1637	2833,00	8276,00	1171,50	0,12	2,16
9	5755,7557	2959,00	8442,00	1204,82	0,03	2,20
10	5838,6769	3136,00	8388,00	1150,71	-0,01	2,26
11	5952,7917	3240,00	8576,00	1129,69	-0,08	2,31
12	6052,1703	3341,00	8429,00	1092,58	-0,21	2,32
13	5848,193	3391,00	8326,00	1023,30	0,00	2,32
14	5889,4014	3224,00	8417,00	1034,52	-0,01	2,38
15	5829,7619	3059,00	8446,00	1013,97	0,00	2,44
16	5754,4937	2988,00	8395,00	991,77	0,05	2,43
17	5713,4541	3047,00	8520,00	1010,51	0,15	2,36
18	5702,1055	3225,00	8558,00	1080,65	0,29	2,21
19	5733,9841	3422,00	8365,00	1138,31	0,23	1,96
20	5596,8337	3336,00	8131,00	1117,26	0,16	1,89
21	5426,7888	3299,00	7886,00	1031,21	0,12	2,00
22	5435,0013	3483,00	7645,00	908,06	0,17	2,11
23	5359,3297	3522,00	7794,00	911,10	0,27	2,13
24	5108,6629	3325,00	7624,00	936,21	0,33	2,07

6 Methods

As a first step, data aggregation level has to be chosen. In recent literature, previous contribution on the day ahead electricity markets have been based on daily aggregations of electricity prices (mean, median values, and so on), but in the present work, each hour of the day has been modeled separately in order to capture the day markets microstructure (Huisman et al., 2007). Indeed, day ahead negotiation results in one price for each hour of the day even when Power Exchange rules allow not only hourly offers, but also block orders, combining different hourly products. If on the one hand, certain types of contracts, such as options contracts, use the daily average prices as a reference, on the other hand some plants build their offers referring to the expected delivery price during the day. For instance, the Open Cycle Gas Turbine (OCGT) plants, which have high variable costs and short time of start-up, schedule their production considering only the expected price of peak.-oad hours. On the same path, time differences are significant for pump storages that, by buying electricity when there are low prices and selling it when prices are higher, perform time-shift. In addition to this consideration regarding the operators' bidding strategies, also companies with specific consumption structures, may sign contracts referring to only a few hours of the day, instead of standard base-load and peak-load contracts (Huisman et al., 2007). The analysis has been carried at hourly level also because each hourly price reflects different market fundamentals: demand and supply daily variation and generation plants' operational constraints (Weron and Misiorek, 2005; Longstaff and Wang, 2004; Karakatsani and Bunn, 2008; Bunn and Gianfreda, 2010). This approach is also consistent with previous contributions showing that it leads to better forecasting performance (Cuaresma et al., 2004; Knittel and Roberts, 2005; Karakatsani and Bunn, 2008) and with a multi model specification for short term forecast adopted in the demand forecasting research (Weron and Misiorek, 2008).

Considering the evidence of market integration and the growing interdependency among national European electricity markets, the present work is based on a multiple time series approach in forecasting electricity prices. To jointly model daily national time series of day ahead electricity market, a Vector Autoregressive (VAR) model has been applied. The following section briefly introduces this model.

6.1 An introduction to Vector Autoregressive Models for Multivariate Time Series

Vector Autoregressive (VAR) models have been introduced by Sims (Sims, 1980) as a tool for overcoming identification issues afflicting old macroeconomic models, since they require few assumptions about internal structure of data to be modeled, leaving to data and to their statistical

interactions the definition of the model itself. One possible explanation for failures of old macroeconomics models has indeed been identified in the insufficient representation of dynamic interactions in a system of variables (Lütkephol and Krätzig, 2004, p. 86).
On the opposite side, this does not means that VARs models do not need the requirement of arbitrary assumptions; for example, the choice of the variables to be included in model, the number of lags and so on are discretionally chosen by the modeler and they heavily affect model estimations.

Generally speaking, given a set of k time series $Y_t = (Y_{1t,} \dots . Y_{kt})'$, with *t=1 … T*, a Vector Autoregressive model of order *p*, or briefly VAR(p), is written in following way:

$$Y_t = A_1 \, Y_{t-1} + \cdots + \, A_p \, Y_{t-p} + \, \varepsilon_t \tag{6.1}$$

Where Y_t is the vector, of k elements, of endogenous variables at a specific time *t*; A_i is a set of *p* square matrices, of size (*k x k*), each of them containing parameters related to endogenous variables at a past time *t-i*; *p* is the chosen number of lags and finally ε_t is a vector of white noise errors with zero mean and covariance matrix $E(\varepsilon_t \varepsilon_t') = \Sigma$ constant in time.
In other words, a VAR(p) model is then a dynamic regression model of simultaneous equations in which a mixing of past values of variables itself are used as regressors.
In practical applications, base VAR(p) models could be too restrictive for correctly describe the information contained in data. Due to this, the model is extended including other deterministic terms, as for instance constant, linear trend, seasonal dummy variables, or exogenous stochastic variables. In such a case, a VAR(p) model including deterministic terms and exogenous variables can be written in the following way:

$$Y_t = \, A_1 \, Y_{t-1} + \cdots + \, A_p \, Y_{t-p} + \, B_0 Z_t + \, B_1 Z_{t-1} + \cdots + \, B_q \, Z_{t-q} + C_0 \, D_t + \, \varepsilon_t \tag{6.2}$$

where, beside the variables of standard VAR(p) model introduced in previous equation (6.1), a vector of dummy variables D_t (*m x 1*) and a vector of exogenous variables Z_t (of size *h x 1*) have been introduced, with related coefficient matrices C_0 *(k x m*) and B_j *(k x h*), with *j = 1,… q*, where *q* is the number of lags for exogenous variable.

Using the "*Lag"* operator L, the standard VAR(p) model can be also written in a more compact way in the following form:

$$A(L)\, Y_t = \varepsilon_t \tag{6.3}$$

Where $A(L) = I_k - A_1 L - \cdots - A_p L^p$ is a polynomial of order p of lag operator with matrix coefficients.

Given this formulation it is possible to demonstrate that the process VAR(p) Y_t is stable if all roots of characteristic polynomial $det(I_k - A_1 z - \cdots - A_p z^p)$ lie outwards the complex circle of radius one. In such case Y_t is I(0) and level VAR(p) form is the correct representation.

If instead, equation $det(I_k - A_1 z - \cdots - A_p z^p) = 0$ has at least one solution, called unit root, with $z = 1$, while all other roots are outside to the unit circle, then some or all the k time series $Y_t = (Y_{1t,} \ldots . Y_{kt})'$ are integrated and could also be cointegrated[24].

In this case, if process Y_t is *I(1)* and variables can be cointegrated, VAR(p) level form is not the most appropriate representation, since it does not account for cointegration relationship amongst the variables.

Cointegration relations can instead be treated explicitly using a re-parameterization of the standard level form VAR(p) by subtracting Y_{t-1} on both side of equation and reorganizing terms in a different way. These operations lead to a Vector Error Correction model, or VEC model, that has the following form:

$$\Delta Y_t = \Pi\, Y_{t-1} + \Gamma_1\, \Delta Y_{t-1} + \cdots + \Gamma_{p-1}\, \Delta Y_{t-p+1} + \varepsilon_t, \tag{6.4}$$

where matrix $\Pi = -(I_k - A_1 - \cdots - A_p)$, of size *k x k*, contains long term coefficients, while *k x k* matrices $\Gamma_j = -(A_{j+1} + \cdots + A_p)$ with *j = 1 , ... p-1* are related to short term behavior. In VEC model, ΔY_t variable and its lags cannot have stochastic trend since they are I(0) because, by assumption, Y_t is *I(1)*. So $\Pi\, Y_{t-1}$ is the only term that can potentially be I(1) but, since the left term of equation (6.4) is I(0), also the term $\Pi\, Y_{t-1}$ itself must be I(0) and matrix Π must contain cointegration relations, if any.

If a VAR(p) process has a unit root, which means that $det(I_k - A_1 z - \cdots - A_p z^p) = 0$ for $z = 1$, then matrix Π must be singular by definition, so $rank(\Pi) = r < k$. At this point two possibilities arise: the first one is $rank(\Pi) = 0$, and the second one is $0 < rank(\Pi) < k$.

[24] The set Y_t is said to be cointegrated if a linear combination of its time series that is I(0) exists.

In the first case $rank(\Pi) = 0$ means that matrix Π is the null matrix, so the *I(1)* process Y_t is not cointegrated and VEC model is reduced to a VAR(p-1) in the first differences of the level variable:

$$\Delta Y_t = \Gamma_1 \, \Delta Y_{t-1} + \cdots + \Gamma_{p-1} \, \Delta Y_{t-p+1} + \varepsilon_t \tag{6.5}$$

More interesting is instead the case $0 < rank(\Pi) < k$, in which the *I(1)* process Y_t contain r linearly independent cointegration vectors and *k-r* common stochastic trends. Moreover, in this case, Π matrix can also be decomposed in the following way:

$$\Pi = \alpha \, \beta' \tag{6.6}$$

Where both "loading matrix" α and "cointegration matrix" β are $k \ x \ r$ matrices of full rank r. In particular β' rows can be seen as a base of the r cointegration vectors, while matrix α components distribute the evolution of cointegration vectors over the differentiated process ΔY_t. Under this decomposition, VEC process in then written as

$$\Delta Y_t = \alpha \, \beta' \, Y_{t-1} + \Gamma_1 \, \Delta Y_{t-1} + \cdots + \Gamma_{p-1} \, \Delta Y_{t-p+1} + \varepsilon_t \tag{6.7}$$

where $\beta' \, Y_{t-1}$ is $I(0)$. However, Π decomposition is not unique since any non singular square matrix *H* of size *r* can be used to obtain a new decomposition:

$$\alpha \, \beta' = \alpha \, H \, H^{-1} \, \beta' = (\alpha \, H) \, (\beta \, {H^{-1}}')' = \alpha^* \beta^{*\prime} \tag{6.8}$$

So Π decomposition identifies only the cointegration space, which is the space spanned by cointegration vectors, and in order to get a unique decomposition additional restrictions are required.

6.2 Model specification

6.2.1 Unit root and stationarity tests

The first step in the model specification process is to investigate the order of integration of each of the 24 time series for each country. Several tests can be implemented to this aim, broadly classified in two major categories: unit root and stationarity tests. The first set of tests checks the null hypothesis (H_0) that there is a unit root against the alternative of stationarity of a DGP, while, on the opposite, the second set of tests checks a stationarity H_0 against an alternative of a unit root.

Within the first set of tests, Augmented Dickey-Fuller (ADF) test (1979) has been applied to the 192 daily day ahead electricity price time series. In this test the stochastic part is modeled by an AR process. In order to correctly specify the test, since data visual inspection does not highlight a trend, only a constant term has been included in the test regression to capture the non zero mean. Moreover, the decision on the AR order is based on the Bayesian Information Criterion (Schwarz, 1978) starting from the maximum lag order determined applying the Schwert rule of thumb (1989). The null hypothesis of unit root has been rejected at 1% level of significance for all the time series analyzed, but three cases (IPEX price at hours 13^{th},14^{th} and 23^{rd}) where the null hypothesis has been rejected at 5%.

To further explore the presence of unit root in the analyzed time series, Phillips-Perron (PP) test (1988) has been performed. PP test is robust to general forms of heteroskedasticity in the error term and it does not require the specification of the lag length for the test regression, but it accounts for serial correlation by using the Newey–West (1987) heteroskedasticity and autocorrelation consistent covariance matrix estimator. Confirming the ADF results, the PP test rejects the null hypothesis of unit root for all the 192 time series at 1% level of significance.

Coming to stationarity tests, where the null hypothesis is that the DGP is stationary, versus the alternative that it is I(1), Kwiatkowsky-Phillips-Schmidt-Shin (KPSS, 1992) test has been performed assuming a level stationary process with non zero mean. The maximum lag order for the test has been derived through an automatic bandwidth selection (Newey West, 1994) and a Quadratic Spectral kernel has been used for the autocovariance function. The null hypothesis of stationarity is rejected for almost all the time series: in 146 cases Ho is rejected at 1% level of significance, in 23 cases at 5%, in 10 cases at 10%. Only in 13 cases (Belpex prices at hours 2^{nd} 3^{rd}, at hours from 6^{th} to 11^{th} and 18^{th} -19^{th}; EPEXFR price at hours from 9^{th} to 11^{th}) KPSS does not reject the null of stationarity. ADF, PP and KPSS results are shown in **Table 6.1**, **Table 6.2** and **Table 6.3** respectively.

Table 6.1: Augmented Dickey-Fuller test

Hour	EXAA	BELPEX	EPEXFR	EPEXDE	IPEX	APX	BSP	EPEXCH
1	-3,22***	-4,73***	-4,58***	-4,16***	-2,67***	-4,28***	-3,81***	-3,92***
2	-3,75***	-4,68***	-4,44***	-4,79***	-2,94***	-4,26***	-4,01***	-4,21***
3	-4,09***	-4,49***	-4,40***	-5,21***	-2,88***	-4,49***	-4,20***	-4,27***
4	-4,23***	-4,02***	-4,24***	-5,43***	-3,03***	-4,44***	-4,27***	-4,43***
5	-4,21***	-4,27***	-4,33***	-5,18***	-2,96***	-4,55***	-4,26***	-4,49***
6	-3,69***	-4,36***	-4,26***	-4,66***	-3,19***	-4,03***	-4,03***	-4,07***
7	-3,75***	-4,18***	-4,35***	-4,85***	-2,96***	-3,93***	-4,40***	-3,90***
8	-4,63***	-6,19***	-4,85***	-5,11***	-2,95***	-4,45***	-4,58***	-4,28***
9	-5,00***	-4,73***	-5,58***	-4,98***	-3,33***	-4,77***	-4,74***	-4,63***
10	-4,49***	-4,91***	-6,28***	-4,44***	-4,40***	-4,64***	-4,63***	-4,58***
11	-3,95***	-4,83***	-6,33***	-4,24***	-3,94***	-5,04***	-4,41***	-4,55***
12	-3,44***	-5,00***	-5,85***	-3,98***	-3,42***	-5,31***	-4,40***	-4,34***
13	-3,06***	-4,86***	-5,22***	-3,49***	-2,25**	-5,40***	-3,73***	-4,02***
14	-2,97***	-4,58***	-4,69***	-3,40***	-2,31**	-5,07***	-3,78***	-4,12***
15	-3,03***	-4,91***	-4,84***	-3,48***	-2,70***	-5,02***	-4,04***	-4,14***
16	-3,11***	-5,04***	-4,89***	-3,55***	-3,04***	-5,11***	-4,09***	-4,04***
17	-3,04***	-4,55***	-4,45***	-3,42***	-3,19***	-4,70***	-4,10***	-3,94***
18	-3,18***	-3,93***	-3,83***	-3,48***	-2,75***	-3,85***	-3,73***	-3,66***
19	-3,52***	-3,98***	-4,54***	-3,84***	-2,68***	-3,98***	-3,74***	-3,90***
20	-3,49***	-3,75***	-4,23***	-3,71***	-3,11***	-3,89***	-3,64***	-3,92***
21	-3,39***	-4,12***	-4,45***	-3,73***	-3,19***	-4,62***	-3,92***	-3,47***
22	-3,35***	-4,61***	-4,99***	-3,84***	-2,63***	-3,85***	-3,97***	-3,55***
23	-2,82***	-4,68***	-5,00***	-3,18***	-2,30**	-4,96***	-3,60***	-3,58***
24	-2,53***	-4,51***	-4,38***	-3,46***	-2,43***	-3,73***	-3,95***	-3,89***

*** *p-value* < 0.01; ** *p-value* < 0.05; * *p-value* < 0.10

MacKinnon (1994) critical values

Table 6.2: Phillips-Perron test

Hour	EXAA	BELPEX	EPEXFR	EPEXDE	IPEX	APX	BSP	EPEXCH
1	-11,81***	-16,76***	-13,55***	-16,39***	-13,00***	-19,74***	-14,59***	-10,17***
2	-12,12***	-14,06***	-11,47***	-16,30***	-13,70***	-16,52***	-13,99***	-10,33***
3	-13,46***	-13,09***	-11,46***	-16,53***	-14,71***	-16,49***	-14,11***	-11,47***
4	-12,37***	-12,10***	-11,43***	-15,33***	-14,03***	-14,75***	-14,41***	-11,26***
5	-12,40***	-15,18***	-14,43***	-16,15***	-13,97***	-14,99***	-14,52***	-11,33***
6	-14,44***	-17,93***	-16,51***	-15,92***	-14,58***	-15,75***	-14,80***	-11,61***
7	-19,60***	-20,85***	-18,80***	-20,15***	-20,52***	-20,81***	-17,65***	-15,45***
8	-19,97***	-33,77***	-20,04***	-21,35***	-23,70***	-21,39***	-18,49***	-17,09***
9	-20,23***	-20,80***	-24,92***	-21,43***	-24,59***	-21,78***	-18,64***	-17,34***
10	-18,98***	-20,37***	-23,67***	-20,92***	-22,85***	-22,15***	-17,55***	-15,95***
11	-17,35***	-20,21***	-26,66***	-20,08***	-19,90***	-22,77***	-16,59***	-15,51***
12	-15,64***	-20,11***	-25,95***	-18,93***	-17,56***	-22,50***	-15,60***	-14,85***
13	-14,42***	-20,07***	-19,89***	-18,16***	-15,36***	-22,30***	-14,88***	-13,49***
14	-15,16***	-21,03***	-17,47***	-18,40***	-16,95***	-25,12***	-15,89***	-14,48***
15	-15,50***	-21,45***	-18,58***	-18,83***	-18,05***	-22,79***	-16,17***	-14,54***
16	-15,67***	-20,89***	-18,40***	-18,62***	-17,82***	-19,64***	-16,11***	-14,14***
17	-14,46***	-19,07***	-16,69***	-16,99***	-17,44***	-18,43***	-15,75***	-13,17***
18	-11,37***	-15,41***	-13,91***	-13,75***	-12,28***	-14,05***	-13,16***	-11,04***
19	-10,86***	-13,13***	-14,66***	-13,15***	-10,69***	-12,70***	-11,33***	-9,38***
20	-11,26***	-12,42***	-11,30***	-14,38***	-11,84***	-12,75***	-12,34***	-9,36***
21	-11,04***	-14,03***	-11,33***	-14,51***	-14,11***	-16,52***	-14,55***	-8,36***
22	-10,54***	-16,21***	-13,31***	-14,97***	-11,97***	-17,49***	-14,10***	-8,43***
23	-9,38***	-18,25***	-13,20***	-15,52***	-11,16***	-17,99***	-12,56***	-8,35***
24	-8,49***	-17,76***	-11,66***	-16,95***	-9,55***	-20,06***	-11,88***	-8,40***

*** *p-value* < 0.01; ** *p-value* < 0.05; * *p-value* < 0.10

MacKinnon (1994) critical values

Table 6.3: Kwiatkowsky-Phillips-Schmidt-Shin test

Hour	EXAA	BELPEX	EPEXFR	EPEXDE	IPEX	APX	BSP	EPEXCH
1	6,78***	0,42*	0,67**	5,05***	2,75***	1,59***	4,58***	1,71***
2	5,51***	0,26	0,86***	3,72***	1,82***	0,68**	4,38***	1,70***
3	4,26***	0,35	0,60**	2,64***	1,45***	0,70**	3,83***	1,71***
4	3,27***	0,67**	0,41*	1,85***	1,56***	0,90***	3,15***	1,70***
5	3,42***	0,63**	0,52**	2,16***	1,66***	0,78***	3,28***	1,91***
6	4,73***	0,28	0,69**	3,15***	2,52***	0,77***	4,2***	2,06***
7	3,96***	0,27	0,59**	2,43***	3,43***	0,71**	2,83***	1,45***
8	2,14***	0,18	0,55**	1,88***	3,57***	0,50**	1,91***	1,16***
9	2,57***	0,21	0,25	2,04***	3,17***	0,40*	1,77***	0,87***
10	4,17***	0,25	0,18	3,69***	1,69***	0,52**	1,99***	1,05***
11	6,06***	0,34	0,24	5,35***	4,51***	0,76***	2,64***	1,54***
12	7,77***	0,51**	0,80***	6,75***	6,52***	0,77***	3,31***	2,45***
13	8,67***	1,12***	1,95***	7,62***	6,96***	0,58**	4,35***	3,62***
14	8,53***	1,22***	2,98***	7,33***	7,06***	0,59**	4,21***	3,78***
15	8,13***	1,23***	2,72***	6,99***	6,03***	0,58**	3,40***	3,10***
16	7,09***	1,26***	2,89***	6,02***	4,25***	0,47**	2,68***	2,49***
17	5,39***	1,07***	2,79***	4,88***	2,60***	0,44*	2,09***	2,02***
18	2,86***	0,33	1,44***	2,76***	1,52***	0,61**	1,63***	1,52***
19	1,69***	0,32	0,55**	1,61***	2,48***	0,61**	1,45***	0,89***
20	1,95***	0,40*	0,41*	1,55***	4,01***	0,68**	1,67***	0,81***
21	3,17***	0,37*	0,64**	3,00***	3,99***	1,06***	2,18***	1,38***
22	4,96***	0,38*	1,10***	4,06***	3,49***	1,58***	2,10***	1,83***
23	7,55***	0,40*	1,34***	6,58***	4,25***	2,04***	2,77***	1,90***
24	9,09***	0,37*	0,99***	6,99***	3,31***	3,01***	3,57***	1,62***

*** *p-value* < 0.01; ** *p-value* < 0.05; * *p-value* < 0.10

KPSS (1992) critical values

Unit root tests, on the one hand, and stationarity test, on the other hand, show contradictory evidence about the integration properties of the 192 daily day ahead electricity price series. This result is well known in literature, since several scholars has found different integration properties of day ahead electricity prices and there is no a conclusive evidence. To best of our knowledge, no studies are fully dedicated to the exploration of the integration properties of electricity day ahead prices. Some scholars have found electricity price series to be stationary, using several tests. Amongst others, Boisseleau (2004), using ADF statistics finds six European countries' daily average prices time series for 2002 to be stationary. Bunn and Gianfreda (2010), analyzing average day ahead electricity prices and forward price from five European countries for the period 2001-2005, perform unit root tests ADF and PP, after de-trending and de-seasonalising, and find evidence of stationarity for all the series, but Spanish and Dutch ones, while the forward prices series become progressively more non stationary. Escribano et al. (2011), analyzing daily average of day ahead spot electricity prices from Argentina, Australia, New Zeland, Scandinavia and Spain for different period moving from 1993 to 2004, apply first ADF test that always rejects the unit root hypothesis and the results are confirmed with Boswijk (2001) unit root test robust to heteroskedasticity. These results are confirmed also after the application of a filter to eliminate outliers. Lucia and Schwarz

(2002) implement ADF and PP test on daily average day ahead price from NordPool for the period 1993-1999 and the tests reject the unit root hypothesis. Karakatsani and Bunn (2008) perform ADF and PP tests, after accounting for seasonality, and they reject the unit root hypothesis for the UK spot market daily average prices for the period 2001- 2002.

On the other hand, amongst others, Bosco et al. (2010) using data from 1999 to 2007 for six European day ahead markets find electricity price to be I(1) applying unit root test based on Lucas Pseudo Likelihood Ratio test (the statistics are based on the same auxiliary model as the ADF). The same results are confirmed using stationarity tests KPSS and its robust version IKPSS proposed by de Jong et al (2007), obtained computing the KPSS statistics on the sign of median centered data. Bollino et al. (2013) exploring data from four European national markets for the period 2004-2010, are not able to reject the unit root hypothesis in levels, using ADF test, while considering first differences the series are stationary. Alternative unit root test (PP) and stationarity test (KPSS) lead to qualitatively similar results.

This evidence suggests the presence of fractional integration in electricity price time series, but this possibility has been considered only by recent contributions. Haldrup et al., 2010, analyzing day ahead hourly electricity spot price for NordPool for the period 2000- 2003, estimate the order of integration using a parametric ARFIMA model, after having found contradictory evidence from PP unit root test and KPSS test. On the same path, Koopman et al. (2007) analyzing daily day ahead price of four European markets for the period 1993-2005, allow for the possibility of fractional integration through a seasonal periodic Reg-ARFIMA-GARCH model. Pellini (2012b), considering daily average day ahead electricity price for 15 PXs from the foundation data to January 2012, finds contradictory evidence from PP and KPSS tests; the author performs the Gaussian Semiparametric test (Robinson and Henry, 1998) for long memory, that indicate that the series show long memory, since the estimated parameter d lies between 0.5 and 1. Gianfreda and Grossi (2012) looking at daily medians of day ahead Italian zonal price between 2005 and 2008, capture the presence of fractional integration through an ARFIMA model, after having obtained opposite results from the PP and the KPSS test. Houllier and de Menezes (2013) using ARFIMA model find that hourly electricity spot price time series for the period 2009- 2011 of six European markets are fractionally integrated and characterized by the presence of long memory.

Given these unclear results, the present work proceeds setting the models under two hypotheses: first assuming that all price series are jointly I(0) and then assuming the presence of unit root for all the series.

6.2.2 The models implemented

Under the first hypothesis, as an attempt to catch the dynamic interactions between European electricity markets, 24 VAR models, one for each hour of the day, incorporating hourly prices for all the eight markets analyzed are set up.

The determination of the autoregressive order is reached through information criteria, especially using Akaike Information Criterion-AIC (1974), Hannan and Quinn-HQ (1979) and Schwarz Bayesian Information Criterion-BIC (1978). AIC criterion asymptotically overestimates lag order with positive probability and in general BIC is the most parsimonious criterion. Paulsen (1984) shows that these results hold both in case of stationary process and in case of integrated processes in presence of cointegration (Lütkephol and Krätzig, 2004, p. 111). For all the 24 models, information criteria do not provide an unanimous evidence about the optimal number of lag to be included (**Table 6.4**).

In details, for all the model AIC criterion suggests the inclusion of 7 lags, HQ criterion confirms this choice for 11 hours (7^{th} -11^{th}, 13^{th}-17^{th} and 20^{th}) while BIC criterion indicate the inclusion of only one lag for half of the hours. When there are differences in the order chosen by the criteria, models have been specified according to the AIC criterion (as in Karakatsani and Bunn, 2008). This choice is related to the importance of incorporating high autocorrelation order in modeling electricity prices, as shown by Knittel and Roberts (2005).

Table 6.4: Lag selection VAR models

Hour 1

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32590,3		55,8534	55,9449	56,096
1	-30152	4876,7	51,7913	51,9874	52,3111
2	-29919,4	465,19	51,5028	51,8035*	52,2999*
3	-29801,1	236,57	51,41	51,8152	52,4843
4	-29713,6	175,08	51,3697	51,8795	52,7212
5	-29616,5	194,08	51,3132	51,9275	52,9419
6	-29527,5	178,1	51,2703	51,9892	53,1763
7	-29453,8	147,38*	51,2537*	52,0772	53,437

Hour 2

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32322,8		55,3957	55,4872	55,6382
1	-29810,4	5024,8	51,2068	51,4028	51,7266*
2	-29605,5	409,8	50,9657	51,2663*	51,7628
3	-29496,4	218,02	50,8887	51,2939	51,963
4	-29435,6	121,68	50,8941	51,4039	52,2456
5	-29356	159,16	50,8674	51,4818	52,4962
6	-29277,3	157,36	50,8423	51,5612	52,7483
7	-29208,4	137,88*	50,8339*	51,6574	53,0171

Hour 3

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32544,5		55,775	55,8665	56,0176
1	-30185	4719	51,8477	52,0437	52,3675*
2	-30033,8	302,26	51,6986	51,9992*	52,4957
3	-29933,3	201,13	51,636	52,0412	52,7103
4	-29850,4	165,67	51,6038	52,1136	52,9554
5	-29787,3	126,25	51,6053	52,2197	53,2341
6	-29692,3	190,01	51,5523	52,2712	53,4583
7	-29588,8	207,06*	51,4846*	52,3081	53,6679

Hour 4

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32723,7		56,0817	56,1732	56,3242
1	-30061,6	5324,3	51,6366	51,8327	52,1564*
2	-29889,8	343,52	51,4522	51,7529*	52,2493
3	-29805	169,64	51,4166	51,8218	52,4909
4	-29718,5	173,02	51,3781	51,8879	52,7296
5	-29635,8	165,48	51,346	51,9604	52,9748
6	-29538,8	193,92	51,2897	52,0086	53,1957
7	-29440,1	197,39*	51,2303*	52,0538	53,4135

Hour 5

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32583,1		55,8411	55,9326	56,0837
1	-30208,8	4748,7	51,8884	52,0845	52,4082*
2	-30012,3	392,88	51,6618	51,9625*	52,4589
3	-29925,3	174,07	51,6224	52,0276	52,6967
4	-29832,7	185,17	51,5735	52,0833	52,925
5	-29757,5	150,52	51,5542	52,1686	53,183
6	-29637,6	239,69	51,4587	52,1776	53,3647
7	-29552,1	171,11*	51,4218*	52,2453	53,6051

Hour 6

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32589,2		55,8516	55,9431	56,0942
1	-30300,2	4578,1	52,0449	52,2409	52,5647*
2	-30116,9	366,56	51,8408	52,1414*	52,6378
3	-30022,6	188,7	51,7889	52,1941	52,8632
4	-29924,9	195,46	51,7312	52,2409	53,0827
5	-29795,9	257,85	51,6201	52,2344	53,2488
6	-29667,5	256,89	51,5098	52,2287	53,4158
7	-29550,3	234,38*	51,4188*	52,2423	53,6021

Hour 7

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-33333,1		57,1241	57,2156	57,3667
1	-31588	3490,1	54,2481	54,4441	54,7679*
2	-31369,7	436,6	53,9841	54,2847	54,7811
3	-31223,4	292,64	53,8432	54,2484	54,9175
4	-31117,6	211,52	53,7718	54,2816	55,1233
5	-31003,7	227,73	53,6865	54,3008	55,3152
6	-30823,8	359,91	53,4881	54,207	55,3941
7	-30662,2	323,17*	53,3211*	54,1446*	55,5044

Hour 8

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-36972,8		63,3512	63,4427	63,5938
1	-35679,6	2586,4	61,2482	61,4442	61,768*
2	-35490,3	378,51	61,0339	61,3345	61,8309
3	-35315,8	348,95	60,8449	61,2501	61,9192
4	-35232,5	166,63	60,8118	61,3216	62,1634
5	-35162,6	139,76	60,8018	61,4161	62,4305
6	-35009,8	305,6	60,6498	61,3687	62,5558
7	-34802,3	415,06*	60,4043*	61,2278*	62,5875

Hour 9

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-35009,9		59,9931	60,0846	60,2356
1	-33691,4	2637,1	57,8467	58,0428	58,3665
2	-33343,9	694,96	57,3617	57,6624	58,1588*
3	-33198,5	290,78	57,2225	57,6277	58,2968
4	-33071,1	254,86	57,114	57,6237	58,4655
5	-32970,3	201,62	57,051	57,6653	58,6798
6	-32851,6	237,33	56,9575	57,6764	58,8635
7	-32618,1	467,15*	56,6673*	57,4908*	58,8506

Hour 10

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-35698,6		61,1713	61,2628	61,4139
1	-34225,8	2945,7	58,761	58,9571	59,2808
2	-33804,2	843,21	58,1492	58,4498	58,9462*
3	-33627,9	352,49	57,9571	58,3623	59,0314
4	-33499,6	256,65	57,8471	58,3569	59,1986
5	-33371,1	257,13	57,7366	58,351	59,3654
6	-33245,7	250,72	57,6316	58,3505	59,5376
7	-33108,4	274,5*	57,5063*	58,3298*	59,6896

Hour 11

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-35804		61,3516	61,443	61,5941
1	-34142,6	3322,8	58,6186	58,8146	59,1384
2	-33692,9	899,24	57,9588	58,2595	58,7559*
3	-33527,7	330,52	57,7856	58,1908	58,8599
4	-33394,2	266,89	57,6668	58,1766	59,0183
5	-33266,6	255,27	57,5579	58,1722	59,1867
6	-33126,3	280,66	57,4273	58,1462	59,3333
7	-32969,2	314,15*	57,2681*	58,0916*	59,4513

Hour 12

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-34989,7		59,9584	60,0499	60,201
1	-33156,1	3667,2	56,9309	57,127	57,4507
2	-32912,9	486,36	56,6243	56,925	57,4214*
3	-32768,7	288,35	56,4872	56,8924	57,5615
4	-32641,9	253,67	56,3797	56,8894*	57,7312
5	-32550	183,79	56,3319	56,9463	57,9607
6	-32413,8	272,41	56,2084	56,9273	58,1144
7	-32278,3	271,11*	56,086*	56,9095	58,2692

* selected lag

Hour 13

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-33120,9		56,7611	56,8526	57,0037
1	-31363,4	3514,9	53,8638	54,0599	54,3837
2	-31137	452,84	53,586	53,8866	54,383*
3	-30992,5	288,99	53,4483	53,8535	54,5225
4	-30872,2	240,69	53,3519	53,8616	54,7034
5	-30782,9	178,45	53,3087	53,923	54,9375
6	-30634,7	296,54	53,1645	53,8834	55,0705
7	-30447,4	374,46*	52,9537*	53,7772*	55,1369

Hour 14

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32748,2		56,1235	56,215	56,3661
1	-31004,6	3487,2	53,2499	53,446	53,7697*
2	-30788,7	431,77	52,9901	53,2907	53,7871
3	-30637	303,36	52,8401	53,2453	53,9143
4	-30533,4	207,2	52,7723	53,2821	54,1238
5	-30458,1	150,65	52,7529	53,3673	54,3817
6	-30240,8	434,61	52,4906	53,2095	54,3966
7	-30093,8	293,99*	52,3486*	53,1721*	54,5319

Hour 15

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-33841,8		57,9946	58,0861	58,2372
1	-32044,3	3595,1	55,0287	55,2248	55,5485*
2	-31856,6	375,47	54,817	55,1177	55,6141
3	-31679,8	353,51	54,6241	55,0293	55,6984
4	-31571,9	215,71	54,5491	55,0589	55,9006
5	-31456,1	231,74	54,4604	55,0747	56,0891
6	-31294,6	322,86	54,2937	55,0126	56,1997
7	-31153	283,2*	54,1609*	54,9844*	56,3441

Hour 16

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32917,8		56,4136	56,5051	56,6562
1	-31069,8	3695,9	53,3615	53,5576	53,8813
2	-30833,1	473,29	53,0661	53,3668	53,8632*
3	-30696,8	272,79	52,9423	53,3475	54,0166
4	-30593,8	205,81	52,8757	53,3855	54,2272
5	-30494,5	198,75	52,8152	53,4295	54,4439
6	-30301,2	386,54	52,594	53,3129	54,5
7	-30155	292,42*	52,4534*	53,2768*	54,6366

Hour 17

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32889		56,3643	56,4558	56,6069
1	-30831	4115,8	52,953	53,1491	53,4728*
2	-30614,6	432,82	52,6923	52,9929	53,4893
3	-30481,1	267,14	52,5732	52,9784	53,6475
4	-30374,7	212,71	52,5008	53,0105	53,8523
5	-30253,4	242,5	52,4028	53,0172	54,0316
6	-30080,9	345,11	52,2171	52,936	54,1231
7	-29943	275,74*	52,0907*	52,9142*	54,274

Hour 18

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-33866,7		58,0371	58,1286	58,2797
1	-31513,4	4706,6	54,1205	54,3165	54,6403
2	-31231,1	564,72	53,7469	54,0475	54,5439*
3	-31090,2	281,64	53,6154	54,0206*	54,6897
4	-30979,4	221,69	53,5353	54,0451	54,8868
5	-30868,2	222,37	53,4546	54,0689	55,0833
6	-30759	218,32	53,3773	54,0962	55,2833
7	-30651,1	215,86*	53,3021*	54,1256	55,4854

Hour 19

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-35026,2		60,0208	60,1123	60,2634
1	-32861,9	4328,5	56,4276	56,6237	56,9474
2	-32475,3	773,35	55,8756	56,1762	56,6726*
3	-32278,9	392,66	55,6491	56,0543	56,7234
4	-32134,9	288,1	55,5122	56,022	56,8637
5	-31996,1	277,57	55,3842	55,9986*	57,013
6	-31873	246,22	55,2831	56,002	57,1891
7	-31759,2	227,58*	55,1979*	56,0214	57,3812

Hour 20

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-33883,5		58,0659	58,1573	58,3084
1	-31795,7	4175,6	54,6034	54,7995	55,1232
2	-31510,1	571,19	54,2243	54,5249	55,0214*
3	-31363,5	293,12	54,083	54,4882	55,1573
4	-31245	237,1	53,9897	54,4995	55,3413
5	-31136,1	217,86	53,9129	54,5272	55,5416
6	-30963,3	345,59	53,7267	54,4456	55,6327
7	-30838	250,54*	53,6219*	54,4454*	55,8051

Hour 21

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-33251,2		56,984	57,0755	57,2266
1	-30701,8	5098,7	52,7319	52,928	53,2518*
2	-30481,2	441,2	52,464	52,7646	53,2611
3	-30315,7	331,04	52,2903	52,6955*	53,3646
4	-30205	221,4	52,2104	52,7202	53,562
5	-30105,7	198,55	52,1501	52,7644	53,7788
6	-29958,7	294,14	52,008	52,7269	53,914
7	-29843,3	230,71*	51,9201*	52,7436	54,1033

Hour 22

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32474,7		55,6556	55,7471	55,8982
1	-29532,5	5884,5	50,7313	50,9274	51,2512*
2	-29309,1	446,83	50,4586	50,7592	51,2557
3	-29159,9	298,23	50,313	50,7182*	51,3873
4	-29044,8	230,34	50,2254	50,7352	51,577
5	-28943,5	202,61	50,1616	50,7759	51,7904
6	-28818,1	250,67	50,0567	50,7756	51,9627
7	-28702,5	231,17*	49,9684*	50,7919	52,1517

Hour 23

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31533,1		54,0447	54,1362	54,2872
1	-28537,8	5990,7	49,0295	49,2256	49,5494
2	-28310,2	455,23	48,7496	49,0503	49,5467*
3	-28173,8	272,76	48,6258	49,031*	49,7001
4	-28076,3	194,86	48,5686	49,0784	49,9201
5	-27984	184,66	48,5201	49,1345	50,1489
6	-27867	234,05	48,4294	49,1483	50,3354
7	-27770,8	192,47*	48,3743*	49,1977	50,5575

Hour 24

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31714		54,3542	54,4457	54,5968
1	-28601,6	6224,9	49,1387	49,3348	49,6585
2	-28349,5	504,2	48,8169	49,1175	49,6139*
3	-28168,7	361,49	48,6171	49,0223*	49,6914
4	-28070,4	196,68	48,5584	49,0682	49,9099
5	-27970,1	200,53	48,4964	49,1107	50,1251
6	-27864	212,19	48,4243	49,1432	50,3303
7	-27779,3	169,44*	48,3889*	49,2124	50,5721

*selected lag

Preliminary data analysis shows that all the time series display seasonality. For all the models, the weekly deterministic seasonality of day ahead electricity prices has been captured through the inclusion of dummy variables.
So under the assumption of time series stationarity, for each of the 24 hours the following model has been set:

$$\boldsymbol{p_t} = A + B_1\,\boldsymbol{p_{t-1}} + \cdots + B_n\,\boldsymbol{p_{t-n}} + \Gamma\boldsymbol{d_t} + \boldsymbol{\varepsilon_t} \tag{6.9}$$

where $\boldsymbol{p_t}$ is a vector (8x1) that contains the prices of the eight countries at time *t*, $\boldsymbol{p_{t-1}}\ldots\boldsymbol{p_{t-n}}$ are the price vectors of previous *n* day, where *n*=7 according to AIC criterion, A (8x1) is the vector of the constant, $\boldsymbol{d_t}$ is a vector (6x1) of dummy variables for the day of the week**,** $\boldsymbol{\varepsilon_t}$ is the vector of residuals.

Moreover, each model has been extended including an exogenous variable. According to previous literature and given the close correlation between load and price, hourly load has been introduced. No other variables, such as weather conditions or temperatures have been modeled explicitly. In fact, load incorporates expectations about other possible drivers, as weather conditions (Weron, 2009). On the same path, no other possible drivers of day ahead electricity prices have been modeled explicitly such as fuel price, RES generation or cross border exchanges. The inclusion of such variables, on the one hand would foster a significant growth of the number of parameters to be estimated in the model, and on the other hand not all the possible variables are available for all the countries and the periods considered at hourly level. Accordingly, for each of the 24 hours the following VAR-X model has been set:

$$\boldsymbol{p_t} = A + B_1\,\boldsymbol{p_{t-1}} + \cdots + B_n\,\boldsymbol{p_{t-n}} + \Theta\boldsymbol{z_t} + \Gamma\boldsymbol{d_t} + \boldsymbol{\varepsilon_t} \tag{6.10}$$

where $\boldsymbol{p_t}$ is a vector (8x1) with prices for the eight countries at time *t*, A (8x1) is the vector of the constant, $\boldsymbol{p_{t-1}}\ldots\boldsymbol{p_{t-n}}$ are the vectors of the prices of previous *n* day, where *n*=7 according to AIC criterion[25],$\boldsymbol{z_t}$ (1x8) is the vector of country load at time *t*, $\boldsymbol{d_t}$ is a vector (6x1) of dummy variables for the day of the week**,** $\boldsymbol{\varepsilon_t}$ is the vector of residuals.

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[25] Also in the case of the inclusion of the load, the same qualitative considerations about lag selection hold. AIC suggests the inclusion of 7 lags for all the hours but hour 2nd and the same indication arises from HQ criterion for 9 hours (7th ; 9th -11th ; 13th -17th), while BIC indicates the inclusion of only one lag for all the hours, but 5 (9th-11th;19th-20th). See **Table B.1** in Appendix B for lag selection in this case.

Due to the unclear evidence about price time series integration properties, in the following the alternative hypothesis of the presence of unit root for all the time series is considered. Under this hypothesis, the VEC models represent the suitable framework.

For each of the 24 hours of the day, a VEC model has been estimated, including 6 lags (due to the 7 lags included in the VAR model), a non restricted constant and dummy variables for the day of the week. In this framework, in the model specification also the cointegrating rank has to be chosen. For this purpose, sequential testing procedures based on likelihood ratio (LR)–type tests and a method based on the minimization of information criteria have been applied.

Johansen (1995) multiple trace test procedure (Trace test) considers a sequence of hypotheses where the null hypothesis is that the cointegration rank is equal to *r*, while the alternative H_1 is that the cointegration rank is greater than *r*. The first null hypothesis is H_0 (0): rank(Π) = 0 versus H_1(0): rank(Π) > 0. If H_0 (0) cannot be rejected, a VAR process in first differences has to be considered, since no cointegrating relationships held amongst the variables analyzed. In the opposite case, the following hypothesis has to be considered. If all the null hypotheses can be rejected, a VAR process is the adequate representation of the DGP. The procedure ends when the null hypothesis cannot be rejected for the first time, and the corresponding cointegrating rank is selected.

Another sequential procedure is the Johansen (1995) maximum eigenvalue test[26], where the null hypothesis H_0 is the existence of *r* cointegrating relations against the alternative H_1 of *r+1* cointegrating relations. The first H_0 is the absence of cointegrating relationships. The same considerations referring to the previous procedure held.

Moreover, also a method based on information criteria has been considered, as shown by Gonzalo and Pitarakis (1998) and Aznar and Salvador (2002). As in the case of lag order selection, the number of cointegration relationships minimizing either the BIC or the HQ criterion provides a consistent estimator of the number of cointegrating equations.

These methodologies do not provide a unanimous result, as **Table 6.5** displays.

[26] This name spring from the fact that the part of the LL that changes with *r* is a simple function of the eigenvalues of a (KxK) matrix.

Table 6.5: Cointegration rank

Hour 1					
Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	452,586	193,662	54,398	53,234	52,520
1	258,925	75,732	54.316*	53,102	52,359
2	183,193	51,540	54,336	53,081	52,311
3	131,653	48,892	54,368	53,076	52,284
4	82,761	33,354	54,388	53,065	52,255
5	49,407	25.744*	54,410	53,063	52,238
6	23.663*	11,992	54,425	53.060*	52,224
7	11,671	11,671	54,441	53,064	52,220
8	-	-	54,443	53,060	52.212*

Hour 2					
Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	461,778	176,855	54,070	52,905	52,192
1	284,923	80,903	54.004*	52,791	52,047
2	204,020	60,996	54,020	52,764	51,995
3	143,024	48,234	54,042	52,750	51,958
4	94,790	36,612	54,063	52,740	51,930
5	58,178	31,117	54,081	52,734	51,909
6	27,060	15.858*	54,092	52,727	51,890
7	11.202*	11,202	54,103	52,726	51,882
8	-	-	54,106	52.723*	51.875*

Hour 3					
Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	476,472	177,946	54,616	53,451	52,737
1	298,525	83,918	54.549*	53,335	52,592
2	214,608	69,533	54,562	53,306	52,536
3	145,074	53,204	54,575	53,283	52,491
4	91,870	38,879	54,591	53,268	52,458
5	52,991	26.224*	54,607	53,260	52,435
6	26,767	17,028	54,622	53,257	52,421
7	9.738*	9,738	54,633	53,256	52,412
8	-	-	54,637	53.254*	52.406*

Hour 4					
Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	447,771	157,243	54,326	53,161	52,447
1	290,528	90,992	54.279*	53,066	52,322
2	199,536	63,166	54,285	53,029	52,260
3	136,369	51,692	54,305	53,013	52,221
4	84,677	34,821	54,322	53,000	52,189
5	49,856	23.193*	54,343	52,996	52,170
6	26,663	17,092	54,361	52,996	52,159
7	9.571*	9,571	54,371	52,994	52,150
8	-	-	54,375	52.992*	52.145*

Hour 5					
Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	501,491	167,890	54,569	53,404	52,690
1	333,601	113,803	54,512	53,299	52,555
2	219,797	70,836	54.495*	53,239	52,469
3	148,961	57,450	54,507	53,215	52,423
4	91,511	34,566	54,519	53,196	52,386
5	56,946	28,915	54,539	53,192	52,367
6	28,031	17.806*	54,552	53,187	52,350
7	10.225*	10,225	54,561	53,184	52,340
8	-	-	54,565	53.182*	52.334*

Hour 6					
Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	458,605	172,906	54,632	53,467	52,753
1	285,699	84,559	54.570*	53,357	52,613
2	201,141	63,737	54,582	53,326	52,557
3	137,404	52,654	54,601	53,309	52,517
4	84,750	34,844	54,618	53,295	52,485
5	49,906	26.640*	54,638	53,291	52,466
6	23.266*	13,430	54,653	53,288	52,451
7	9,836	9,836	54,667	53,290	52,446
8	-	-	54,671	53.288*	52.440*

Hour 7					
Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	490,763	187,217	56,794	55,629	54,915
1	303,547	94,269	56.717*	55,504	54,761
2	209,278	67,055	56,720	55,464	54,695
3	142,222	52,616	56,736	55,444	54,652
4	89,606	38,477	56,752	55,430	54,619
5	51,129	25.068*	56,769	55,422	54,597
6	26,061	16,686	56,785	55,420	54,584
7	9.375*	9,375	56,796	55,419	54,575
8	-	-	56,801	55.417*	54.570*

Hour 8					
Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	636,230	211,442	64,258	63,094	62,380
1	424,788	141,492	64,158	62,945	62,201
2	283,296	99,994	64,113	62,858	62,088
3	183,302	68,312	64.096*	62,804	62,012
4	114,991	43,950	64,097	62,775	61,964
5	71,041	39,126	64,108	62,762	61,936
6	31,914	19.014*	64,111	62,746	61,909
7	12.901*	12,901	64,119	62,742	61,898
8	-	-	64,120	62.737*	61.889*

Hour 9					
Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	597,818	217,247	60,364	59,199	58,485
1	380,570	148,266	60,258	59,044	58,301
2	232,305	81,106	60.206*	58,951	58,181
3	151,198	58,048	60,208	58,916	58,124
4	93,150	38,639	60,219	58,897	58,086
5	54,511	25.712*	60,236	58,889	58,064
6	28,799	16,197	60,251	58,887	58,050
7	12.602*	12,602	60,263	58,886	58,042
8	-	-	60,264	58.881*	58.033*

Hour 10					
Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	565,339	208,514	61,020	59,855	59,141
1	356,825	160,017	60,922	59,709	58,965
2	196,808	74,252	60.859*	59,603	58,834
3	122,556	41,207	60,868	59,576	58,784
4	81,349	32.168*	60,895	59,573	58,762
5	49,181	22,453	60,919	59,572	58,746
6	26,728	15,931	60,937	59,573	58,736
7	10.797*	10,797	60,949	59,572	58,728
8	-	-	60,952	59.569*	58.721*

Hour 11					
Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	533,174	201,524	60,540	59,375	58,661
1	331,651	146,348	60,449	59,236	58,492
2	185,303	66,478	60.400*	59,144	58,374
3	118,825	47,130	60,416	59,124	58,332
4	71,695	28.394*	60,438	59.116*	58,305
5	43,301	22,354	60,465	59,118	58,293
6	20.947*	13,731	60,484	59,119	58,282
7	7,215	7,215	60,498	59,121	58,277
8	-	-	60,504	59,121	58.273*

Hour 12					
Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	545,793	200,377	59,237	58,073	57,359
1	345,416	148,560	59,148	57,935	57,191
2	196,856	65,764	59.096*	57,841	57,071
3	131,092	54,265	59,113	57,821	57,029
4	76,827	31.784*	59,128	57,806	56,995
5	45,043	24,209	59,152	57,805	56,979
6	20.834*	14,466	59,169	57.804*	56,967
7	6,368	6,368	59,182	57,805	56,961
8	-	-	59,189	57,806	56.959*

Hour 13

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	512,984	189,915	56,243	55,078	54,364
1	323,069	105,692	56,163	54,950	54,207
2	217,378	78,576	56.155*	54,899	54,129
3	138,802	56,339	56,159	54,867	54,075
4	82,463	34,873	56,172	54,849	54,039
5	47,590	26,905	56,192	54,845	54,020
6	20.685*	14.510*	56,207	54.842*	54,005
7	6,175	6,175	56,220	54,843	53,999
8	-	-	56,227	54,844	53.996*

Hour 14

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	507,318	184,508	55,739	54,574	53,860
1	322,810	97,351	55,665	54,452	53,708
2	225,459	70,853	55.665*	54,409	53,639
3	154,607	54,355	55,677	54,385	53,593
4	100,252	47,415	55,691	54,369	53,558
5	52,837	29,710	55,699	54,353	53,527
6	23.128*	15.004*	55,711	54.346*	53,509
7	8,124	8,124	55,724	54,346	53,503
8	-	-	55,729	54,346	53.498*

Hour 15

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	531,898	195,125	57,605	56,440	55,727
1	336,773	105,620	57,521	56,308	55,564
2	231,153	80,357	57.512*	56,256	55,487
3	150,796	53,324	57,515	56,223	55,431
4	97,472	44,323	57,531	56,208	55,398
5	53,149	28,845	57,541	56,195	55,369
6	24.305*	16.339*	57,554	56,189	55,353
7	7,966	7,966	57,565	56,188	55,344
8	-	-	57,571	56.188*	55.340*

Hour 16

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	469,425	182,034	55,792	54,627	53,913
1	287,391	89,259	55.721*	54,507	53,764
2	198,132	65,072	55,728	54,472	53,703
3	133,059	49,023	55,746	54,454	53,662
4	84,037	33,743	55,766	54,443	53,633
5	50,294	26.163*	55,787	54,441	53,615
6	24.131*	14,939	55,803	54,438	53,601
7	9,192	9,192	55,815	54,438	53,594
8	-	-	55,820	54.437*	53.589*

Hour 17

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	461,447	182,716	55,445	54,280	53,566
1	278,730	83,662	55.373*	54,160	53,416
2	195,068	67,983	55,386	54,131	53,361
3	127,085	48,503	55,401	54,109	53,317
4	78,582	31.847*	55,422	54,099	53,289
5	46,735	23,490	55,445	54,098	53,273
6	23.245*	14,191	55,463	54,098	53,261
7	9,054	9,054	55,476	54,099	53,255
8	-	-	55,481	54.098*	53.250*

Hour 18

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	483,731	210,264	56,750	55,585	54,871
1	273,467	96,813	56,650	55,437	54,694
2	176,655	58,907	56.650*	55,395	54,625
3	117,748	55,535	56,674	55,382	54,590
4	62,213	24.222*	56,688	55.365*	54,555
5	37.991*	16,624	56,719	55,372	54,547
6	21,367	14,691	56,744	55,379	54,542
7	6,675	6,675	56,757	55,379	54,535
8	-	-	56,764	55,380	54.533*

Hour 19

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	522,342	206,571	58,793	57,628	56,914
1	315,771	95,214	58.697*	57,484	56,740
2	220,557	79,218	58,699	57,443	56,673
3	141,338	58,135	58,702	57,410	56,618
4	83,204	35,089	58,713	57,391	56,580
5	48,115	26.001*	58,733	57,387	56,561
6	22.113*	15,874	58,749	57,384	56,547
7	6,239	6,239	58,760	57.383*	56,539
8	-	-	58,768	57,385	56.537*

Hour 20

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	439,187	166,117	57,102	55,937	55,223
1	273,069	77,258	57.047*	55,833	55,090
2	195,811	73,917	57,066	55,810	55,041
3	121,894	43,426	57,075	55,783	54,991
4	78,468	29.226*	57,101	55,778	54,968
5	49,242	21,829	57,127	55,780	54,955
6	27,413	15,417	57,146	55,781	54,945
7	11.996*	11,996	57,158	55,781	54,937
8	-	-	57,160	55.777*	54.929*

Hour 21

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	400,227	169,691	55,159	53,995	53,281
1	230,536	75,487	55.101*	53,887	53,144
2	155,049	51,916	55,122	53,866	53,096
3	103,133	41,513	55,153	53,861	53,069
4	61,620	23.125*	55,180	53.858*	53,047
5	38.496*	15,486	55,212	53,865	53,040
6	23,009	12,647	55,238	53,873	53,037
7	10,363	10,363	55,253	53,876	53,032
8	-	-	55,256	53,873	53.026*

Hour 22

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	393,603	191,235	53,146	51,981	51,268
1	202,368	71,065	53.066*	51,853	51,109
2	131,304	42.800*	53,091	51.836*	51,066
3	88,504	32,838	53,131	51,839	51,047
4	55.666*	21,674	53,168	51,845	51,035
5	33,992	13,916	53,201	51,854	51,029
6	20,076	12,574	53,228	51,864	51,027
7	7,501	7,501	53,243	51,866	51,022
8	-	-	53,250	51,867	51.019*

Hour 23

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	436,515	216,225	51,324	50,159	49,445
1	220,291	65,755	51.219*	50,005	49,262
2	154,535	50,413	51,249	49,994	49,224
3	104,123	44,375	51,282	49,990	49,198
4	59.747*	30.115*	51,307	49.984*	49,174
5	29,633	13,409	51,332	49,985	49,159
6	16,223	9,565	51,360	49,995	49,158
7	6,659	6,659	51,378	50,001	49,157
8	-	-	51,385	50,002	49.154*

Hour 24

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	417,642	199,404	51,382	50,218	49,504
1	218,239	63,924	51.294*	50,081	49,337
2	154,314	55,556	51,327	50,071	49,301
3	98,758	39.254*	51,354	50,062	49,270
4	59.505*	25,230	51,384	50.061*	49,251
5	34,275	17,424	51,413	50,067	49,241
6	16,851	9,396	51,437	50,073	49,236
7	7,455	7,455	51,456	50,079	49,235
8	-	-	51,462	50,079	49.231*

In detail, the maximum eigenvalue test indicates a lower number of cointegration relationship than the one suggested by trace statistics, for all the hours but 4 (13^{th} -15^{th} and 23^{rd}) where the tests agree. BIC criterion suggests a number of cointegrating relationships low (generally 1 or 2) and always lower than the one indicated by the other methods; on the other hand, HQ indicates a large number of cointegrating relationship, in some hour (2^{nd}-10^{th}; 15^{th}-17^{th} and 20^{th}) equal to 8, suggesting the stationarity of the variables included[27]. Finally, the decision has been based on the trace statistics, both because information criteria methodology is not widespread and because maximum eigenvalue shows multiple-testing problem. Since the trace test indicates that the series are cointegrated, the number of cointegrating equations is imposed in the VEC model. Cointegration implies that the variables in the system share at list one common trend and this finding is in line with previous literature on European market integration that have highlighted the presence of cointegration among national markets.

Summarizing, for hours from 22^{nd} to 24^{th}, 4 relations are imposed; 5 for hours 18^{th} and 21^{st} ; 6 for hours 1^{st}, 6^{th}, from 11^{th} to 17^{th} and 19^{th} and 7 for the hours from 2^{nd} to 5^{th}, from 7^{th} to 10^{th} and 20^{th}. Therefore, under the unit root hypothesis, 24 VEC models have been set, including in the term $\Pi\, \boldsymbol{p_{t-1}}$ the cointegrating relationships:

$$\Delta \boldsymbol{p_t} = A + \Pi\, \boldsymbol{p_{t-1}} + B_1\, \Delta\, \boldsymbol{p_{t-1}} + \cdots + B_{n-1}\, \Delta \boldsymbol{p_{t-n+1}} + \Gamma \boldsymbol{d_t} + \boldsymbol{\varepsilon_t} \tag{6.11}$$

where $\Delta \boldsymbol{p_t}$ is a vector (8x1) that contains the differenced prices of the eight countries at time *t*, $\Delta \boldsymbol{p_{t-1}} \ldots \Delta \boldsymbol{p_{t-n}}$ are the vectors of the differenced prices of the previous n days, where *n*=7 according to the underlying VAR process, Π (8x8) the matrix of long term relationship, $\boldsymbol{p_{t-1}}$ is a vector (8x1) of lagged price, $\boldsymbol{d_t}$ is a vector (6x1) of dummy variables for the day of the week**,** $\boldsymbol{\varepsilon_t}$ is the vector of residuals.

Also in this case, the model has been extended including an exogenous variable, the load, in first difference, represented by variable $\Delta \boldsymbol{z_t}$ in the general equation

$$\Delta \mathbf{p_t} = \mathrm{A} + \Pi\, \mathbf{p_{t-1}} + \mathrm{B}_1\, \Delta\, \mathbf{p_{t-1}} + \cdots + \mathrm{B}_{n-1}\, \Delta \mathbf{p_{t-n+1}} + \Theta \Delta \mathbf{z_t} + \Gamma \mathbf{d_t} + \boldsymbol{\varepsilon}_\mathbf{t} \tag{6.12}$$

[27] The same indication arises from AIC.

Appendix B

Table B.1: Lag selection VAR-X models

Hour 1

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31414,5		53,9512	54,1473	54,471
1	-29873,6	3081,8	51,4244	51,7251	52,2215*
2	-29684,2	378,74	51,2099	51,6151*	52,2842
3	-29594,2	180,05	51,1654	51,6752	52,5169
4	-29525,9	136,59	51,1581	51,7724	52,7868
5	-29443	165,74	51,1258	51,8447	53,0318
6	-29361,9	162,24	51,0965	51,92	53,2797
7	-29288,6	146,58*	51,0806*	52,0086	53,5411

Hour 2

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31179,3		53,5489	53,745	54,0687
1	-29547,9	3263	50,8672	51,1678	51,6642*
2	-29373	349,8	50,6774	51,0826*	51,7517
3	-29286,4	173,08	50,6389*	51,1486	51,9904
4	-29238,3	96,29	50,666	51,2803	52,2948
5	-29174,7	127,21	50,6667	51,3856	52,5727
6	-29101,5	146,32	50,651	51,4745	52,8343
7	-29036	131,11*	50,6484	51,5764	53,1088

Hour 3

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31557,1		54,1952	54,3913	54,715
1	-29888,9	3336,4	51,4507	51,7513	52,2477*
2	-29761,1	255,56	51,3416	51,7468*	52,4159
3	-29679,2	163,97	51,3108	51,8206	52,6623
4	-29613,5	131,25	51,308	51,9223	52,9368
5	-29561,6	103,91	51,3286	52,0475	53,2346
6	-29477,3	168,65	51,2938	52,1173	53,4771
7	-29373,9	206,68*	51,2265*	52,1546	53,687

Hour 4

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31619,5		54,3019	54,498	54,8218
1	-29804,9	3629,2	51,3069	51,6076	52,104*
2	-29665,2	279,37	51,1774	51,5826*	52,2517
3	-29600,2	130,1	51,1756	51,6854	52,5272
4	-29533,6	133,05	51,1713	51,7857	52,8001
5	-29465,4	136,45	51,1641	51,883	53,0701
6	-29379,4	172,03	51,1264	51,9499	53,3097
7	-29283,2	192,39*	51,0713*	51,9994	53,5318

Hour 5

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31533,7		54,1552	54,3513	54,6751
1	-29956,7	3154,2	51,5666	51,8672	52,3636*
2	-29790,5	332,25	51,3919	51,7971*	52,4661
3	-29725,1	130,95	51,3893	51,8991	52,7409
4	-29650,8	148,54	51,3718	51,9861	53,0005
5	-29590,5	120,62	51,3781	52,097	53,2841
6	-29483,5	213,98	51,3045	52,128	53,4878
7	-29398,6	169,84*	51,2687*	52,1968	53,7292

Hour 6

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31553,9		54,1897	54,3857	54,7095
1	-30040,2	3027,3	51,7095	52,0101	52,5066*
2	-29883,6	313,17	51,5511	51,9563*	52,6254
3	-29799,9	167,4	51,5174	52,0272	52,8689
4	-29726,4	147,02	51,5011	52,1155	53,1299
5	-29620,5	211,78	51,4295	52,1484	53,3355
6	-29498,3	244,49	51,3298	52,1533	53,513
7	-29376,4	243,69*	51,2308*	52,1589	53,6913

Hour 7

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32294,4		55,4567	55,6527	55,9765
1	-31177,6	2233,7	53,6554	53,956	54,4525*
2	-30981,8	391,51	53,43	53,8352	54,5043
3	-30832,6	298,55	53,2841	53,7939	54,6356
4	-30755,3	154,58	53,2614	53,8757	54,8901
5	-30672,2	166,09	53,2288	53,9477	55,1348
6	-30504,3	335,85	53,051	53,8745	55,2342
7	-30329,4	349,82*	52,8612*	53,7893*	55,3217

Hour 8

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-36138,2		62,0328	62,2289	62,5526
1	-35289,1	1698,1	60,6897	60,9903	61,4867*
2	-35127,5	323,17	60,5227	60,9279	61,597
3	-34955,8	343,46	60,3384	60,8482*	61,6899
4	-34885,6	140,47	60,3277	60,9421	61,9565
5	-34833,1	104,88	60,3475	61,0664	62,2535
6	-34686,4	293,46	60,206	61,0295	62,3892
7	-34480,8	411,13*	59,9638*	60,8918	62,4243

Hour 9

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-34183,2		58,6881	58,8842	59,208
1	-33299,5	1767,4	57,2857	57,5863	58,0828
2	-32987,5	624,05	56,8614	57,2666	57,9357*
3	-32856,6	261,67	56,747	57,2568	58,0986
4	-32729,3	254,61	56,6387	57,2531	58,2675
5	-32634,9	188,82	56,5867	57,3056	58,4927
6	-32521,9	226,02	56,5028	57,3263	58,6861
7	-32296,3	451,19*	56,2264*	57,1544*	58,6869

Hour 10

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-34828,5		59,7921	59,9881	60,3119
1	-33882,6	1891,7	58,2833	58,5839	59,0804
2	-33484,6	796	57,7119	58,1171	58,7862*
3	-33328,9	311,35	57,555	58,0648	58,9066
4	-33204,4	248,94	57,4516	58,0659	59,0803
5	-33088,6	231,63	57,3629	58,0818	59,2689
6	-32958,6	259,99	57,25	58,0735	59,4333
7	-32820,9	275,52*	57,1238*	58,0519*	59,5843

Hour 11

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-34916,5		59,9427	60,1388	60,4625
1	-33803,8	2225,3	58,1486	58,4492	58,9456
2	-33383,3	841,01	57,5386	57,9438	58,6129*
3	-33237,6	291,46	57,3988	57,9086	58,7503
4	-33104,8	265,71	57,281	57,8954	58,9098
5	-32988,9	231,74	57,1923	57,9112	59,0983
6	-32846,9	283,91	57,0589	57,8824	59,2421
7	-32690,4	313,07*	56,9006*	57,8286*	59,3611

Hour 12

Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-34116		58,5731	58,7692	59,0929
1	-32844,9	2542,1	56,508	56,8086	57,3051*
2	-32637,1	415,73	56,2619	56,6671	57,3362
3	-32508,4	257,37	56,1512	56,661	57,5027
4	-32379,2	258,33	56,0397	56,6541*	57,6685
5	-32295,7	166,97	56,0064	56,7253	57,9124
6	-32163,2	265	55,8892	56,7127	58,0724
7	-32027,2	272,05*	55,766*	56,694	58,2264

* Selected lag

Hour 13					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32263,3		55,4034	55,5994	55,9232
1	-31056,8	2413	53,4487	53,7494	54,2458*
2	-30864,3	384,93	53,2289	53,6341	54,3032
3	-30740,2	248,26	53,1261	53,6358	54,4776
4	-30625,9	228,49	53,0401	53,6544	54,6689
5	-30538,6	174,72	53,0001	53,719	54,9061
6	-30390,3	296,55	52,856	53,6794	55,0392
7	-30203,8	373,08*	52,6463*	53,5743*	55,1068

Hour 14					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31884,2		54,7548	54,9509	55,2746
1	-30709,4	2349,5	52,8544	53,1551	53,6515*
2	-30508,6	401,68	52,6203	53,0255	53,6946
3	-30355,3	306,44	52,4677	52,9774	53,8192
4	-30259	192,69	52,4123	53,0267	54,0411
5	-30191,4	135,12	52,4062	53,1251	54,3122
6	-29979,5	423,83	52,1532	52,9766	54,3364
7	-29829,7	299,73*	52,0063*	52,9343*	54,4667

Hour 15					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32969,3		56,6113	56,8073	57,1311
1	-31721,9	2494,8	54,5866	54,8873	55,3837*
2	-31547,4	348,99	54,3976	54,8028	55,4719
3	-31364,5	365,75	54,1942	54,704	55,5457
4	-31266	196,98	54,1352	54,7495	55,764
5	-31160,8	210,47	54,0647	54,7836	55,9707
6	-31001,5	318,56	53,9016	54,7251	56,0849
7	-30859,5	284,12*	53,7681*	54,6961*	56,2286

Hour 16					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32018,7		54,985	55,1811	55,5048
1	-30743,8	2549,8	52,9133	53,214	53,7104*
2	-30521,3	445,18	52,642	53,0472	53,7163
3	-30378,6	285,24	52,5075	53,0173	53,859
4	-30288,1	181,05	52,4621	53,0765	54,0909
5	-30196,5	183,23	52,4149	53,1338	54,3209
6	-30004,1	384,84	52,1952	53,0186	54,3784
7	-29850,6	307,03*	52,042*	52,9701*	54,5025

Hour 17					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31910,1		54,7991	54,9952	55,3189
1	-30511,5	2797,1	52,5159	52,8165	53,3129*
2	-30320,5	381,97	52,2986	52,7038	53,3729
3	-30189,2	262,73	52,1834	52,6931	53,5349
4	-30093,8	190,73	52,1297	52,744	53,7585
5	-29983,1	221,38	52,0498	52,7687	53,9558
6	-29812,4	341,36	51,8673	52,6908	54,0505
7	-29669,9	285,1*	51,7329*	52,661*	54,1934

Hour 18					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32679,9		56,1162	56,3122	56,636
1	-31196,3	2967,2	53,6874	53,988	54,4844*
2	-30972,5	447,56	53,414	53,8192*	54,4883
3	-30855,4	234,26	53,3231	53,8329	54,6747
4	-30754,7	201,41	53,2603	53,8747	54,8891
5	-30650,2	208,99	53,191	53,91	55,0971
6	-30547,7	204,84	53,1253	53,9488	55,3086
7	-30434,5	226,54*	53,041*	53,9691	55,5015

Hour 19					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-33928,6		58,2526	58,4487	58,7724
1	-32542,1	2773,1	55,9899	56,2905	56,7869
2	-32237,7	608,82	55,5786	55,9838	56,6529*
3	-32076,1	323,25	55,4116	55,9213	56,7631
4	-31936	280,1	55,2815	55,8958	56,9102
5	-31809,2	253,61	55,174	55,8929*	57,08
6	-31694,5	229,31	55,0873	55,9108	57,2706
7	-31580,5	228,09*	55,0017*	55,9298	57,4622

Hour 20					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32886,9		56,4704	56,6664	56,9902
1	-31523,1	2727,7	54,2465	54,5472	55,0436
2	-31277	492,28	53,9349	54,3401*	55,0092*
3	-31156,4	241,07	53,8382	54,348	55,1897
4	-31050,5	211,91	53,7664	54,3807	55,3952
5	-30956,5	187,84	53,7152	54,4341	55,6212
6	-30786,2	340,68	53,5333	54,3568	55,7165
7	-30659,8	252,84*	53,4265*	54,3545	55,887

Hour 21					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32113		55,1463	55,3424	55,6661
1	-30436,6	3352,8	52,3877	52,6883	53,1848*
2	-30257,5	358,22	52,1908	52,596	53,2651
3	-30114	286,92	52,0548	52,5646*	53,4063
4	-30026,6	174,78	52,0148	52,6291	53,6436
5	-29938,4	176,55	51,9733	52,6922	53,8793
6	-29797	282,75	51,8409	52,6644	54,0241
7	-29689,1	215,82*	51,7658*	52,6938	54,2262

Hour 22					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31202,9		53,5892	53,7853	54,109
1	-29254	3897,7	50,3645	50,6651	51,1615*
2	-29075,1	357,95	50,1678	50,573	51,242
3	-28945,2	259,63	50,0552	50,5649*	51,4067
4	-28850,4	189,64	50,0024	50,6168	51,6312
5	-28766,6	167,56	49,9686	50,6875	51,8746
6	-28646,4	240,46	49,8724	50,6959	52,0556
7	-28534,5	223,81*	49,7904*	50,7185	52,2509

Hour 23					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-30175,8		51,832	52,0281	52,3519
1	-28267,3	3817	48,6763	48,977	49,4734*
2	-28091,2	352,24	48,4845	48,8897*	49,5588
3	-27982,5	217,43	48,408	48,9178	49,7596
4	-27901,5	162,07	48,3789	48,9932	50,0076
5	-27817,8	167,25	48,3453	49,0642	50,2513
6	-27710,4	214,89	48,271	49,0944	50,4542
7	-27610,5	199,82*	48,2095*	49,1376	50,67

Hour 24					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-30304		52,0514	52,2474	52,5712
1	-28321,1	3965,8	48,7684	49,069	49,5655*
2	-28120,1	402,07	48,534	48,9392	49,6083
3	-27973,8	292,64	48,3931	48,9029*	49,7446
4	-27890,6	166,39	48,3603	48,9746	49,989
5	-27801,8	177,54	48,3179	49,0368	50,2239
6	-27702,7	198,22	48,2578	49,0813	50,4411
7	-27611,2	182,91*	48,2109*	49,1389	50,6713

* Selected lag

7 Day ahead electricity price forecasting

The present work proposes a multiple time series approach in forecasting hourly day ahead electricity prices. The presented set attempts to fill the gap between two strands of the empirical literature on electricity prices which have so far developed independently of each other, the forecasting literature and the market integration one.

Multiple time series model can account for the presence of interdependency between the analyzed markets and, especially under the hypothesis of unit root variables, the imposition of cointegrating relationships in the model allows accounting for the market integration process. In such a way, the adopted approach enlarges the information used in the models, so may lead to better forecasting performance comparing to those got from simple time series.

In the following sections, the specified model are used for short term forecasting, also providing a comparison between the forecasting performances obtained from these models and the one coming from benchmark simple time series models. The forecasting exercise has been performed both on the original dataset and after a pre-filtering procedure aimed to detect and substitute extreme spikes in the considered time series. Moreover, in the last paragraph multiple time series forecast are made conditional on potential future trends of the exogenous variable included in the model.

7.1 Short term forecasting

This section proposes a comprehensive comparison between the forecasting performances of simple time series models, traditionally suggested in the empirical literature to forecast day ahead electricity prices, and the ones of multiple time series models able to capture the possible dynamic interactions or even cointegration between day ahead electricity markets of countries increasingly integrated. As previous discussed, two hypotheses are considered: on the one hand stationarity of the series and on the other hand the presence of unit root.

7.1.1 Models setting

Under the first hypothesis, the 24 VAR models (specified in section 6.2.2) are applied. Moreover, 192 autoregressive models (AR) have been estimated, as a benchmark reference, one for each hour of the day and for each of the eight countries considered. In these models, lag order is selected through information criteria, fixing seven as maximum lag order, again preferring AIC criterion in case of not unanimous indications. As explained above, this choice is related to the importance of incorporating high autocorrelation order in modeling electricity prices, as shown by Knittel and Roberts (2005). For model checking Ljung & Box (1978) portmanteau test is performed. When the null hypothesis of no remaining residual autocorrelation is rejected, a larger order is introduced.[28] The benchmark simple time series model set for each hour and for each country is:

$$p_t = \alpha + \beta_1 p_{t-1} + \cdots + \beta_n p_{t-n} + \Gamma \boldsymbol{d_t} + \varepsilon_t \tag{7.1}$$

where p_t is the price at time t, α is a constant, p_{t-1} ... p_{t-n} are the prices of previous days, n is the selected lag order, $\boldsymbol{d_t}$ is a vector (6x1) of dummy variables for the day of the week**,** ε_t is the error term.

In a similar way, under the unit root hypothesis, the 24 VEC models specified in section 6.2.2 are applied and 192 benchmark autoregressive models have been specified one for each hour of the day and each country, using variables in first difference, due to the I(1) hypothesis.
Moreover, also each simple time series model has been extended including the load.

Summing up, under the hypothesis of stationarity of day ahead electricity price time series the following models have been specified:

- 24 VAR models, one for each hour of the day
- 192 AR benchmark simple time series model, one for each hour of the day (24) and each considered country (8)
- 24 VAR-X models, including load as exogenous variable
- 192 AR-X models, including load as exogenous variable.

Under the hypothesis of non stationarity of day ahead electricity price time series the following models have been specified:

- 24 VEC models, one for each hour of the day
- 192 ARI benchmark simple time series model, one for each hour of the day (24) and each considered country (8)
- 24 VEC-X models, including load as exogenous variable
- 192 ARI-X models, including load as exogenous variable.

Each model has been used to make one step ahead forecast in a four weeks out-of-sample interval, given the daily frequency of data. The dataset has been split into an in-sample period running from October 1st, 2010 to June 30th, 2013 and an out-of-sample period from July 1st to July 29th, 2013. All the models have been estimated using a recursive scheme. The model structures are

[28] A larger lag order is introduced for EPEXCH price hour 7th both in the AR and in the AR-X model, EPEXCH price hour 8th in the AR model, BELPEX price hour 8th and IPEX price hour 23th in the ARI and ARI-X models, and EPEXFR price hours 9th -12th in the ARI-X model.

the same throughout all the forecasting period, but every day the model coefficients have been estimated again using all the past values of the variables included. For an illustrative purpose, for a AR model, forecasts for the day *t+1* are obtained using:

$$p_{t+1} = \hat{\alpha}_t + \hat{\beta}_{1,t}\, p_t + \cdots + \hat{\beta}_{n,t}\, p_{t-n+1} + \hat{\Gamma}_t \boldsymbol{d}_{\boldsymbol{t+1}} \tag{7.2}$$

where the hat values are the parameters estimated with all the available information at the present day *t*.

A comparison of the forecasting performance of all the estimated models has been carried. Given the peculiar data features, as described in the preliminary analysis, three measures of forecast accuracy have been provided: Mean Absolute Percentage Error (MAPE), Symmetric Mean Absolute Percentage Error (SMAPE) and Root Mean Square Error (RMSE) loss functions. MAPE is defined as the average absolute difference between the actual value (A_t) and the forecasted value (F_t) divided by the actual value:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_{t-}F_t}{A_t}\right|$$

MAPE is widely used in forecasting literature, but it could provide misleading results when electricity prices drop to zero, since MAPE value becomes very large, due to the presence of price at the denominator. This issue can be overcome using SMAPE with the mean of forecasted value and the true one at the denominator:

$$SMAPE = 2\frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_{t-}F_t}{A_t + F_t}\right|$$

Moreover, for a comparison purposes, a scale dependent measure RMSE has been computed. RMSE represents the sample standard deviation of the differences between predicted values and observed values:

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}(A_{t-}F_t)^2}{n}}$$

It is important remind that RMSE is sensitive to outliers (Hyndman and Koehler, 2006).

7.1.2 Results

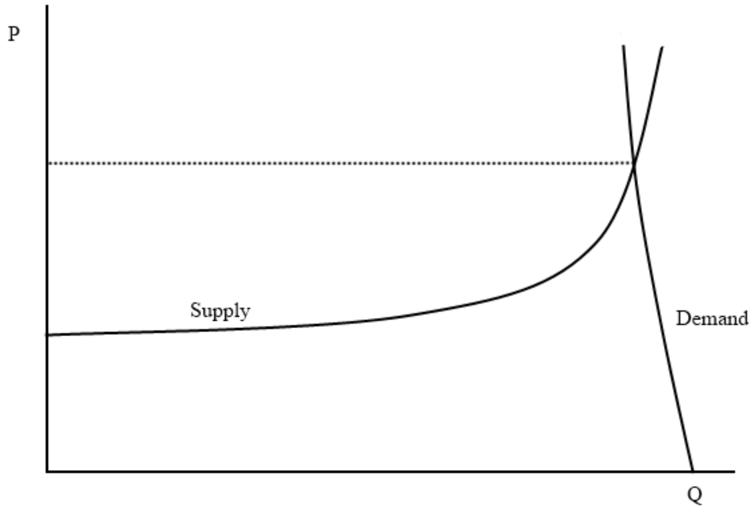
A comprehensive comparison of forecasting results on the out-of-sample period highlights that all forecasting performance indicators lead to the same qualitative findings.

Figure 7.1: Average hourly RMSE (€/MWh)

The average loss function for the whole out of sample period for each hour of the day indicates a higher forecasting error for the hours with higher load, independently from the chosen indicator (in **Figure 7.1** RMSE is used). In these hours errors are larger due to the higher price volatility. This origins from the structure of the market itself; in detail, the supply curve becomes steeper toward the right, with the typical convex ‘hockey stick’ shape. The “more expensive” plants are requested to produce only for higher load value. Due to this, small variation of the demand can lead to larger price variation (**Figure 7.2**).

Moreover, the volatility is exacerbated in this part of the supply curve, since it is possible for the market operator to exercise market power, because there is low demand elasticity and the other suppliers are not able to increase their production, as it is instead possible in the first steps of the supply function (Borenstein, 2002).

Figure 7.2: Supply and demand structure



Source: Borenstein, 2002, p.197

The SMAPE measures for the out-of-sample period (from July 1st to July 29th, 2013) are displayed in the **Table 7.2**, **Table 7.3**, **Table 7.4** and **Table 7.5**. Multiple time series model forecasting performance and simple time series ones are compared: the best result for each hour is in bold. The tables reporting MAPE and RMSE values are in the Appendix C of the present chapter.

MAPE and SMAPE indicators almost always have the same size, with the most significant difference being observed when forecasts of Austrian day ahead electricity prices are performed for the hours between the 14th and the 17th. In these time period the out-of-sample interval indeed includes some zero or close-to-zero Austrian day ahead electricity prices, so the MAPE indicator tends to explode because of its very nature. However, extreme MAPE values turn into lower, though still high, SMAPE values and therefore also this second indicator highlights a relatively worse forecasting performance in the case of Austrian day ahead electricity prices for the hours between the 14th and the 17th. Regardless of the estimated model, when considering all the hours of the day a SMAPE value of 12% is obtained on average, while when the analysis is limited to the hours between the 14th and the 17th the average SMAPE value rises to 22%. Moreover, relatively higher MAPE and SMAPE values have been obtained in the case of both Belgian and French prices. In particular, in these countries the SMAPE indicator is close to 30% or even exceed this value for some specific hours or intervals (for example the 8th hour for Belgium and the hours from the 9th to the 12th for France). These relatively poor MAPE and SMAPE values have been achieved in these special hours for Belgium and France due to the presence in the corresponding in-sample intervals of extremely marked price spikes as shown by simple summary statistics. This feature directly impacts on the estimated coefficients. No estimated model indeed includes jump components or regime switching, although the literature has ascertained that these features can improve forecasting performance in presence of extremely marked price spikes. When these specific hours are not considered, SMAPE values around 18% are reached for Belgium and France.

Generally speaking, better forecasting performances are obtained for the remaining countries. The MAPE and SMAPE indicators indeed reach average values of 13% for Germany and Slovenia, 11% for the Netherlands and Switzerland and 9% for Italy when all the hours of the day are considered and regardless of the estimated model (**Table 7.1**).

Table 7.1: The average SMAPE errors in percentages for all the hours of the day (%)

	Austria	Belgium	France	Germany	Italy	Netherland	Slovenia	Switzerland
AR	11,77	20,24	18,47	12,48	8,89	10,87	12,46	10,67
AR-X	11,15	19,79	17,34	12,60	8,70	10,68	12,47	10,78
VAR	11,75	19,84	24,38	12,97	8,79	10,97	13,75	11,44
VAR-X	12,99	20,66	47,31	13,42	8,75	11,40	14,53	12,35
ARI	12,10	19,43	17,43	12,59	9,16	11,00	13,14	10,13
ARI-X	11,47	19,85	17,22	12,64	8,71	10,71	13,08	10,40
VEC	11,83	19,70	24,26	13,44	9,01	11,05	13,97	11,69
VEC-X	10,98	19,53	28,25	13,49	8,90	11,30	14,27	10,98

Forecasting results also show that multiple time series models do not necessarily improve forecasting performances compared with those obtained from simple time series models.

More specifically, under the assumption that all the price series are stationary, VAR models result in better forecasting performances compared with AR models in 74 cases, approximately 40% of combinations between hours of the day and countries. However, this value decreases to 39 cases, just over 20% when both VAR models and AR models are extended to the corresponding VAR-X models and AR-X models, by introducing exogenous variables. Under the assumption that all the price series contain unit roots, VEC models outperform ARI models in 89 cases, equal to 46% of combinations between hours of the day and countries and a similar value (85 cases, equal to 44%) is obtained when exogenous variables are added and VEC-X and ARI-X models are compared.

Table 7.2: SMAPE errors from AR and VAR models (%)

				AR				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**5,96**	19,79	**12,58**	7,07	**4,92**	**18,57**	**7,82**	**10,01**
2	**6,71**	18,62	16,94	**10,34**	6,47	11,42	**7,46**	**9,83**
3	**7,04**	20,27	**20,34**	**10,32**	7,71	8,05	**7,38**	**8,29**
4	8,21	**27,80**	**26,96**	**11,64**	9,65	**8,89**	**8,90**	9,27
5	**7,21**	**28,06**	**26,39**	**11,45**	9,63	**10,29**	**9,28**	**7,64**
6	**7,29**	20,15	18,61	**14,61**	**8,55**	**8,85**	**9,90**	6,31
7	**8,59**	**20,40**	18,65	**11,88**	**7,42**	11,04	**11,38**	**8,46**
8	**9,30**	47,79	**17,76**	**11,79**	**6,94**	9,66	15,13	**9,58**
9	**9,02**	**16,04**	**19,60**	**9,79**	**9,41**	**9,23**	**16,96**	**9,60**
10	11,91	**19,68**	**23,11**	13,52	9,03	**10,20**	**15,00**	**10,69**
11	14,55	20,59	**27,55**	16,50	9,60	10,78	**13,72**	13,21
12	17,38	22,70	**24,55**	18,11	11,28	**8,12**	**10,63**	14,02
13	17,47	18,88	19,39	18,66	11,88	**10,28**	**10,18**	**16,22**
14	23,46	19,62	18,88	18,41	15,71	**9,93**	**11,81**	**16,08**
15	22,58	**21,66**	19,50	20,09	15,91	**9,38**	**13,13**	**16,93**
16	21,68	19,07	17,03	**17,38**	13,50	**9,94**	**16,85**	**16,47**
17	21,76	**15,51**	**13,30**	**13,60**	**9,92**	**11,35**	**18,88**	**16,12**
18	**13,25**	**16,80**	**15,69**	**11,59**	**8,13**	14,13	**19,58**	**12,60**
19	**10,68**	**15,42**	**14,64**	**9,43**	**5,69**	**12,02**	15,53	**9,65**
20	7,86	17,57	16,22	7,72	6,96	10,76	7,51	7,48
21	9,27	19,84	18,97	**9,93**	**5,98**	11,86	11,40	7,85
22	**7,06**	**17,78**	17,75	**9,29**	**8,93**	**9,38**	**16,57**	**6,24**
23	7,86	**11,29**	9,76	**9,57**	**5,80**	**9,83**	**12,33**	6,87
24	**6,37**	**10,39**	**9,03**	**6,83**	**4,33**	**17,03**	**11,71**	**6,57**
				VAR				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	6,67	**18,71**	12,81	**6,96**	5,65	18,73	9,08	11,30
2	7,09	**16,64**	**16,76**	11,28	**6,23**	**11,33**	9,47	10,42
3	8,19	**18,21**	21,78	11,58	**7,27**	**7,80**	7,90	9,23
4	**7,44**	28,59	28,01	15,28	**9,03**	9,40	10,10	**7,99**
5	8,12	30,59	26,80	12,00	**9,33**	10,53	9,58	8,62
6	8,57	**19,36**	**17,21**	15,54	8,64	9,13	10,92	**6,16**
7	8,96	22,16	**18,40**	13,52	7,72	**10,50**	12,43	9,38
8	10,58	**39,25**	19,63	16,03	7,74	**9,64**	**14,96**	11,53
9	9,52	17,09	33,80	11,87	10,29	9,94	20,26	9,82
10	**11,58**	20,31	76,49	**12,10**	**8,63**	10,80	17,62	10,76
11	**12,18**	**19,96**	93,81	**14,22**	**9,25**	**8,58**	14,54	**12,85**
12	**14,83**	**21,04**	33,86	**16,39**	**10,29**	8,46	10,71	**13,28**
13	**15,31**	**16,22**	**17,56**	**16,54**	**10,96**	10,45	12,49	16,66
14	**22,84**	**18,53**	**16,90**	**17,12**	**13,89**	11,63	12,75	18,54
15	**22,09**	22,17	**16,74**	**17,27**	**14,82**	10,89	15,81	18,34
16	**21,10**	**18,78**	**16,98**	17,66	**12,22**	10,29	21,66	19,91
17	**21,70**	15,77	14,49	14,74	11,16	11,37	22,61	19,90
18	15,32	21,04	17,59	14,20	9,04	**13,59**	22,45	14,67
19	12,69	16,49	16,80	10,83	5,84	12,09	**14,68**	10,30
20	**7,42**	**16,40**	**15,24**	**6,44**	**6,17**	**9,97**	**6,74**	**6,89**
21	**8,63**	**18,31**	**18,17**	10,72	6,11	**11,73**	**10,63**	**7,54**
22	7,16	18,25	**16,80**	10,07	9,53	9,39	17,38	7,23
23	**7,32**	11,49	**9,13**	10,15	6,23	10,10	12,69	**6,42**
24	6,71	10,76	9,26	8,76	4,81	17,03	12,53	6,79

Table 7.3: SMAPE errors from AR-X and VAR-X models (%)

				AR-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**5,71**	**17,28**	13,52	**7,27**	**4,84**	**18,51**	**7,90**	**9,87**
2	**6,01**	18,10	19,07	**11,92**	**6,40**	**11,08**	**7,65**	**9,93**
3	**6,26**	21,58	21,65	**10,99**	7,45	**7,39**	8,86	**8,52**
4	**7,10**	**29,16**	**29,58**	15,37	9,68	**8,94**	**9,67**	**9,27**
5	**8,75**	**28,63**	**26,56**	13,33	9,69	**10,29**	**9,83**	**7,60**
6	9,40	21,16	20,38	15,80	8,45	**7,97**	**10,22**	**6,32**
7	**8,43**	**21,99**	20,51	**9,69**	7,62	**9,12**	**10,33**	**8,33**
8	**9,50**	**36,00**	**17,24**	**10,56**	**7,14**	**7,85**	**13,43**	**9,07**
9	**9,43**	**16,23**	**13,67**	**9,11**	**9,66**	**8,24**	**15,15**	**10,45**
10	**11,46**	**19,75**	**15,45**	13,31	**9,64**	**9,64**	**12,68**	**10,91**
11	**12,88**	20,84	**17,83**	15,87	**9,50**	10,63	**12,62**	**13,54**
12	**15,31**	22,13	**20,05**	17,55	10,38	**8,64**	**10,31**	**14,33**
13	**15,67**	18,07	**17,43**	**17,98**	**10,78**	**10,25**	**10,24**	**16,27**
14	**22,08**	**18,97**	**18,01**	**17,45**	**13,96**	**10,95**	**12,33**	**15,88**
15	**21,14**	**21,46**	**17,80**	**19,17**	**14,19**	**10,43**	**14,24**	**16,97**
16	**19,65**	**18,42**	**15,52**	**17,32**	12,63	**10,76**	**17,56**	**16,81**
17	**20,07**	**16,68**	**13,98**	**13,70**	**9,99**	11,35	**18,91**	**16,29**
18	**12,21**	**17,08**	**15,27**	**12,23**	8,43	**13,55**	**19,67**	**13,26**
19	**10,10**	**15,48**	**12,82**	**9,96**	6,24	**11,80**	**14,31**	**9,97**
20	**7,36**	16,76	15,35	7,88	7,07	10,94	**8,82**	7,64
21	**8,83**	19,37	18,36	**10,06**	**6,08**	**11,87**	12,94	**7,79**
22	**6,78**	**18,16**	**17,30**	**9,31**	**8,94**	**9,31**	**16,95**	**6,25**
23	**7,52**	**11,09**	**9,56**	**9,58**	**5,81**	**9,78**	**12,83**	**6,92**
24	**6,01**	**10,52**	**9,16**	**6,97**	**4,31**	**16,98**	**11,86**	**6,55**
				VAR-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	7,55	18,59	**12,13**	8,46	5,57	18,65	8,38	11,04
2	7,85	**17,08**	**16,59**	13,69	6,52	11,53	8,91	11,29
3	9,83	**20,12**	**21,01**	12,01	**6,84**	8,95	**7,79**	10,95
4	9,01	29,73	29,87	**12,94**	**8,66**	9,72	10,28	10,05
5	9,18	34,65	30,62	**12,64**	**9,12**	10,82	10,45	10,90
6	**8,67**	**21,01**	**19,07**	**15,33**	**8,33**	9,61	11,32	7,51
7	10,37	22,63	**19,98**	11,04	**7,60**	10,38	12,22	9,36
8	10,94	43,13	19,06	14,40	8,03	9,07	14,82	11,43
9	12,30	17,05	33,70	10,90	10,71	9,56	20,36	11,00
10	13,75	19,91	91,55	**11,82**	10,63	11,79	18,57	14,01
11	15,17	**20,36**	617,04	**14,19**	9,83	**10,55**	15,24	14,75
12	16,80	**20,95**	33,34	**17,05**	**10,13**	9,59	13,80	14,60
13	18,08	**17,45**	17,43	18,62	10,96	11,00	14,81	16,78
14	24,53	19,40	18,22	20,05	14,59	12,07	14,71	18,23
15	22,64	22,07	17,89	20,20	14,31	12,39	17,49	18,15
16	21,75	20,86	19,11	19,63	**10,93**	11,02	23,44	19,80
17	21,74	18,12	16,44	14,66	10,31	**11,22**	22,53	20,23
18	15,52	21,65	17,85	14,58	**7,90**	13,64	23,48	14,72
19	13,56	15,67	15,94	11,01	**5,69**	12,49	14,69	10,88
20	9,10	**15,15**	**14,23**	**7,34**	**6,28**	**10,54**	9,33	**7,59**
21	10,39	**18,29**	**17,28**	10,55	6,17	12,06	**11,85**	10,03
22	8,24	19,48	17,59	9,95	9,33	9,67	17,72	8,31
23	8,46	11,60	10,11	10,46	6,49	10,17	13,62	7,07
24	6,36	10,89	9,31	10,53	5,11	17,03	12,82	7,78

Table 7.4: SMAPE errors from ARI and VEC models (%)

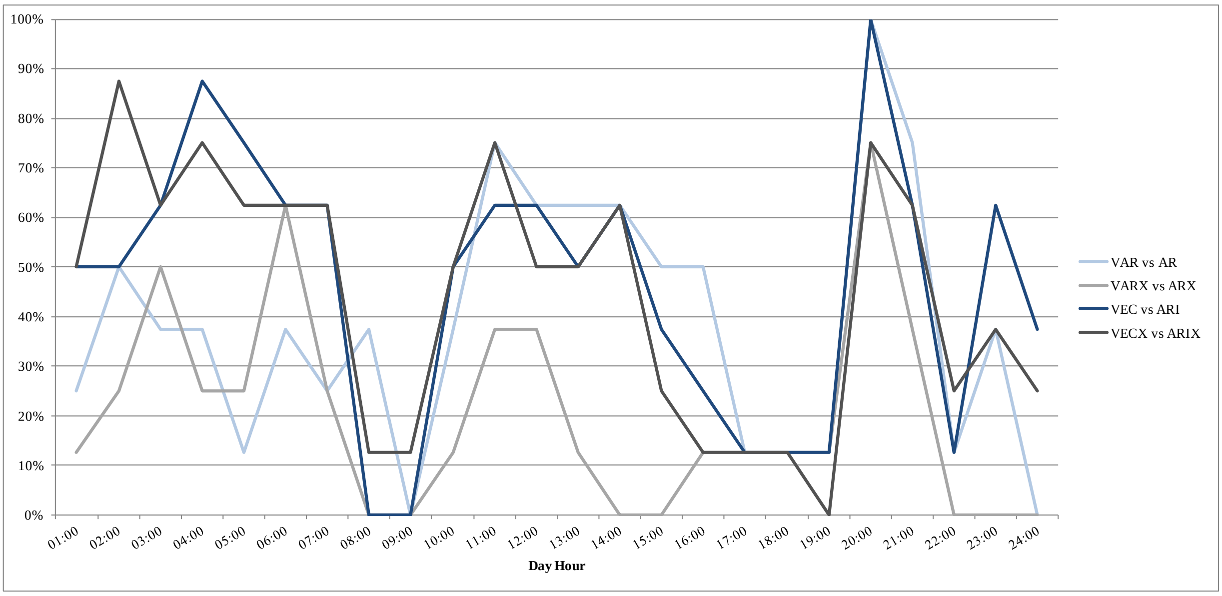
				ARI				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**6,47**	20,66	14,98	7,86	**4,97**	18,94	**8,39**	**9,44**
2	7,30	21,66	19,48	**10,10**	6,46	**10,77**	**9,18**	**9,64**
3	**7,63**	22,02	22,15	12,28	7,59	**6,79**	9,39	**8,09**
4	8,87	28,82	28,06	**13,99**	9,37	9,46	10,71	8,96
5	8,59	**26,54**	26,88	12,43	9,58	11,02	11,30	**7,69**
6	**8,32**	19,30	18,56	**14,60**	**8,51**	10,38	12,56	6,82
7	9,32	24,00	24,25	**12,18**	7,82	11,25	**12,16**	**8,69**
8	**9,04**	**27,37**	**16,91**	**14,32**	**7,50**	**9,58**	**14,69**	**9,33**
9	**9,12**	**14,13**	**12,16**	**10,27**	**9,62**	**9,01**	**17,27**	**9,38**
10	12,29	**19,43**	**13,32**	13,15	9,13	10,87	**15,57**	**9,08**
11	13,85	21,07	**15,45**	16,22	10,41	10,97	**13,76**	**12,07**
12	17,58	23,04	**17,48**	17,96	11,90	**7,88**	11,29	**13,36**
13	17,73	18,20	**17,96**	18,80	12,16	**10,42**	**10,77**	**14,49**
14	23,89	17,94	18,38	17,61	16,17	**9,85**	**12,82**	**15,05**
15	23,08	**20,34**	18,57	**18,04**	16,31	**9,40**	**13,92**	**15,29**
16	21,81	**16,12**	**15,61**	**15,65**	14,54	**10,05**	**17,49**	**14,99**
17	22,15	**13,28**	**13,88**	**12,79**	**10,68**	**11,22**	**18,94**	**14,79**
18	**12,64**	**16,59**	**15,18**	**11,54**	**8,66**	14,39	**20,00**	**11,38**
19	**10,41**	**15,56**	**14,80**	**9,87**	**6,01**	**12,15**	15,35	**9,44**
20	8,43	18,19	16,63	7,23	6,87	11,14	6,71	7,41
21	9,48	20,68	**19,54**	**9,61**	**6,10**	12,09	11,88	7,66
22	**7,04**	**18,77**	**18,25**	**9,24**	**8,95**	9,44	**16,87**	**6,21**
23	8,14	11,63	10,10	**9,76**	**6,08**	10,07	**12,20**	6,55
24	7,17	11,09	9,82	**6,77**	**4,37**	**16,96**	**12,23**	**7,23**
				VEC				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	6,56	**18,67**	**13,32**	**7,76**	5,84	**18,70**	10,24	10,69
2	**7,19**	**16,57**	**16,82**	11,28	**6,30**	11,25	9,54	10,36
3	8,34	**18,50**	**21,94**	**11,57**	**7,12**	7,74	**7,98**	9,17
4	**7,59**	**28,38**	**27,93**	15,21	**8,89**	**9,46**	**10,08**	**8,01**
5	**8,17**	29,77	**26,75**	**11,98**	**9,30**	**10,56**	**9,63**	8,60
6	9,08	**18,28**	**17,24**	15,99	8,63	**9,18**	**11,17**	**5,82**
7	**8,93**	**22,43**	**18,46**	13,64	**7,82**	**10,50**	12,43	9,33
8	10,53	39,40	19,64	16,13	7,91	9,65	15,11	11,46
9	9,53	17,07	33,87	11,88	10,50	9,97	20,30	9,84
10	**11,52**	20,42	78,39	**12,13**	**8,69**	**10,81**	17,55	10,76
11	**12,36**	**19,74**	81,73	**14,93**	**9,64**	**8,60**	15,09	14,56
12	**14,98**	**20,61**	33,96	**17,10**	**10,85**	8,57	**11,26**	16,42
13	**15,16**	**15,92**	18,83	**17,50**	**11,39**	10,62	12,90	17,56
14	**23,54**	**17,39**	**16,87**	**17,46**	**14,03**	12,21	13,30	19,30
15	**22,44**	21,77	**17,24**	18,67	**15,12**	11,18	16,38	18,58
16	**20,91**	17,48	16,43	17,86	**12,88**	10,46	21,78	20,19
17	**21,29**	14,55	13,91	14,51	11,75	11,40	22,68	20,16
18	15,27	20,64	16,89	14,24	9,74	**13,60**	22,37	15,12
19	13,22	17,57	18,53	11,64	6,20	12,47	**15,22**	11,10
20	**7,71**	**17,17**	**15,95**	**6,64**	**6,60**	**10,04**	**5,77**	**6,84**
21	**8,09**	**18,79**	19,95	11,29	6,26	**11,78**	**11,37**	**6,68**
22	7,18	19,87	19,12	10,36	9,56	**9,39**	17,32	6,62
23	**7,36**	**11,23**	**9,13**	11,20	6,41	**10,07**	12,65	**6,07**
24	**7,06**	**10,49**	**9,35**	11,49	4,85	17,05	13,25	7,24

Table 7.5: SMAPE errors from ARI-X and VEC-X models (%)

ARI-X								
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	6,36	19,05	14,79	7,47	**4,98**	**18,66**	**8,54**	**9,42**
2	6,43	20,49	20,20	11,17	6,50	**10,77**	9,52	9,82
3	**7,04**	22,89	24,13	12,30	7,40	**6,71**	9,99	**8,67**
4	7,68	30,97	29,51	**13,61**	9,42	**9,92**	11,25	9,05
5	9,55	29,23	26,02	**12,16**	9,64	**10,95**	11,66	**7,73**
6	10,17	22,19	20,49	**15,08**	**8,33**	**9,24**	12,49	6,78
7	9,10	25,55	23,98	**10,60**	**7,73**	**8,83**	11,10	8,43
8	9,85	**27,70**	**16,55**	**12,64**	**7,03**	**8,07**	**12,87**	**9,27**
9	9,67	**14,49**	**12,81**	**9,96**	**9,68**	**8,29**	**15,34**	**10,04**
10	11,45	**20,30**	**14,37**	13,54	8,62	**10,33**	**13,18**	10,22
11	12,67	22,16	**15,38**	16,05	9,59	11,00	**12,53**	12,76
12	15,17	23,26	**15,41**	17,60	10,46	**8,07**	**10,77**	**14,13**
13	15,42	17,49	**16,28**	18,26	10,72	**10,45**	**11,08**	**14,90**
14	22,75	17,05	17,74	17,65	13,70	**10,13**	**13,22**	**15,27**
15	21,57	**19,42**	**17,36**	**18,23**	14,12	**10,00**	**15,03**	**15,45**
16	**20,09**	**17,05**	**15,31**	**16,53**	13,27	**10,33**	**17,71**	**15,24**
17	**20,42**	15,02	**14,24**	**13,56**	**10,52**	**11,08**	**19,42**	**15,02**
18	**11,56**	**16,83**	**15,14**	**12,23**	**8,80**	13,83	**20,06**	**11,95**
19	**9,86**	**15,46**	**13,02**	**10,47**	**6,09**	**11,84**	**13,95**	**9,81**
20	**7,75**	17,45	**15,35**	7,67	6,99	10,96	8,38	7,62
21	9,04	20,27	**18,47**	**10,25**	**6,10**	11,82	13,29	7,82
22	7,22	19,15	**17,51**	**9,43**	**8,95**	**9,22**	**17,50**	**6,31**
23	7,90	11,80	9,78	**9,74**	**5,99**	**9,88**	**12,69**	**6,61**
24	6,58	11,17	**9,34**	**7,23**	**4,34**	**16,70**	**12,39**	**7,19**
VEC-X								
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**5,73**	**17,64**	**12,93**	**6,64**	5,82	18,67	10,85	9,87
2	**5,66**	**16,23**	**16,83**	**10,08**	**6,43**	11,90	**9,39**	**8,68**
3	7,51	**19,08**	**20,95**	**12,11**	**7,27**	8,60	**8,55**	9,10
4	**6,20**	**28,39**	**28,95**	15,12	**9,26**	10,72	**10,44**	**7,69**
5	**6,77**	**29,20**	**25,00**	12,72	**9,35**	12,09	**10,33**	7,90
6	**7,32**	**19,01**	**18,81**	17,07	8,50	10,92	**10,04**	**4,71**
7	**6,90**	**21,90**	**19,15**	17,70	7,93	10,56	**10,72**	**8,19**
8	**9,45**	41,40	20,55	15,44	7,32	8,90	13,27	11,08
9	**8,98**	16,40	37,64	11,86	10,34	9,32	19,67	11,12
10	**10,51**	20,39	98,27	**12,55**	**8,02**	10,60	17,42	**10,12**
11	**12,20**	**19,84**	146,21	**13,82**	**9,55**	**8,92**	14,30	**12,70**
12	**13,74**	**20,45**	33,80	**15,70**	**9,80**	9,05	11,78	14,18
13	**12,97**	**14,84**	16,82	**15,98**	**10,37**	10,91	13,50	15,61
14	**21,46**	**16,95**	**17,57**	**16,89**	**12,98**	11,99	16,14	17,83
15	**21,35**	20,86	20,58	20,74	**14,09**	11,33	19,55	16,17
16	21,20	17,15	19,72	18,22	**13,09**	10,76	23,00	19,38
17	20,99	**14,89**	16,94	13,65	12,82	11,47	23,05	20,09
18	15,12	19,79	16,06	14,50	10,45	**13,58**	22,60	13,81
19	12,79	16,97	16,99	12,15	6,42	12,04	14,90	10,67
20	7,88	**17,42**	16,42	**6,99**	**6,57**	**10,06**	**6,35**	**6,71**
21	**7,96**	**19,34**	20,37	11,70	6,26	**11,76**	**12,59**	**6,79**
22	**6,88**	**19,05**	18,89	9,77	9,64	9,29	17,67	6,66
23	**7,36**	**11,06**	**9,08**	10,88	6,45	10,57	12,98	7,02
24	**6,56**	**10,60**	9,54	11,55	4,81	17,14	13,35	7,39

By analyzing the forecasting results at the hourly level it can be observed not only that forecasting errors on average increase in ramp-up hours in the morning, but also that in these hours simple time series models outperform multiple ones, suggesting that country-specific price movements prevail over possible price interactions between countries. On the other hand, multiple time series models (and especially VEC-X model) outperform simple time series model mainly around hour 20^{th} and 21^{st}. Analyzing SMAPE values at hourly level, without considering the countries, **Figure 7.3** displays the number of times (as percentage) in which each multiple time series model results in better forecasting performances compared with the correspondent simple time series model according to this indicator.

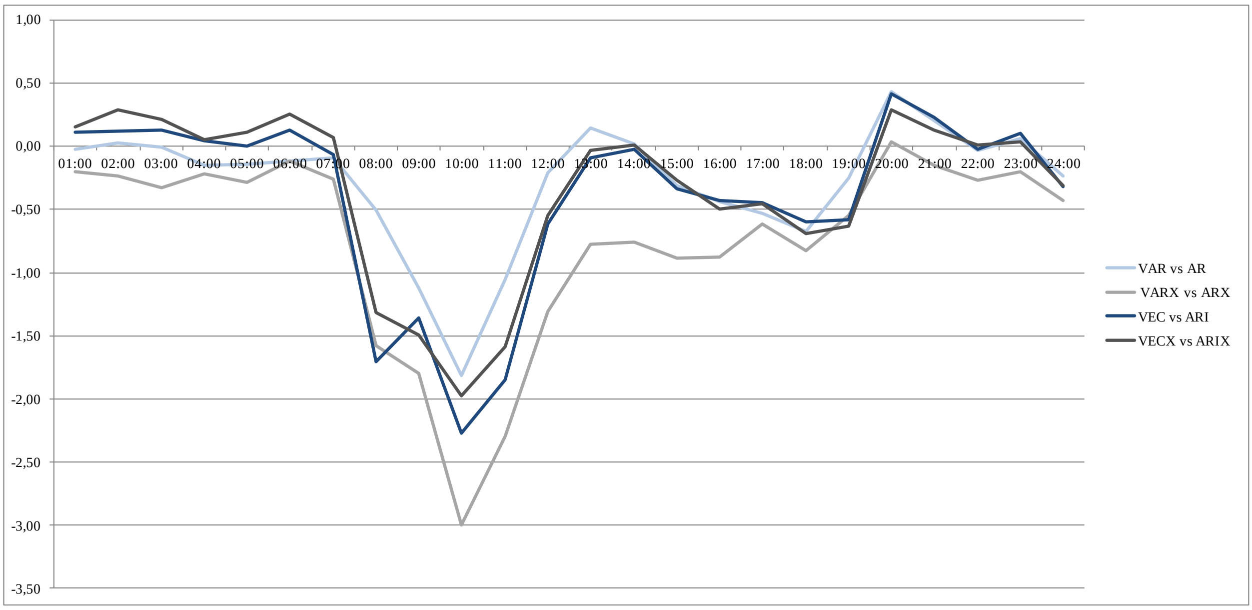
Figure 7.3: Hourly multiple times series model vs simple time series model



The analysis reveals also that the inclusion of exogenous variables does not improve the forecasting performance. The inclusion of electricity load values results in better forecasting of day ahead electricity prices only in 50% of combinations between hours of the day and countries irrespective of whether AR and AR-X models or ARI and ARI-X models are compared. In addition, when VAR and VAR-X models or VEC and VEC-X models are compared more accurate forecasts are achieved only in nearly 33% and 55% of the cases respectively, after including into the proposed models also electricity load values as exogenous variables.

Both under the assumption that all the price series are stationary and that all the price series contain unit roots, when multiple time series models beat simple time series models lower gains are obtained in the forecasting performance, compared with the opposite situation where simple time series models outperform multiple ones. **Figure 7.4** displays hourly average differences between RMSE values of simple time series models and the corresponding multiple time series model. The situation in which multiple time series models outperform the simple time series is represented in the upper part of the figure, and in this case the difference do not overcome 0,5€/MWh while, when the opposite situation happens, higher difference values are reached, close to 3 €/MWh in the case of the comparison between VAR-X and AR-X.

Figure 7.4: Hourly average Delta RMSE



Forecasting exercises thus show that simple and multiple time series models result in comparable forecasting performances: no estimated model is able to outperform the other ones in all combinations between hours of the day and countries.

7.1.3 Conclusion

Up to now, most of the contributions on short term forecasting of day ahead electricity prices do not include in the estimated models the possibility of dynamic interactions between several interconnected day ahead electricity markets. This section aims to compare the forecasting performance of hourly simple time series model and multiple time series models, in order to investigate whether or not multiple time series models perform better.

At present the implemented forecasting exercise does not allow stating that estimating multiple time series models, and especially including potential cointegration relationship between day ahead electricity price series, greatly improve their forecasting performance compared to estimating single time series models. The more general literature on macroeconomic forecasting is already familiar with this potential result, even if macroeconomic time series and day ahead electricity prices have quite different features. Within this literature, indeed, Elliott (2006) notes that the inclusion of cointegrating relationships does not necessarily improve the forecasting performance of VAR models, as this depends on "almost all the parameters in the design, including the covariance matrix of the errors" (Anderson and Vahid, 2011, p. 17).

The analysis reveals that the adoption of multiple time series may provide better results only in some hours (20^{th} and 21^{st}), while in others simple time series models outperform multiple time series ones (ramp up hours in the morning). In order to further deep this preliminary evidence, one possible way could be to consider other variables in the analysis: for instance, the flows between countries could be investigated to verify if this result may be potentially linked with the utilization of cross border capacity, or/and the hourly quantity of electricity produced by RES plants can be further explored.

Moreover, the peculiar features of day ahead electricity prices are only partially captured by the implemented models.

First of all, this work relies on two strong hypotheses about the time series stationarity properties; the implementation of both simple and multiple time series models allowing for fractional integration may result in better forecasting performance.

Moreover, the presence of marked price spikes in the in-sample time series impacts the coefficients estimation in the model. Thus, a new evaluation of the forecasting performances of all estimated models after applying some pre-filtering procedure to all day ahead electricity prices, in order to remove at least their more pronounced spikes, has been carried on and reported in the section 7.2.

Furthermore, another explanation for the results may be precisely the presence of heteroskedasticity in all or part of the time series analyzed that is not captured in the models estimated in the present work.

Accordingly, future developments include heteroskedasticity modeling, through estimating ARCH/GARCH components in the proposed framework.

Finally, further analyses are needed in order to verify whether or not the results are robust not only to different in-sample and out-of-sample periods but also to the inclusion of different countries in the estimated models.

7.2 Pre-filtered short term forecasting

In order to address one of the potential criticism of the previous setting, the same comparison between multiple time series and simple time series models has been performed again after data pre-filtering.

As discussed in the first part of the present work, electricity is a quite unique commodity, due to its non-storability at economics conditions. This characteristic eliminates the buffering effect and forces spot prices to depend widely on supply and demand conditions in each moment and this increases the probability of sudden large price changes, named spikes, especially when demand is high (Huisman and Kiliç, 2013; De Jong, 2006). Moreover, spikes are so extreme because of the bidding strategies implemented by some market players, knowing the inelasticity of demand in the short run (Borenstein, 2002; Weron 2006). Furthermore, in the present framework of increasing penetration of RES production, spike issue has assumed a growing importance, since, as found by Lindström and Regland (2012), the frequency of extreme events is positively related to the amount of RES in the system. Thus, electricity is a commodity with a volatility level well above the one registered in other financial markets (Simonsen, 2005, Janzcura et al., 2013). Moreover, spikes are not homogeneous in time, being more frequent in high consumption periods, due to the very structure of day ahead markets. While there is a general agreement that spikes are a peculiar feature of the electricity price, there is no a general consensus on how to deal with them in forecasting. Even the presence of a single spike is capable of considerably changing the estimation of the coefficients of a time series model, but different approach can be followed to face this issue. On the one hand, some scholars have adopted models that can account for such extreme observations, like jump diffusion models (Cuaresma et al., 2004; Knittel and Roberts, 2005) or regime switching models (Haldrup et al., 2010); on the other hand, other scholars have sustained that it is appropriate to use a procedure to detect and minimize the spikes effect, since these events are unpredictable by their very nature (Conejo et al., 2005; Contreras et al., 2003).

In the present section, an outlier treatment has been applied and after the treatment, the same methodology of section 7.1 is followed in order to compare results with the ones obtained in section 7.1.2.

7.2.1 Spike detection and substitution

The first step in outlier treatment is to decide how to identify them, since in literature, there is no commonly accepted definition of a price spike (Weron, 2006, Janzcura et al., 2013, Trück et al., 2007). Some authors suggest as identification method a fixed price threshold, where all values exceeding a chosen level are classified as spikes (Lapuerta and Moselle, 2001; Boorgert and Dupont, 2007), others a fixed price change threshold, where price variations exceeding certain value are identified as outlier (Bierbrauer et al., 2004). Other scholars use a variable price threshold, treating as outlier all prices exceeding the mean price level by three standard deviation and removing them one by one with a recursive filter, or, in a related method, a certain percentage of the highest/lowest prices is considered an outlier (Trück et al., 2007); again, a variable price change threshold can be used (Cartea and Figueroa, 2005; Weron et al., 2004). Other methods with different levels of complexity have been applied to deal with this issue, such as Wavelet filtering or a Markov regime switching model classification; for a complete review of the outlier treatment, see Janzcura et al. (2013).

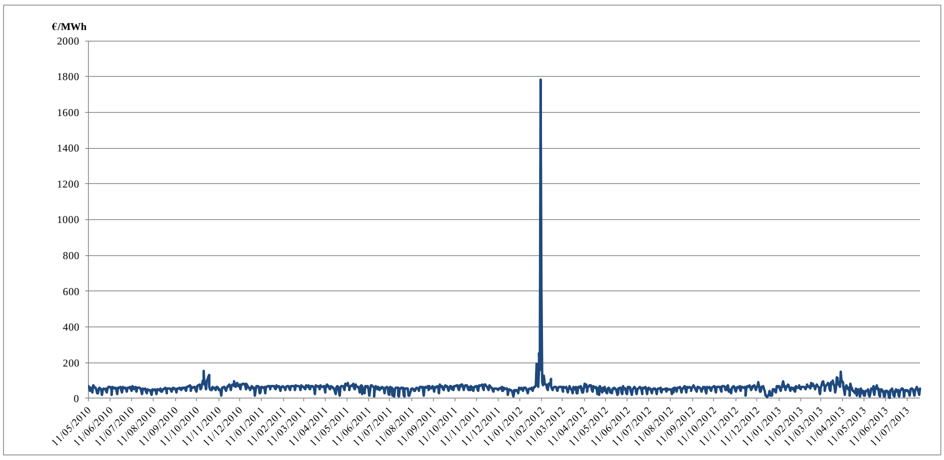
Once identified the spikes, in time series outliers cannot be simply dropped but it is necessary to select a technique to replace them. Some authors suggest to smooth prices exceeding the threshold with a logarithmic function or to replace them by the thresholds themselves (Weron, 2006); others replace the extreme observations by the mean of the two neighboring prices (Weron, 2008) or by one of the neighboring prices (Geman and Roncoroni, 2006), but in these cases problems can arise when there are two or more consecutive outliers. Using an alternative approach, Bierbrauer et al. (2007) replace spikes by the median of all prices having the same weekday and month as the outlier, considering the seasonal behavior of the series as suggested by Trück et al. (2007).

In the present work a variable price threshold has been used for spikes identification on the dataset described in chapter 5 (“original dataset” from now on). Spike detection is done iteratively, through an algorithm that filters the data exceeding the threshold at that specific iteration. Then, the identified spikes have been replaced with thresholds themselves.

7.2.2 Filtered dataset description

As shown by simple summary statistics on the original dataset, particularly marked spikes can be found both in the daily prices series of the 8th hour in Belgium (2999 €/MWh) and in the daily prices series of the hours between the 8th and the 13th in France. For an illustrative purpose, French day ahead electricity price time series for hour 10th has been represented in **Figure 7.5**.

Figure 7.5: EPEX France Spot price time series (Hour 10th)



The filtered procedure has led to the substitution of 3657 values on the original dataset, just over 1% of the total observations.

By comparing minimum prices, after the filtering procedure Belgian, French, German and Dutch markets, that showed dip even below -200 €/MWh, display minimum price less lower than -10€/MWh. The replacement of particularly marked spikes both in the daily prices series of Belgium and France has led the maximum price of these markets to be less above 110 €/MWh, instead of around 2000 €/MWh. As **Figure 7.6** shows, the dispersion degree of the 192 daily price series around their average is strongly decreased. Indeed, in peak-load hours French daily day ahead price standard deviation has been reduced from 27,04 €/MWh on average to 15,83 €/MWh and Belgian from 21,75€/MWh to 15€/MWh, in line with the standard deviation registered for the other markets. The Belgian and French day ahead electricity markets exhibit the highest standard deviation of daily prices in nearly all off-peak hours in the morning, while the highest standard deviation of daily prices in off-peak hours in the evening is shown by the Slovenian and Italian day ahead electricity markets.

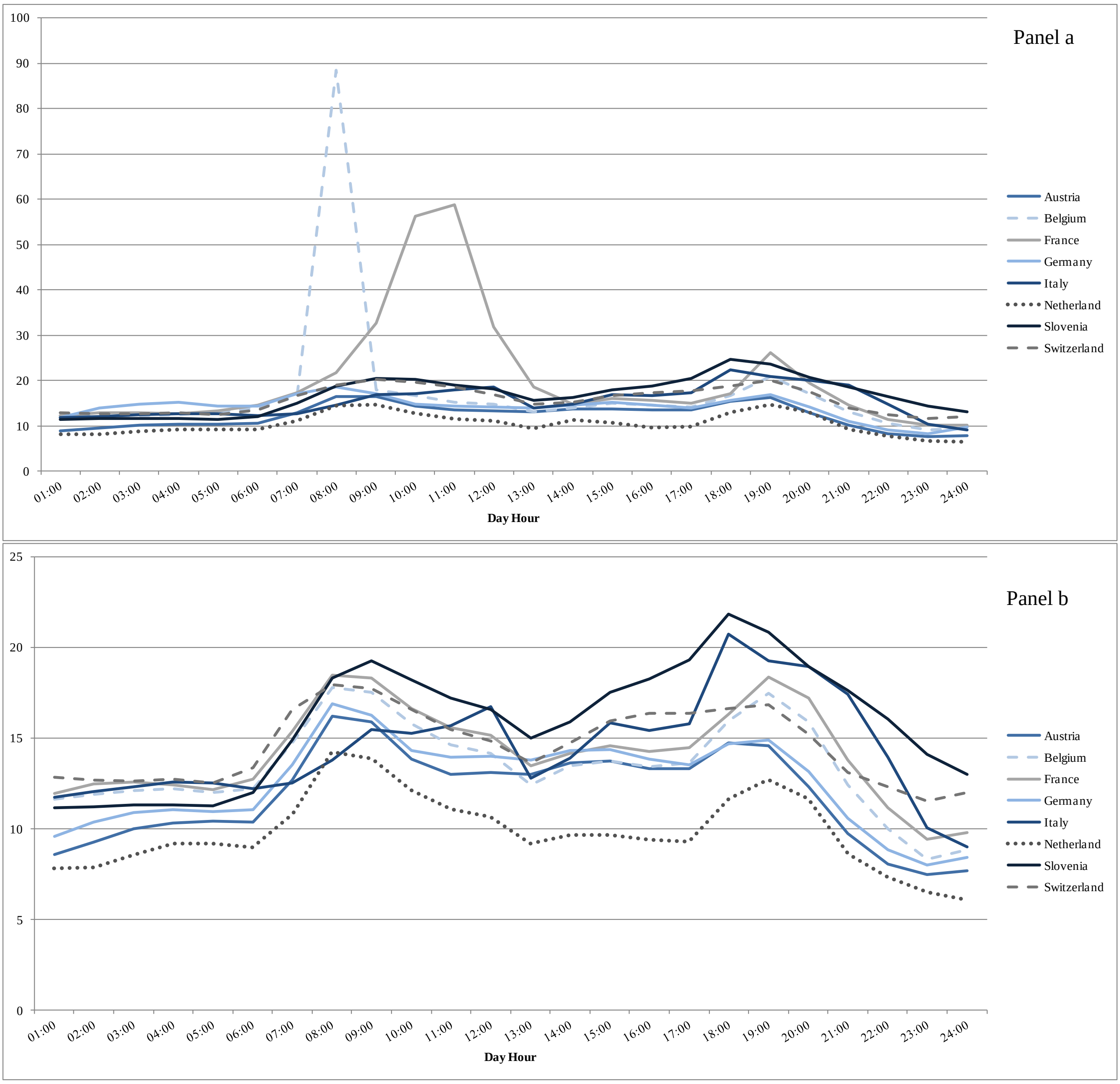
For an illustrative purpose, **Table 7.6** displays summary statistic for EPEXFR. The descriptive statistics for the other markets are in Appendix C.

Table 7.6: Summary statistics for EPEX France price (Pre-filtered dataset)

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	40,65	7,94	75,95	11,96	-0,28	3,57	0,979***
2	37,15	1,01	73,75	12,46	-0,14	3,20	0,984***
3	33,06	0,00	70,04	12,60	-0,08	2,82	0,988***
4	28,14	-9,14	64,65	12,41	0,00	2,34	0,977***
5	26,99	-9,69	62,82	12,15	0,00	2,22	0,969***
6	31,66	-6,60	69,15	12,72	-0,25	2,57	0,973***
7	39,38	-6,91	85,07	15,39	-0,37	3,05	0,965***
8	48,34	-7,55	103,43	18,49	-0,36	3,22	0,969***
9	52,80	-2,63	107,40	18,34	-0,31	3,69	0,966***
10	54,88	4,57	104,41	16,63	-0,31	4,11	0,963***
11	55,36	8,05	101,82	15,61	-0,46	4,29	0,955***
12	56,13	10,04	101,33	15,18	-0,52	4,40	0,952***
13	55,17	13,88	95,47	13,50	-0,77	4,45	0,943***
14	51,89	8,71	94,21	14,18	-0,75	4,04	0,950***
15	49,52	5,18	93,11	14,60	-0,59	3,93	0,960***
16	46,97	3,63	89,62	14,29	-0,57	3,85	0,961***
17	46,30	2,47	89,50	14,49	-0,47	3,79	0,964***
18	50,73	4,87	99,06	16,32	-0,03	4,03	0,970***
19	57,16	9,57	111,31	18,36	0,35	4,24	0,966***
20	57,99	9,60	108,91	17,21	0,21	4,10	0,976***
21	53,14	11,62	94,30	13,82	-0,43	4,12	0,971***
22	48,61	14,98	81,85	11,18	-0,62	4,52	0,954***
23	50,71	21,96	78,73	9,44	-0,19	4,62	0,964***
24	46,43	16,62	75,44	9,78	-0,19	4,37	0,971***

Even after the filtering procedure, the Shapiro-Wilk W test (Shapiro and Wilk, 1965) statistically confirms the presence of non-normality in nearly all daily prices series distribution. Out of 192 daily prices series the null hypothesis of normality can be rejected in 179 cases at the 1% significance level, in 7 cases (Austrian day ahead electricity prices of hours 20th, German of hour 21st; Italian of hours 1st - 3rd; Dutch for hour 15th; Swiss of hour 6th) at the 5% significance level. Only in the remaining 6 cases (Swiss day ahead electricity prices of the 2nd - 5th hours, Italian day ahead electricity prices of the 6th hour and Austrian day ahead electricity prices of hours 21st) the null hypothesis of normal distribution cannot be rejected.

Figure 7.6: Standard deviation by countries on the original (a) and on the filtered (b) dataset



7.2.3 Models settings

In this section, multiple time series model have been set for each of the 24 hours of the day and 192 simple time series models have been set as a benchmark reference.

In order to correctly specify the models, the stationarity properties of the 192 daily day ahead time series have been investigated trough unit root and stationarity tests (for the detailed procedure see section 6.2.1). Within the first set of tests, ADF test (1979) has been applied to the 192 daily day ahead electricity price time series. The null hypothesis of unit root has been rejected at 1% level of significance for all the time series analyzed but two cases (IPEX price at hours 13th and 23rd) where the null hypothesis has been rejected at 5%. Confirming the ADF results, the PP test (1988) rejects the null hypothesis of unit root for all the 192 time series at 1% level of significance. Coming to stationarity test, KPSS test (1992) has been performed assuming a level stationary process with non-zero mean. The null hypothesis of stationarity is rejected for almost all the time series: in 150 cases H_0 is rejected at 1% level of significance, in 24 cases at 5%, in 12 cases at 10%. Only in 6 cases (BELPEX prices at hours 2nd, 7th - 10th and 18th) KPSS does not reject the null of stationarity. ADF, PP and KPSS results for the pre-filtered series are shown in **Table 7.7**, **Table 7.8** and **Table 7.9** respectively.

Table 7.7: Augmented Dickey- Fuller test (Pre-filtered dataset)

Hour	EXAA	BELPEX	EPEXFR	EPEXDE	IPEX	APX	BSP	EPEXCH
1	-3,10***	-4,81***	-4,68***	-3,66***	-2,68***	-4,40***	-3,73***	-3,91***
2	-3,67***	-4,70***	-4,40***	-4,04***	-2,94***	-4,18***	-3,96***	-4,21***
3	-4,07***	-4,48***	-4,37***	-4,47***	-2,91***	-4,44***	-4,17***	-4,28***
4	-4,23***	-3,95***	-4,24***	-4,74***	-3,04***	-4,40***	-4,27***	-4,44***
5	-4,21***	-4,30***	-4,38***	-4,63***	-2,96***	-4,52***	-4,26***	-4,50***
6	-3,66***	-4,33***	-4,27***	-3,96***	-3,19***	-3,97***	-4,00***	-4,08***
7	-3,73***	-4,24***	-4,32***	-4,01***	-2,95***	-3,88***	-4,39***	-3,90***
8	-4,49***	-4,46***	-4,60***	-4,67***	-2,83***	-4,36***	-4,53***	-4,22***
9	-4,82***	-4,60***	-4,87***	-4,82***	-3,14***	-4,48***	-4,78***	-4,42***
10	-4,32***	-4,77***	-4,89***	-4,34***	-4,21***	-4,49***	-4,59***	-4,24***
11	-3,84***	-4,77***	-4,90***	-4,13***	-3,60***	-4,86***	-4,27***	-4,08***
12	-3,39***	-5,00***	-4,88***	-3,93***	-3,13***	-5,20***	-4,29***	-3,99***
13	-3,05***	-4,85***	-4,37***	-3,45***	-2,21**	-5,26***	-3,70***	-3,83***
14	-2,98***	-4,52***	-4,50***	-3,36***	-2,34***	-4,91***	-3,76***	-4,05***
15	-3,04***	-4,98***	-4,73***	-3,42***	-2,65***	-4,91***	-3,96***	-4,01***
16	-3,12***	-5,10***	-4,79***	-3,51***	-2,94***	-5,00***	-4,02***	-3,91***
17	-3,02***	-4,53***	-4,37***	-3,38***	-3,04***	-4,59***	-4,02***	-3,74***
18	-3,08***	-3,91***	-3,80***	-3,36***	-2,75***	-3,77***	-3,63***	-3,36***
19	-3,29***	-3,81***	-3,91***	-3,53***	-2,59***	-3,61***	-3,53***	-3,58***
20	-3,34***	-3,52***	-3,82***	-3,54***	-3,00***	-3,62***	-3,51***	-3,65***
21	-3,22***	-4,06***	-4,28***	-3,58***	-3,06***	-4,43***	-3,87***	-3,46***
22	-3,07***	-4,60***	-4,96***	-3,72***	-2,54***	-3,75***	-3,94***	-3,51***
23	-2,71***	-4,58***	-4,81***	-3,07***	-2,23**	-4,93***	-3,57***	-3,53***
24	-2,41***	-4,54***	-4,32***	-3,06***	-2,44***	-3,59***	-3,94***	-3,99***

*** *p-value* < 0.01; ** *p-value* < 0.05; * *p-value* < 0.10

MacKinnon (1994) critical values

Table 7.8: Phillips-Perron Test (Pre-filtered dataset)

Hour	EXAA	BELPEX	EPEXFR	EPEXDE	IPEX	APX	BSP	EPEXCH
1	-11,54***	-15,89***	-13,41***	-16,15***	-13,01***	-19,94***	-14,47***	-10,17***
2	-12,00***	-13,45***	-11,60***	-16,49***	-13,72***	-16,50***	-13,63***	-10,34***
3	-13,39***	-13,09***	-11,58***	-16,91***	-14,49***	-16,11***	-13,94***	-11,50***
4	-12,37***	-11,51***	-10,99***	-15,78***	-14,03***	-14,71***	-14,18***	-11,30***
5	-12,40***	-11,82***	-11,05***	-15,49***	-13,97***	-14,89***	-14,32***	-11,36***
6	-14,37***	-13,62***	-12,18***	-16,06***	-14,54***	-15,68***	-14,74***	-11,62***
7	-19,61***	-18,63***	-16,76***	-20,93***	-20,39***	-20,82***	-17,66***	-15,45***
8	-20,11***	-21,05***	-19,36***	-21,40***	-24,13***	-21,79***	-18,94***	-17,72***
9	-20,22***	-20,83***	-19,33***	-21,21***	-25,14***	-21,72***	-18,94***	-17,44***
10	-19,26***	-20,57***	-18,31***	-20,80***	-23,73***	-21,88***	-17,93***	-15,93***
11	-17,40***	-20,22***	-17,58***	-19,92***	-20,55***	-22,64***	-16,78***	-15,30***
12	-15,60***	-20,20***	-17,17***	-18,75***	-17,67***	-22,26***	-15,48***	-15,00***
13	-14,36***	-19,80***	-16,15***	-18,03***	-14,56***	-22,35***	-14,69***	-13,38***
14	-15,13***	-21,01***	-17,44***	-18,14***	-16,56***	-21,75***	-15,88***	-14,78***
15	-15,47***	-20,65***	-17,78***	-17,91***	-18,06***	-20,57***	-16,17***	-15,01***
16	-15,65***	-19,95***	-17,61***	-17,80***	-18,02***	-19,47***	-16,13***	-14,55***
17	-14,45***	-18,83***	-16,81***	-16,55***	-17,26***	-17,89***	-15,69***	-13,21***
18	-11,35***	-15,43***	-14,00***	-13,57***	-12,29***	-14,01***	-13,26***	-10,35***
19	-10,60***	-12,66***	-11,43***	-13,11***	-10,72***	-12,47***	-11,73***	-8,73***
20	-10,72***	-11,71***	-10,69***	-13,53***	-11,98***	-12,00***	-12,61***	-8,30***
21	-11,14***	-13,55***	-11,43***	-14,15***	-11,62***	-16,01***	-14,22***	-7,86***
22	-10,68***	-15,72***	-13,32***	-15,01***	-11,66***	-16,95***	-13,82***	-8,45***
23	-9,47***	-16,39***	-13,12***	-15,66***	-10,99***	-17,99***	-12,48***	-8,42***
24	-8,51***	-14,94***	-11,64***	-14,93***	-9,47***	-18,77***	-11,77***	-8,40***

*** *p-value* < 0.01; ** *p-value* < 0.05; * *p-value* < 0.10

MacKinnon (1994) critical values

Table 7.9: Kwiatkowsky-Phillips-Schmidt-Shin test (Pre-filtered dataset)

Hour	EXAA	BELPEX	EPEXFR	EPEXDE	IPEX	APX	BSP	EPEXCH
1	6,91***	0,41*	0,74**	6,03***	2,75***	1,56***	4,75***	1,71***
2	5,60***	0,27	0,91***	4,91***	1,82***	0,69**	4,56***	1,70***
3	4,27***	0,35*	0,62**	3,50***	1,45***	0,71**	3,95***	1,72***
4	3,27***	0,72**	0,39*	2,39***	1,56***	0,90***	3,25***	1,71***
5	3,42***	0,78***	0,46*	2,68***	1,66***	0,80***	3,37***	1,92***
6	4,75***	0,37*	0,62**	4,05***	2,52***	0,79***	4,26***	2,06***
7	3,98***	0,30	0,53**	3,37***	3,45***	0,72**	2,83***	1,45***
8	2,27***	0,26	0,53**	2,25***	3,86***	0,53**	2,03***	1,30***
9	2,86***	0,23	0,48**	2,37***	3,68***	0,48**	1,94***	1,14***
10	4,50***	0,27	0,93***	4,01***	1,90***	0,57**	2,33***	1,46***
11	6,39***	0,36*	1,60***	5,58***	5,30***	0,83***	3,14***	2,23***
12	7,91***	0,55**	2,41***	6,88***	7,20***	0,80***	3,88***	3,19***
13	8,70***	1,12***	3,25***	7,71***	7,12***	0,62**	4,52***	4,09***
14	8,53***	1,23***	3,22***	7,41***	7,12***	0,72**	4,31***	3,99***
15	8,13***	1,38***	3,15***	7,15***	6,19***	0,63**	3,55***	3,46***
16	7,09***	1,30***	3,24***	6,14***	4,37***	0,50**	2,82***	2,80***
17	5,42***	1,06***	2,92***	4,96***	2,70***	0,49**	2,24***	2,35***
18	3,09***	0,34	1,55***	3,04***	1,54***	0,73**	1,74***	1,82***
19	2,00***	0,40*	0,84***	1,99***	2,64***	0,72**	1,57***	1,10***
20	2,12***	0,41*	0,49**	1,76***	4,27***	0,70**	1,80***	0,95***
21	3,26***	0,38*	0,71**	3,14***	4,15***	1,10***	2,25***	1,48***
22	5,08***	0,43*	1,10***	4,16***	3,57***	1,59***	2,15***	1,83***
23	7,75***	0,45*	1,47***	6,75***	4,34***	2,03***	2,82***	1,91***
24	9,29***	0,39*	1,05***	7,95***	3,36***	3,03***	3,61***	1,61***

*** *p-value* < 0.01; ** *p-value* < 0.05; * *p-value* < 0.10

KPSS (1992) critical values

As considering the original data, unit root tests, on the one hand, and stationarity test, on the other hand, show contradictory evidence about the integration properties of the price series, so the models have been set considering two assumptions: first that all the series are stationary and then that all the series contain a unit root.

Table 7.10 displays the information criteria for the determination of the autoregressive order; for all the models, 7 lags are included.

Moreover, 192 autoregressive models have been estimated, as a benchmark reference, one for each hour and for each of the country considered.[29]

Under the hypothesis of unit root for all the series, 24 VEC models are estimated. Johansen (1995) multiple trace test procedure, the maximum eigenvalue test and a method based on minimizing information criteria have been applied to check the possibility of cointegration between the electricity price time series. These methodologies do not provide a unanimous result; therefore the decision is based on the trace statistics. Since the test indicates that the series are cointegrated, the number of cointegrating equations is imposed in the VEC model. For hours 18^{th} and from 21^{nd} to 24^{th}, 4 relations are imposed; 5 relations for hours 6^{th}; 6 for hours 1^{st}, from 11^{th} to 15^{th}, 17^{th} and 19^{th}; and finally 7 for the hours from 2^{nd} to 5^{th}, from 7^{th} to 10^{th} , 16^{th} and 20^{th} (**Table 7.11**).

Also in this case, 192 autoregressive models have been specified one for each hour of the day and each country.

For all the models, under both the hypotheses, the weekly deterministic seasonality of day ahead electricity prices has been captured through the inclusion of dummy variables. Moreover, each model has been extended including load as exogenous value.[30] Each model has been used to make one step ahead forecast in a four weeks out-of-sample interval (from July 1^{st} to July 29^{th}, 2013). Three measures of forecast accuracy have been provided: MAPE, SMAPE and RMSE loss functions.

[29] Lag order is selected trough information criteria, fixing 7 as maximum lag order. A larger lag order is introduced for EPEXCH price hour 7^{th}-8^{th} both in the AR and in the AR-X model, EPEXCH price hour 9^{th}; 13^{th};15^{th}-17^{th} in the AR model, EPEXDE price hours 24^{th} in the AR-X model.

[30] In the model VAR-X, AIC indicates the inclusion of 7 lags for all the hours, but hours 2^{nd}, where 3 lags have been selected (**Table C.16** in Appendix C).

Table 7.10: Lag selection for VAR models estimated (Pre-filtered dataset)

Hour 1					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31725		54,373	54,4645	54,6156
1	-29208,4	5033,3	50,1769	50,3729	50,6967
2	-28969,5	477,69	49,8777	50,1783*	50,6748*
3	-28854,9	229,2	49,7911	50,1963	50,8654
4	-28778,9	152,02	49,7706	50,2804	51,1221
5	-28694,2	169,53	49,7351	50,3494	51,3638
6	-28607,1	174,18	49,6956	50,4145	51,6016
7	-28527,2	159,72*	49,6684*	50,4919	51,8517

Hour 2					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31175,9		53,4336	53,5251	53,6762
1	-28696,2	4959,5	49,3006	49,4966	49,8204*
2	-28508,5	375,39	49,0889	49,3896*	49,886
3	-28404,9	207,21	49,0212	49,4264	50,0955
4	-28345,5	118,68	49,0292	49,5389	50,3807
5	-28273,6	143,82	49,0156	49,63	50,6444
6	-28194,7	157,78	48,9901	49,709	50,8961
7	-28115,2	159,01*	48,9636*	49,7871	51,1469

Hour 3					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31576,4		54,1187	54,2102	54,3613
1	-29299,8	4553,2	50,3333	50,5294	50,8531*
2	-29138,7	322,18	50,1672	50,4678*	50,9643
3	-29044,4	188,72	50,1153	50,5205	51,1896
4	-28965,3	158,2	50,0894	50,5992	51,441
5	-28904,1	122,33	50,0943	50,7086	51,723
6	-28814,7	178,88	50,0508	50,7697	51,9568
7	-28702,1	225,07*	49,9677*	50,7912	52,151

Hour 4					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31621,4		54,1957	54,2872	54,4382
1	-29058	5126,8	49,9196	50,1156	50,4394*
2	-28899,7	316,48	49,7583	50,059*	50,5554
3	-28824,8	149,89	49,7396	50,1448	50,8139
4	-28741,9	165,85	49,7072	50,217	51,0588
5	-28654,5	174,72	49,6673	50,2816	51,296
6	-28561,5	186,03	49,6176	50,3365	51,5236
7	-28471,9	179,11*	49,5739*	50,3974	51,7571

Hour 5					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31421		53,8528	53,9443	54,0954
1	-28939	4964	49,716	49,9121	50,2358*
2	-28768	342,09	49,5329	49,8335*	50,3299
3	-28693,4	149,06	49,5148	49,92	50,5891
4	-28599,9	187,07	49,4643	49,9741	50,8158
5	-28520,5	158,68	49,4381	50,0524	51,0668
6	-28422,1	196,91	49,3791	50,098	51,2851
7	-28345,8	152,59*	49,3581*	50,1815	51,5413

Hour 6					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31276,7		53,606	53,6975	53,8486
1	-28843,5	4866,4	49,5527	49,7487	50,0725*
2	-28673,6	339,89	49,3714	49,672*	50,1685
3	-28597,7	151,74	49,3511	49,7563	50,4254
4	-28506,2	182,95	49,3041	49,8139	50,6556
5	-28371,4	269,69	49,1829	49,7972	50,8116
6	-28258,3	226,25	49,0988	49,8177	51,0048
7	-28139,4	237,68*	49,005*	49,8285	51,1882

Hour 7					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31900		54,6724	54,7639	54,915
1	-30056,1	3687,9	51,6272	51,8232	52,147
2	-29818,1	475,85	51,3296	51,6302	52,1267*
3	-29677,6	281,07	51,1987	51,6039	52,2729
4	-29579,7	195,89	51,1406	51,6503	52,4921
5	-29463,7	232	51,0516	51,666	52,6804
6	-29294,6	338,08	50,8719	51,5908	52,7779
7	-29132,3	324,69*	50,7037*	51,5271*	52,8869

Hour 8					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32473,3		55,6532	55,7447	55,8958
1	-30971,3	3003,9	53,1931	53,3891	53,7129
2	-30702,7	537,26	52,843	53,1436	53,64*
3	-30516	373,37	52,6331	53,0383	53,7074
4	-30431,1	169,82	52,5973	53,1071	53,9488
5	-30328,1	206,05	52,5305	53,1449	54,1593
6	-30196	264,16	52,414	53,1329	54,32
7	-29974,9	442,25*	52,1452*	52,9687*	54,3285

Hour 9					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32538,9		55,7654	55,8569	56,008
1	-31104,2	2869,4	53,4203	53,6164	53,9401*
2	-30878,9	450,55	53,1444	53,445*	53,9415
3	-30758,5	240,84	53,0479	53,4531	54,1222
4	-30670,9	175,12	53,0076	53,5173	54,3591
5	-30614	113,81	53,0197	53,634	54,6485
6	-30495,6	236,89	52,9265	53,6455	54,8326
7	-30255,7	479,78*	52,6256*	53,4491	54,8089

Hour 10					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32125,1		55,0574	55,1489	55,3
1	-30440	3370,1	52,284	52,4801	52,8039*
2	-30259,8	360,48	52,0852	52,3858	52,8822
3	-30118,4	282,7	51,9528	52,358*	53,0271
4	-30017,1	202,6	51,889	52,3988	53,2406
5	-29936,6	161,18	51,8607	52,475	53,4894
6	-29816,2	240,68	51,7643	52,4832	53,6703
7	-29702,6	227,18*	51,6794*	52,5029	53,8627

Hour 11					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32341,7		55,4281	55,5196	55,6706
1	-30459,2	3765	52,3168	52,5129	52,8366*
2	-30271,7	374,98	52,1055	52,4062*	52,9026
3	-30148	247,45	52,0034	52,4086	53,0777
4	-30052,3	191,35	51,9492	52,4589	53,3007
5	-29973,7	157,21	51,9242	52,5385	53,553
6	-29826,6	294,14	51,7821	52,501	53,6881
7	-29686,4	280,36*	51,6517*	52,4752	53,835

Hour 12					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32602,8		55,8747	55,9662	56,1173
1	-30594,8	4015,9	52,5489	52,7449	53,0687*
2	-30411,4	366,79	52,3446	52,6452*	53,1417
3	-30299,2	224,4	52,2621	52,6673	53,3364
4	-30204,4	189,56	52,2095	52,7193	53,561
5	-30145,3	118,33	52,2178	52,8321	53,8465
6	-30011,6	267,43	52,0985	52,8174	54,0045
7	-29899,3	224,44*	52,016*	52,8395	54,1992

* Selected lag

Hour 13					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31860,6		54,6049	54,6964	54,8475
1	-29898,8	3923,5	51,3581	51,5542	51,8779*
2	-29707,5	382,59	51,1403	51,4409	51,9374
3	-29567,2	280,53	51,0098	51,415*	52,0841
4	-29458,7	217,18	50,9335	51,4433	52,2851
5	-29377,5	162,28	50,9042	51,5186	52,533
6	-29241,3	272,52	50,7806	51,4995	52,6866
7	-29069,1	344,22*	50,5956*	51,4191	52,7789

Hour 14					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32076,5		54,9743	55,0658	55,2169
1	-30190	3773,1	51,8562	52,0523	52,376*
2	-29996,1	387,63	51,6341	51,9348	52,4312
3	-29831,3	329,67	51,4616	51,8668	52,5359
4	-29723,6	215,51	51,3867	51,8965	52,7383
5	-29638,5	170,15	51,3507	51,965	52,9795
6	-29425,1	426,86	51,095	51,8139	53,001
7	-29290	270,14*	50,9735*	51,7969*	53,1567

Hour 15					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32783,8		56,1844	56,2759	56,427
1	-30872,7	3822,1	53,0243	53,2204	53,5442*
2	-30665,9	413,72	52,7799	53,0806	53,577
3	-30454,1	423,49	52,5271	52,9323	53,6014
4	-30354,1	200,13	52,4654	52,9752	53,817
5	-30223,9	260,39	52,3522	52,9665	53,981
6	-30050,4	346,86	52,165	52,8839	54,071
7	-29887,6	325,6*	51,9959*	52,8194*	54,1792

Hour 16					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32150,9		55,1016	55,1931	55,3442
1	-30221,7	3858,5	51,9104	52,1065	52,4303*
2	-30004,1	435,17	51,6477	51,9483	52,4447
3	-29865,2	277,81	51,5195	51,9247	52,5938
4	-29757,6	215,09	51,445	51,9548	52,7965
5	-29645,9	223,41	51,3634	51,9777	52,9922
6	-29446,3	399,23	51,1314	51,8503	53,0374
7	-29302,1	288,45*	50,9941*	51,8176*	53,1774

Hour 17					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32339		55,4234	55,5149	55,666
1	-30185,6	4306,8	51,8487	52,0448	52,3685*
2	-29971,4	428,43	51,5917	51,8924	52,3888
3	-29844	254,76	51,4833	51,8885	52,5576
4	-29741,4	205,17	51,4173	51,927	52,7688
5	-29613,6	255,51	51,3082	51,9225	52,937
6	-29425,3	376,72	51,0954	51,8143	53,0014
7	-29286,4	277,82*	50,9673*	51,7908*	53,1505

Hour 18					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-33242		56,9684	57,0599	57,211
1	-30685,9	5112,2	52,7047	52,9008	53,2246
2	-30396,1	579,73	52,3183	52,6189	53,1154*
3	-30268,1	255,93	52,2089	52,6141*	53,2832
4	-30178,5	179,08	52,1652	52,6749	53,5167
5	-30084,5	188,12	52,1138	52,7281	53,7425
6	-29963,7	241,65	52,0165	52,7354	53,9225
7	-29858,8	209,78*	51,9466*	52,77	54,1298

Hour 19					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-33110,5		56,7434	56,8349	56,986
1	-30714,4	4792,2	52,7535	52,9495	53,2733
2	-30471,1	486,66	52,4467	52,7473*	53,2437*
3	-30351,9	238,31	52,3523	52,7575	53,4266
4	-30247,7	208,44	52,2835	52,7933	53,635
5	-30141,9	211,69	52,2119	52,8262	53,8407
6	-30043	197,74	52,1523	52,8712	54,0583
7	-29917,9	250,1*	52,0478*	52,8713	54,231

Hour 20					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32949,3		56,4677	56,5591	56,7102
1	-30582,7	4733,2	52,5282	52,7243	53,048*
2	-30415	335,46	52,3507	52,6514	53,1478
3	-30276,1	277,74	52,2226	52,6278*	53,2969
4	-30176,5	199,28	52,1617	52,6714	53,5132
5	-30096,7	159,62	52,1346	52,749	53,7634
6	-29957,8	277,85	52,0064	52,7253	53,9124
7	-29823,3	268,91*	51,8859*	52,7094	54,0691

Hour 21					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32797,8		56,2084	56,2999	56,451
1	-30058,2	5479,2	51,6309	51,8269	52,1507
2	-29824,3	467,81	51,3402	51,6408	52,1372*
3	-29672	304,6	51,1891	51,5943*	52,2634
4	-29571,8	200,54	51,1271	51,6368	52,4786
5	-29481,2	181,09	51,0816	51,696	52,7104
6	-29327,5	307,48	50,9281	51,647	52,8341
7	-29221,6	211,79*	50,8564*	51,6799	53,0397

Hour 22					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-32137,3		55,0784	55,1699	55,321
1	-29113,6	6047,5	50,0147	50,2108	50,5345
2	-28872,4	482,45	49,7115	50,0121	50,5086*
3	-28720,1	304,59	49,5604	49,9656*	50,6347
4	-28605,2	229,67	49,4735	49,9832	50,825
5	-28507,5	195,43	49,4158	50,0301	51,0445
6	-28397,5	219,96	49,3371	50,056	51,2431
7	-28298,7	197,74*	49,2775*	50,1009	51,4607

Hour 23					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31036,4		53,1948	53,2863	53,4374
1	-27894,8	6283,2	47,9295	48,1256	48,4493
2	-27646,9	495,79	47,6149	47,9155	48,412*
3	-27498,1	297,63	47,4698	47,875*	48,5441
4	-27389,9	216,44	47,3941	47,9039	48,7457
5	-27298,7	182,34	47,3477	47,962	48,9764
6	-27188,3	220,83	47,2682	47,9871	49,1742
7	-27098,9	178,86*	47,2247*	48,0482	49,408

Hour 24					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-30996,4		53,1265	53,218	53,369
1	-27694	6604,8	47,586	47,782	48,1058
2	-27457,4	473,17	47,2907	47,5913	48,0878*
3	-27270,3	374,24	47,0801	47,4853*	48,1544
4	-27166,4	207,79	47,0118	47,5216	48,3633
5	-27057,3	218,23	46,9346	47,549	48,5634
6	-26962,4	189,84	46,8817	47,6006	48,7877
7	-26887,1	150,47*	46,8625*	47,686	49,0457

* Selected lag

Table 7.11: Cointegration rank (Pre-filtered dataset)

Hour 1

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	402,7624	161,3705	52,61664	51,4519	50,73805
1	241,3919	73,275	52,56606*	51,35279	50,60919
2	168,1169	47,3965	52,58946	51,33373	50,5641
3	120,7203	43,1812*	52,62486	51,33273	50,54079
4	77,5392	30,5319	52,65069	51,32823	50,5177
5	47,0073	24,3154	52,67536	51,32863	50,50323
6	22,6919*	11,6559	52,69244	51,32752*	50,49096
7	11,036	11,036	52,70837	51,33131	50,48732*
8					

Hour 2

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	438,6832	174,1294	51,98962	50,82488	50,11102
1	264,5538	78,1517	51,92633*	50,71306	49,96946
2	186,4021	55,6867	51,94487	50,68913	49,9195
3	130,7154	41,1683	51,97201	50,67988	49,88794
4	89,547	34,8032	51,99985	50,67739	49,86686
5	54,7438	28,8965	52,02026	50,67353	49,84813
6	25,8473	14,8994*	52,03278	50,66786*	49,8313
7	10,9479*	10,9479	52,04548	50,66842	49,82443
8			52,04834	50,66522	49,81751*

Hour 3

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	462,4315	175,3782	52,88675	51,72201	51,00815
1	287,0533	87,8302	52,82222*	51,60895	50,86534
2	199,2231	64,3838	52,83111	51,57538	50,80575
3	134,8393	46,9602	52,8496	51,55747	50,76553
4	87,8792	37,4667	52,87167	51,5492	50,73868
5	50,4125	24,8555*	52,88942	51,5427	50,7173
6	25,5569	16,2219	52,90597	51,54105	50,70449
7	9,335*	9,335	52,91735	51,54029*	50,6963
8			52,92182	51,5387	50,69099*

Hour 4

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	446,1103	158,7833	52,45648	51,29174	50,57788
1	287,327	96,9018	52,40848	51,19521	50,4516
2	190,4253	62,5258	52,40834*	51,15261	50,38298
3	127,8995	48,1731	52,42867	51,13654	50,3446
4	79,7264	34,4864	52,44953	51,12707	50,31654
5	45,24	19,804*	52,47026	51,12353*	50,29813
6	25,436	16,8081	52,49184	51,12691	50,29036
7	8,6279*	8,6279	52,50263	51,12557	50,28158
8			52,50781	51,12468	50,27698*

Hour 5

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	470,7966	148,2693	52,19493	51,03019	50,31633
1	322,5273	121,0358	52,1574	50,94413	50,20052
2	201,4915	69,2393	52,13322*	50,87749	50,10786
3	132,2522	54,4964	52,14687	50,85474	50,0628
4	77,7557	33,1074*	52,16143	50,83897	50,02844
5	44,6483	18,5375	52,18353	50,8368*	50,0114
6	26,1108	17,3481	52,20637	50,84144	50,00489
7	8,7627*	8,7627	52,21663	50,83957	49,99558
8			52,22167	50,83854	49,99084*

Hour 6

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	415,3475	145,5426	51,87914	50,7144	50,00054
1	269,8049	91,6662	51,84432*	50,63105	49,88745
2	178,1387	63,795	51,8494	50,59367	49,82404
3	114,3437	46,255	51,86847	50,57634	49,7844
4	68,0887	27,9997*	51,89124	50,56878*	49,75825
5	40,089*	18,1634	51,91843	50,5717	49,7463
6	21,9256	12,2714	51,94164	50,57671	49,74016
7	9,6542	9,6542	51,95695	50,5799	49,7359
8			51,96111	50,57798	49,73027*

Hour 7

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	444,1611	163,1832	53,93701	52,77227	52,05841
1	280,9778	91,5873	53,88462*	52,67135	51,92775
2	189,3905	55,5055	53,88978	52,63405	51,86442
3	133,8851	52,166	53,9171	52,62497	51,83304
4	81,7191	36,3521	53,93399	52,61153	51,801
5	45,3671	20,626*	53,95285	52,60613*	51,78073
6	24,7411	15,0574	53,97362	52,60869	51,77214
7	9,6837*	9,6837	53,98616	52,6091	51,76511
8			53,99028	52,60715	51,75944*

Hour 8

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	545,0017	172,9759	55,70019	54,53545	53,82159
1	372,0258	116,954	55,63805	54,42478	53,68118
2	255,0718	101,2927	55,61794	54,36221	53,59258
3	153,7791	57,4093	55,59966*	54,30753	53,51559
4	96,3698	41,9362	55,61132	54,28886	53,47833
5	54,4336	25,9545*	55,62463	54,2779	53,4525
6	28,4791	17,2791	55,64008	54,27516	53,4386
7	11,2001*	11,2001	55,65041	54,27335*	53,42936
8			55,65302	54,2699	53,42219*

Hour 9

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	517,0743	207,862	56,15411	54,98937	54,27551
1	309,2123	94,292	56,05722*	54,84395	54,10035
2	214,9204	71,3532	56,05968	54,80395	54,03432
3	143,5672	52,7023	56,07122	54,77909	53,98715
4	90,8649	37,2877	56,08757	54,76511	53,95458
5	53,5772	25,9866*	56,10551	54,75878	53,93338
6	27,5906	14,8758	56,12093	54,756*	53,91945
7	12,7147*	12,7147	56,13365	54,75659	53,9126
8			56,13475	54,75163	53,90392*

Hour 10

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	463,2117	205,9892	55,02335	53,85862	53,14476
1	257,2225	85,2047	54,92833*	53,71507	52,97146
2	172,0178	48,0454	54,93985	53,68411	52,91448
3	123,9724	41,967	54,9746	53,68247	52,89054
4	82,0053	30,0817*	55,00165	53,67918	52,86866
5	51,9236	25,1179	55,02676	53,68003	52,85463
6	26,8057	14,5638	55,04304	53,67812*	52,84156
7	12,2419*	12,2419	55,05608	53,67902	52,83503
8			55,05765	53,67453	52,82682*

Hour 11

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	446,2141	204,8905	54,89654	53,73181	53,01795
1	241,3235	79,3187	54,80262*	53,58935	52,84575
2	162,0048	48,2397	54,81999	53,56426	52,79463
3	113,7651	42,1557	54,85456	53,56243	52,77049
4	71,6094	27,1101*	54,88141	53,55895*	52,74842
5	44,4992	22,2684	54,90948	53,56275	52,73735
6	22,2309*	13,3103	54,92861	53,56368	52,72713
7	8,9206	8,9206	54,94289	53,56583	52,72184
8			54,94777	53,56465	52,71694*

Hour 12

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	453,178	196,6299	55,14053	53,97579	53,26194
1	256,5481	73,2279	55,05483*	53,84157	53,09796
2	183,3203	57,0776	55,07828	53,82254	53,05291
3	126,2426	46,5626	55,10404	53,81191	53,01997
4	79,68	31,6174*	55,1265	53,80404	52,99351
5	48,0626	25,8174	55,15008	53,80336	52,97796
6	22,2453*	13,9519	55,16567	53,80075*	52,96419
7	8,2934	8,2934	55,17931	53,80226	52,95827
8			55,18482	53,8017	52,95399*

Hour 13

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	464,4146	186,5957	53,8456	52,68086	51,967
1	277,819	89,1011	53,76989*	52,55663	51,81302
2	188,7178	56,0891	53,77753	52,52179	51,75217
3	132,6287	50,1578	53,80427	52,51214	51,7202
4	82,4709	34,0897	53,82316	52,50069	51,69017
5	48,3812	26,2937*	53,84428	52,49755	51,67215
6	22,0875*	14,7673	53,85939	52,49447*	51,65791
7	7,3202	7,3202	53,87222	52,49516	51,65117
8			53,8787	52,49557	51,64786*

Hour 14

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	484,4507	182,0299	54,28515	53,12041	52,40655
1	302,4208	93,7498	54,21399*	53,00072	52,25712
2	208,671	69,2036	54,21699	52,96126	52,19163
3	139,4674	50,0313	54,23068	52,93855	52,14661
4	89,4361	37,7953	54,24969	52,92722	52,1167
5	51,6408	28,5826	54,26711	52,92039	52,09499
6	23,0582*	14,7484*	54,27995	52,91502*	52,07847
7	8,3097	8,3097	54,2928	52,91574	52,07175
8			54,29829	52,91516	52,06746*

Hour 15

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	486,9567	184,9442	55,31781	54,15308	53,43922
1	302,0125	98,4245	55,24375	54,03049	53,28688
2	203,588	65,0461	55,2421*	53,98637	53,21674
3	138,5419	54,9106	55,25992	53,96779	53,17586
4	83,6314	33,9874	55,27408	53,95161	53,14109
5	49,644	25,3726*	55,2953	53,94857	53,12317
6	24,2715*	15,7524	55,31133	53,9464	53,10985
7	8,5191	8,5191	55,32318	53,94612*	53,10213
8			55,32846	53,94534	53,09763*

Hour 16

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	473,6837	189,604	54,29834	53,13361	52,41975
1	284,0797	90,0225	54,21964*	53,00637	52,26277
2	194,0573	61,6697	54,22636	52,97063	52,201
3	132,3876	52,1167	54,24754	52,95541	52,16348
4	80,2709	31,3917*	54,26448	52,94202	52,13149
5	48,8793	24,0461	54,28828	52,94156	52,11616
6	24,8331	15,1766	54,30564	52,94071*	52,10416
7	9,6565*	9,6565	54,31806	52,941	52,09701
8			54,32221	52,93909	52,09138*

Hour 17

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	463,8329	173,8833	54,25146	53,08672	52,37286
1	289,9496	86,0829	54,18841*	52,97515	52,23154
2	203,8667	74,4221	54,19905	52,94332	52,17369
3	129,4446	52,3416	54,20754	52,91541	52,12347
4	77,1031	29,5316*	54,22425	52,90179*	52,09126
5	47,5715	23,8499	54,24991	52,90318	52,07778
6	23,7216*	14,4766	54,26746	52,90253	52,06598
7	9,245	9,245	54,28058	52,90352	52,05953
8			54,28514	52,90201	52,0543*

Hour 18

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	490,5536	211,9242	55,3449	54,18017	53,46631
1	278,6294	99,7528	55,24397	54,0307	53,2871
2	178,8766	61,9041	55,241*	53,98526	53,21563
3	116,9725	58,44	55,26195	53,96982	53,17788
4	58,5325*	23,6029*	55,27258	53,95012*	53,13959
5	34,9296	16,1201	55,30415	53,95742	53,13202
6	18,8095	13,2001	55,3294	53,96447	53,12792
7	5,6094	5,6094	55,34379	53,96673	53,12274
8			55,35197	53,96884	53,12113*

Hour 19

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	483,0292	212,2497	55,54485	54,38011	53,66625
1	270,7795	74,8193	55,44359*	54,23032	53,48672
2	195,9601	64,3519	55,46545	54,20972	53,44009
3	131,6082	52,7552	55,48396	54,19183	53,39989
4	78,853	34,989	55,50026	54,1778	53,36727
5	43,864	21,8075*	55,52048	54,17376*	53,34836
6	22,0565*	15,6841	55,54007	54,17514	53,33859
7	6,3724	6,3724	55,55198	54,17492	53,33093
8			55,55941	54,17628	53,32857*

Hour 20

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	423,3563	165,5931	55,29699	54,13225	53,41839
1	257,7631	76,5647	55,24221*	54,02894	53,28533
2	181,1984	62,6244	55,26232	54,00659	53,23696
3	118,574	41,9938	55,28256	53,99043	53,19849
4	76,5801	31,2358*	55,30958	53,98711	53,17659
5	45,3444	19,7344	55,33354	53,98681*	53,16141
6	25,61	16,2336	55,35519	53,99026	53,15371
7	9,3763*	9,3763	55,36656	53,9895	53,14551
8			55,37098	53,98786	53,14015*

Hour 21

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	366,5048	146,8732	54,00185	52,83711	52,12325
1	219,6315	69,7228	53,96571*	52,75244	52,00883
2	149,9088	53,3644	53,99264	52,73691	51,96728
3	96,5444	38,7235*	54,0221	52,72997	51,93803
4	57,8209*	22,4612	54,05237	52,72991*	51,91938
5	35,3597	15,47	54,08507	52,73835	51,91295
6	19,8896	10,6407	54,11097	52,74604	51,90949
7	9,249	9,249	54,12791	52,75085	51,90686
8			54,13246	52,74934	51,90163*

Hour 22

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	366,0554	161,1443	52,38746	51,22272	50,50886
1	204,9112	74,1998	52,3371*	51,12383	50,38023
2	130,7114	41,6503*	52,35958	51,10384*	50,33421
3	89,0611	35,1151	52,4007	51,10857	50,31663
4	53,946*	22,9421	52,43457	51,11211	50,30158
5	31,0039	12,0977	52,46679	51,12006	50,29466
6	18,9062	11,8091	52,49605	51,13112	50,29457
7	7,0971	7,0971	52,51182	51,13476	50,29077
8			52,51852	51,1354	50,28769*

Hour 23

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	385,6873	179,0755	50,16994	49,00521	48,29135
1	206,6119	64,7025	50,10173*	48,88846	48,14486
2	141,9094	47,6412	50,13366	48,87793	48,1083
3	94,2682	42,7787	50,16882	48,87669	48,08476
4	51,4895*	25,1264*	50,19506	48,8726*	48,06207
5	26,3632	12,9334	50,2251	48,87838	48,05298
6	13,4298	7,8602	50,25353	48,8886	48,05205
7	5,5695	5,5695	50,27324	48,89618	48,05219
8			50,28146	48,89833	48,05062*

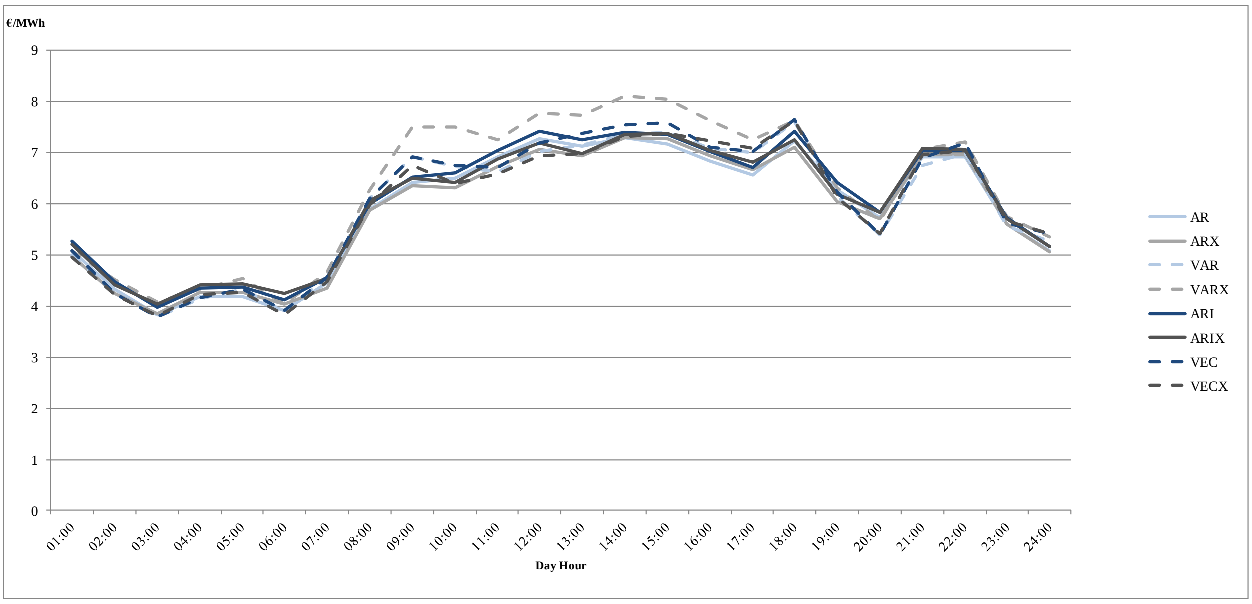
Hour 24

Maximum rank	J_{Trace} Test	J_{max} Test	Information Criteria		
			Schwarz	Hannan-Quinn	Akaike
0	381,4553	171,899	49,70847	48,54373	47,82987
1	209,5563	66,8141	49,6474*	48,43413	47,69053
2	142,7422	51,9355	49,67723	48,4215	47,65187
3	90,8067	36,8719*	49,70811	48,41598*	47,62404
4	53,9348*	23,5379	49,74023	48,41777	47,60724
5	30,3968	15,6056	49,77186	48,42513	47,59973
6	14,7912	8,0654	49,79762	48,43269	47,59614
7	6,7258	6,7258	49,81712	48,44006	47,59607
8			49,82419	48,44107	47,59336*

7.2.4 Results

As considering the original dataset, high hourly average errors have been registered for the hours with higher load. This result was expected since, as explained in the section 7.1.2 it depends from the electricity market structure (**Figure 7.7**).

Figure 7.7: Average hourly RMSE (Pre-filtered dataset)



The SMAPE measures for the out-of-sample period (July 1st, 2013 – July 29th, 2013) are shown in **Table 7.13**, **Table 7.14**, **Table 7.15** and **Table 7.16**. The tables reporting MAPE and RMSE values are in the Appendix C of the present chapter.

Considering the hours with spike presence, a heavy reduction of the errors has been observed. SMAPE average values of Belgian day ahead price time series at hour 8th computed on forecasts based on the original dataset are higher than 30%, with particular bad performance of AR (48%) and VAR-X model (43%). Forecasting on the pre-filtered data have led to lower SMAPE values, ranging between 17% and 23%, according to the considered model. An analogous situation holds for France for hours from 9th to 12th, where using the pre-filtered dataset leads to SMAPE errors ranging from 15% to 17%.

When all the hours of the day are considered and regardless of the estimated model SMAPE values for Belgium and French market decreased from 20% to 18% and from 24% to 17% respectively. Generally speaking, better forecasting performances are obtained for the remaining countries, but forecasting performance after pre-filtering data improve more slightly, since SMAPE indicators have decreased from average values of 12% to 11% for Austria, from 13% to 12% for

Germany, from 11% to 10% for Switzerland. Average SMAPE errors of the Italian, Dutch and Slovenian prices forecasts are almost the same both using original and pre-filtered data (**Table 7.12**).

Table 7.12: The average SMAPE errors for all the hours of the day (%) (Pre-filtered dataset)

	Austria	Belgium	France	Germany	Italy	Netherland	Slovenia	Switzerland
AR	10,89	18,10	17,01	12,10	8,72	10,76	12,38	10,02
AR-X	10,32	18,27	16,77	12,07	8,52	10,60	12,42	10,33
VAR	10,89	18,26	17,10	12,26	8,67	10,74	13,42	10,80
VAR-X	12,12	19,11	17,57	12,81	8,78	11,12	14,22	11,58
ARI	11,10	17,97	17,47	12,29	8,94	10,91	13,06	9,86
ARI-X	10,57	18,44	17,06	12,30	8,50	10,66	12,98	10,15
VEC	10,93	18,17	17,35	12,42	8,80	10,81	13,62	10,93
VEC-X	9,84	17,90	17,07	12,15	8,45	11,09	13,97	10,17

MAPE and SMAPE analyses qualitatively confirm the results obtained with the original dataset in terms of comparison between multiple times series and simple time series: multiple time series models do not necessarily improve forecasting performances compared with those obtained from simple time series models.

More specifically, under the assumption that all the price series are stationary, VAR models result in better forecasting performances compared with AR models in 73 cases less than 40% of combinations between hours of the day and countries. However, this value decreases to 41 cases just 21% when both VAR and AR models are extended to the corresponding VAR-X and AR-X models, by introducing exogenous variables. Under the assumption that all the price series contain unit roots, VEC models outperform ARI models in 86 cases, equal to 45% of combinations between hours of the day and countries and a similar value (99 cases, equal to 52%) is obtained when exogenous variables are added and VEC-X and ARI-X models are compared. Just a slight improvement in VEC-X performance has been registered compared to the performances obtained on the original dataset, possibly due to the removal of the spikes that represent short term deviation from the long term pattern.

Table 7.13: SMAPE errors from AR and VAR models (Pre-filtered dataset)

				AR				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**6,00**	19,96	**12,33**	6,20	**4,93**	**18,48**	**7,82**	**9,96**
2	**6,75**	18,84	16,76	**9,05**	6,45	11,32	**7,56**	**9,74**
3	**7,03**	20,30	**20,48**	**9,33**	7,71	7,83	**7,47**	**8,23**
4	8,15	**27,97**	**27,28**	**10,33**	9,67	**8,78**	**9,01**	9,24
5	**7,15**	**27,28**	**27,24**	**10,92**	9,62	**10,17**	**9,32**	**7,64**
6	**7,37**	19,16	18,10	**12,75**	**8,53**	**8,66**	**9,94**	6,28
7	**8,55**	**18,36**	16,19	**11,17**	**7,47**	10,76	**11,34**	**8,43**
8	**9,29**	18,74	**16,97**	**11,75**	**6,55**	9,41	14,88	**9,60**
9	**9,03**	**15,94**	**14,85**	**9,54**	**8,95**	**8,93**	**17,33**	**8,42**
10	11,58	**15,92**	**15,37**	13,18	8,81	**9,64**	**15,21**	**9,09**
11	13,38	16,16	**16,39**	15,93	9,14	10,52	**13,57**	11,28
12	15,81	17,96	**18,19**	18,03	10,93	**7,98**	**10,18**	12,19
13	16,00	17,32	17,83	18,63	12,29	**10,35**	**9,92**	**12,64**
14	19,21	19,09	18,59	18,46	15,89	**9,91**	**11,71**	**14,49**
15	18,38	**21,40**	19,86	20,30	16,35	**9,60**	**12,89**	**15,95**
16	17,14	19,27	17,36	**17,48**	11,74	**10,07**	**16,57**	**15,24**
17	17,18	**15,47**	**13,35**	**13,75**	**8,94**	**11,71**	**18,46**	**14,77**
18	**13,31**	**16,60**	**15,64**	**11,69**	**8,06**	14,39	**19,75**	**12,10**
19	**10,56**	**15,68**	**14,35**	**9,21**	**5,50**	**11,56**	15,58	**10,01**
20	7,99	17,19	16,12	7,65	6,66	10,34	7,19	7,65
21	9,57	18,51	18,99	**9,76**	**6,05**	11,88	11,43	7,81
22	**7,31**	**16,06**	17,15	**9,20**	**8,82**	**9,39**	**16,19**	**6,27**
23	8,03	**10,95**	9,72	**9,43**	**5,83**	**9,73**	**12,26**	6,94
24	**6,51**	**10,26**	**9,11**	**6,62**	**4,33**	**16,92**	**11,66**	**6,60**
				VAR				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	6,72	**16,68**	10,95	**7,42**	5,56	18,44	8,44	10,95
2	7,30	**16,91**	**16,13**	9,51	**6,26**	**11,35**	8,84	10,51
3	7,91	**18,27**	21,17	9,96	**7,15**	**7,47**	7,56	8,67
4	**7,24**	28,31	28,18	10,64	**8,84**	9,31	9,53	**8,70**
5	8,11	30,81	29,74	10,23	**9,15**	10,64	9,99	8,55
6	8,17	**19,18**	**18,20**	11,41	8,55	8,75	10,65	**6,59**
7	8,20	21,40	**18,96**	11,55	7,80	**10,26**	12,18	10,37
8	10,20	**21,04**	19,28	12,58	7,17	**8,88**	**13,95**	10,83
9	10,13	18,59	16,46	11,55	9,89	9,49	19,78	8,74
10	**11,46**	16,64	15,13	**12,36**	**9,89**	9,80	17,73	10,40
11	**11,31**	**16,24**	14,92	**14,74**	**8,97**	**8,69**	15,53	**10,71**
12	**13,77**	**17,67**	16,96	**16,80**	**10,23**	8,63	10,32	**10,92**
13	**14,71**	**16,28**	**16,79**	**17,62**	**11,90**	10,63	10,93	13,41
14	**19,76**	**18,58**	**18,02**	**18,88**	**14,46**	10,24	12,69	17,63
15	**19,33**	21,80	**19,12**	**19,58**	**15,11**	10,16	15,86	17,31
16	**16,81**	**18,34**	**16,66**	16,91	**10,46**	10,42	20,28	18,44
17	**17,59**	16,56	15,20	15,13	9,35	11,91	20,88	17,54
18	14,58	20,14	16,37	12,72	7,91	**13,96**	22,30	14,06
19	10,38	15,25	14,78	9,57	5,60	11,66	**13,82**	9,06
20	**7,62**	**15,16**	**14,11**	**6,93**	**6,76**	**9,48**	**6,74**	**6,99**
21	**8,81**	**16,62**	**17,73**	10,41	6,37	**11,65**	**11,65**	**7,83**
22	7,56	16,35	**16,24**	10,14	9,28	9,11	17,63	7,31
23	**7,39**	11,02	**9,70**	10,14	6,43	9,98	12,36	**6,25**
24	6,36	10,34	9,56	7,60	5,06	16,94	12,55	7,41

Table 7.14: SMAPE errors from AR-X and VAR-X models (Pre-filtered dataset)

				AR-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**5,83**	**17,64**	12,95	**6,60**	**4,86**	**18,42**	**7,89**	**9,79**
2	**6,07**	18,26	18,92	**9,99**	**6,39**	**11,09**	**7,76**	**9,85**
3	**6,28**	21,66	21,55	**9,74**	7,51	**7,32**	8,87	**8,45**
4	**7,03**	**29,15**	**29,67**	12,66	9,69	**8,90**	**9,67**	**9,24**
5	**8,62**	**28,64**	**27,00**	11,20	9,67	**10,17**	**9,86**	**7,60**
6	9,36	20,17	19,03	13,14	8,42	**7,85**	**10,23**	**6,29**
7	**8,37**	**20,46**	18,36	**9,13**	7,67	**8,90**	**10,31**	**8,32**
8	**9,74**	**20,26**	**16,91**	**10,68**	**6,77**	**7,85**	**13,27**	**9,27**
9	**9,77**	**15,77**	**13,04**	**8,88**	**9,18**	**8,32**	**15,39**	**9,82**
10	**11,10**	**16,15**	**14,50**	12,81	**9,41**	**9,22**	**12,99**	**10,33**
11	**11,68**	16,60	**14,94**	15,53	**9,18**	10,40	**12,33**	**11,72**
12	**14,02**	17,46	**16,02**	17,43	10,05	**8,51**	**9,71**	**12,59**
13	**14,43**	**16,65**	**16,33**	**17,88**	**11,00**	**10,24**	**10,11**	**13,57**
14	**18,02**	**18,68**	**17,78**	**17,65**	**14,36**	**10,42**	**12,48**	**14,56**
15	**17,21**	**21,29**	**18,53**	**19,57**	**14,48**	**10,32**	**14,05**	**16,67**
16	**15,14**	**18,85**	**16,16**	**17,36**	11,07	**10,86**	**17,37**	**16,28**
17	**15,74**	**16,62**	**13,78**	**13,85**	**8,89**	11,72	**18,68**	**15,25**
18	**12,19**	**16,78**	**15,27**	**12,33**	8,33	**13,94**	**19,81**	**12,78**
19	**9,80**	**15,46**	**12,97**	**9,81**	5,77	**11,59**	**14,31**	**10,38**
20	**7,32**	16,55	15,31	7,91	6,79	10,59	**8,87**	7,53
21	**9,05**	17,99	18,08	**10,02**	**6,12**	**11,85**	13,01	**7,91**
22	**7,00**	**16,23**	**16,60**	**9,21**	**8,84**	**9,29**	**16,54**	**6,27**
23	**7,79**	**10,74**	**9,69**	**9,50**	**5,85**	**9,68**	**12,75**	**7,00**
24	**6,06**	**10,52**	**9,14**	**6,89**	**4,28**	**16,86**	**11,79**	**6,58**
				VAR-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	7,81	16,26	**10,71**	8,52	5,55	18,40	7,99	10,58
2	8,41	**18,47**	**16,77**	11,91	6,46	11,86	8,78	11,10
3	9,51	**20,28**	**20,91**	10,79	**6,96**	8,48	**7,47**	9,92
4	8,31	28,68	29,31	**10,62**	**8,67**	9,47	9,97	9,50
5	8,63	32,12	30,36	**11,58**	**9,03**	11,04	10,63	10,78
6	**8,65**	**20,30**	**18,91**	**11,54**	**8,29**	9,22	11,12	8,04
7	10,07	23,92	**19,56**	9,85	**7,71**	10,13	11,40	10,76
8	12,34	23,21	20,21	11,95	7,41	8,22	14,76	12,15
9	13,52	19,20	17,26	11,26	10,48	9,64	20,14	11,17
10	13,72	17,12	15,98	**12,22**	11,60	10,53	18,98	12,66
11	13,57	**17,19**	15,32	**15,07**	9,71	**9,89**	16,19	11,71
12	15,30	**18,43**	16,61	**17,06**	**10,40**	9,55	12,38	11,71
13	17,00	**17,29**	17,54	19,53	11,76	11,06	12,90	13,84
14	21,08	19,96	19,04	21,91	14,70	11,19	14,80	17,25
15	19,91	21,95	19,92	21,65	14,91	11,12	18,01	16,75
16	17,78	19,57	18,38	18,27	**10,34**	11,14	22,11	18,17
17	17,22	18,54	17,09	15,45	9,07	**11,74**	21,33	18,11
18	14,58	20,37	16,88	13,28	**7,52**	13,62	23,17	14,19
19	11,12	15,00	14,26	9,57	**5,75**	12,24	14,29	9,82
20	8,94	**14,82**	**13,16**	**7,56**	**6,95**	**10,03**	9,02	**7,52**
21	10,43	**16,88**	**16,99**	9,83	6,43	11,88	**12,70**	9,30
22	8,56	17,22	16,77	9,72	9,07	9,32	17,89	8,29
23	8,33	11,13	10,23	10,42	6,55	10,06	12,76	6,71
24	6,11	10,65	9,59	7,96	5,32	17,08	12,49	7,96

Table 7.15: SMAPE errors from ARI and VEC models (Pre-filtered dataset)

				ARI				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**6,46**	20,79	14,45	7,43	**4,98**	18,82	**8,38**	**9,42**
2	7,32	21,84	19,43	**9,00**	6,44	**10,89**	**9,14**	**9,56**
3	**7,61**	21,92	22,07	10,87	7,60	**6,76**	9,37	**8,06**
4	8,78	28,91	28,20	**12,28**	9,39	9,37	10,78	8,95
5	8,52	**27,81**	28,82	11,89	9,57	10,90	11,32	**7,69**
6	**8,29**	18,21	17,98	**13,05**	**8,51**	10,14	12,52	6,80
7	9,20	18,47	19,74	**11,27**	7,88	10,97	**12,06**	**8,68**
8	**9,08**	**17,04**	**16,79**	**13,37**	**6,84**	**9,32**	**14,36**	**9,60**
9	**9,33**	**13,74**	**13,91**	**9,74**	**9,08**	**8,81**	**18,20**	**8,79**
10	11,70	**15,05**	**15,02**	12,82	8,76	10,17	**15,88**	**8,88**
11	12,77	16,35	**16,51**	15,96	9,76	10,68	**13,92**	**10,54**
12	15,90	17,88	**17,69**	17,88	11,40	**7,83**	10,99	**11,52**
13	15,98	16,45	**17,71**	18,71	12,58	**10,55**	**10,38**	**12,46**
14	18,94	17,72	18,33	17,89	16,37	**10,11**	**12,62**	**13,66**
15	18,46	**20,29**	19,16	**18,99**	16,88	**9,51**	**13,78**	**15,23**
16	16,74	**16,84**	**16,41**	**16,17**	12,46	**10,18**	**17,17**	**14,69**
17	16,96	**13,57**	**14,01**	**13,18**	**9,61**	**11,58**	**18,27**	**14,12**
18	**12,81**	**16,46**	**15,25**	**11,63**	**8,63**	14,58	**20,10**	**11,92**
19	**10,50**	**16,01**	**14,39**	**9,97**	**5,85**	**11,87**	15,40	**10,33**
20	8,29	17,82	16,56	7,38	6,63	10,62	6,47	7,64
21	9,74	19,20	**19,35**	**9,63**	**6,17**	12,07	11,79	7,95
22	**7,25**	**16,78**	**17,62**	**9,13**	**8,83**	9,39	**16,48**	**6,25**
23	8,36	11,18	10,21	**9,73**	**5,86**	10,00	**12,09**	6,56
24	7,33	10,98	9,78	**7,03**	**4,36**	**16,73**	**12,06**	**7,27**
				VEC				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	6,67	**16,60**	**11,47**	**7,95**	5,90	**18,47**	9,44	10,88
2	**7,32**	**16,97**	**16,23**	9,48	**6,43**	11,28	8,86	10,43
3	7,91	**18,64**	**21,39**	**9,93**	**7,00**	7,36	**7,58**	8,65
4	**7,30**	**28,11**	**28,13**	10,57	**8,80**	**9,40**	**9,54**	**8,68**
5	**8,13**	30,36	**29,79**	**10,25**	**9,16**	**10,66**	**10,03**	8,50
6	8,76	**18,54**	**18,14**	11,23	8,50	**9,05**	**10,75**	**7,06**
7	**8,18**	**21,00**	**19,06**	11,56	**7,93**	**10,29**	12,30	10,42
8	10,14	21,12	19,31	12,62	7,29	8,91	13,82	10,77
9	10,04	18,37	16,27	11,54	10,08	9,55	19,77	8,55
10	**11,46**	16,76	15,21	**12,36**	**9,90**	**9,84**	17,70	10,71
11	**11,44**	**15,95**	15,77	**14,93**	**8,84**	**8,73**	15,88	11,00
12	**14,07**	**17,11**	16,80	**16,99**	**10,28**	8,74	**11,04**	11,89
13	**14,81**	**16,02**	17,24	**18,50**	**11,91**	10,77	11,55	14,18
14	**20,20**	**17,75**	**18,49**	**19,40**	**14,53**	10,50	13,25	18,22
15	**19,50**	21,46	**19,27**	19,51	**15,59**	10,29	16,80	17,71
16	**16,75**	18,69	16,76	16,86	**10,72**	10,40	20,41	18,44
17	**17,26**	15,55	14,14	13,97	9,74	11,91	20,89	17,63
18	14,00	19,86	15,94	12,72	8,41	**14,10**	22,03	13,89
19	10,48	15,70	15,37	9,72	6,13	11,81	**13,55**	8,68
20	**7,76**	**15,26**	**14,39**	**6,88**	**6,76**	**9,51**	**6,04**	**6,90**
21	**8,35**	**16,91**	19,31	10,44	6,41	**11,69**	**12,10**	**7,66**
22	7,43	17,69	18,37	10,39	9,24	**9,20**	17,84	7,22
23	**7,61**	**11,07**	**9,76**	10,98	6,54	**9,94**	12,46	**6,39**
24	**6,80**	**10,53**	**9,72**	9,27	5,06	16,97	13,23	7,93

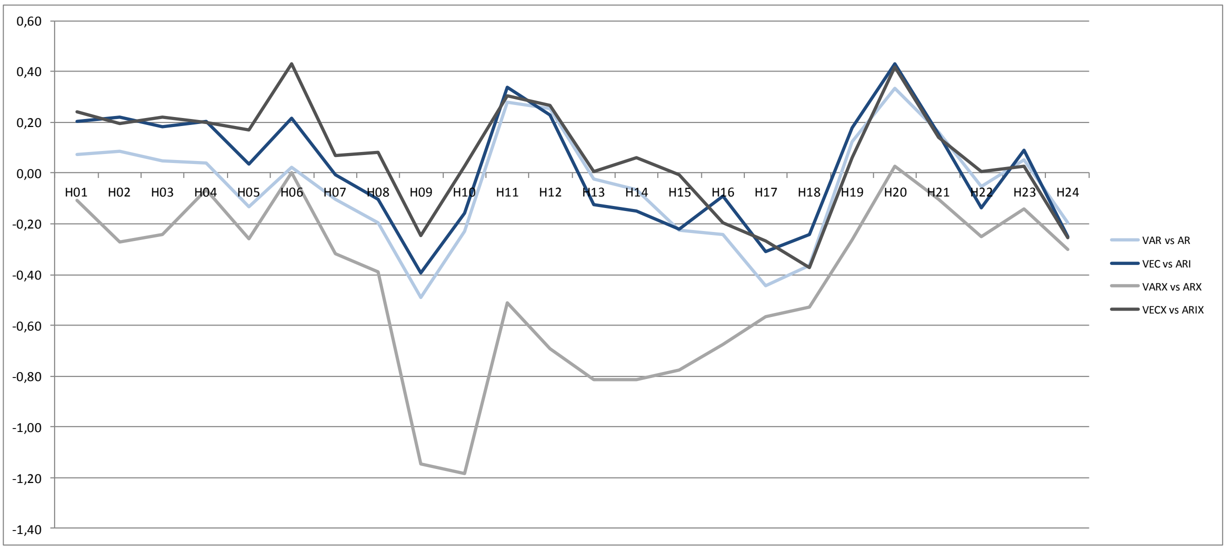
Table 7.16: SMAPE errors from ARI-X and VEC-X models (Pre-filtered dataset)

				ARI-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	6,42	19,20	14,10	7,17	**5,00**	**18,67**	**8,49**	**9,37**
2	6,51	20,50	19,90	9,66	6,46	**10,87**	9,27	9,74
3	**7,04**	22,87	23,87	10,76	7,45	**6,70**	10,00	**8,63**
4	7,60	30,95	29,71	**12,02**	9,43	**9,86**	11,17	9,04
5	9,40	29,14	27,80	**11,21**	9,62	**10,86**	11,69	**7,74**
6	10,15	20,23	18,82	**13,08**	**8,45**	**8,99**	12,46	6,75
7	9,03	21,07	20,01	**9,84**	**7,79**	**8,65**	11,08	8,42
8	10,10	**19,68**	**16,89**	**12,58**	**6,69**	**8,01**	**12,75**	**9,53**
9	9,98	**14,80**	**12,82**	**9,61**	**8,91**	**8,26**	**16,06**	**9,56**
10	11,10	**16,11**	**14,51**	13,09	8,46	**9,76**	**13,20**	10,07
11	11,70	17,00	**14,97**	15,85	8,91	10,71	**12,35**	11,30
12	13,83	17,97	**16,05**	17,45	10,18	**8,07**	**10,00**	**12,09**
13	14,11	15,84	**16,45**	18,12	10,93	**10,56**	**10,48**	**13,01**
14	18,12	16,84	17,48	17,72	14,24	**10,60**	**13,04**	**13,85**
15	17,14	**19,67**	**18,40**	**19,06**	14,78	**10,05**	**14,95**	**15,57**
16	**15,00**	**17,86**	**15,95**	**16,96**	11,40	**10,44**	**17,74**	**15,19**
17	**15,52**	15,20	**13,93**	**13,88**	**8,96**	**11,44**	**19,04**	**14,41**
18	**11,82**	**16,57**	**15,09**	**12,26**	**8,59**	14,08	**20,08**	**12,36**
19	**9,94**	**15,86**	**13,03**	**10,54**	**5,82**	**11,55**	**13,93**	**10,66**
20	**7,70**	17,11	**15,39**	7,84	6,77	10,45	8,75	7,99
21	9,26	18,68	**18,25**	**10,23**	**6,20**	11,75	13,24	8,12
22	7,44	17,09	**16,80**	**9,36**	**8,85**	**9,18**	**17,04**	**6,35**
23	8,15	11,23	9,93	**9,69**	**5,87**	**9,81**	**12,59**	**6,64**
24	6,68	11,12	**9,35**	**7,26**	**4,32**	**16,45**	**12,19**	**7,24**
				VEC-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**5,96**	**16,21**	**10,86**	**7,27**	5,80	18,38	9,91	9,93
2	**5,76**	**18,68**	**18,31**	**8,76**	**6,39**	12,44	**9,50**	**9,59**
3	7,13	**19,38**	**21,00**	**9,53**	**7,06**	8,31	**8,40**	9,22
4	**5,95**	**28,86**	**29,88**	11,61	**9,06**	10,57	**9,98**	**7,49**
5	**7,03**	**29,19**	**28,78**	10,50	**9,21**	11,94	**10,65**	7,92
6	**7,70**	**18,13**	**17,38**	11,42	8,51	10,47	**10,04**	**5,81**
7	**6,24**	**21,60**	**19,38**	12,48	7,97	10,26	**10,96**	**10,01**
8	**8,40**	21,20	19,46	12,94	6,96	8,80	13,31	10,39
9	**9,09**	17,35	15,58	11,13	9,11	8,92	18,95	8,86
10	**9,93**	15,53	14,42	**12,30**	**8,44**	9,47	17,69	**7,70**
11	**10,89**	**15,77**	14,71	**14,25**	**8,98**	**9,00**	15,90	**8,90**
12	**12,50**	**17,02**	15,42	**15,77**	**9,63**	9,13	11,56	9,42
13	**12,36**	**14,40**	16,18	**16,80**	**9,78**	11,11	11,80	13,47
14	**16,72**	**17,25**	**17,92**	**18,65**	**12,71**	10,80	14,86	16,13
15	**16,67**	20,58	17,38	18,13	**13,27**	10,71	19,35	15,47
16	15,61	16,82	15,91	15,66	**10,99**	10,85	21,53	18,21
17	16,26	**14,92**	15,98	13,85	9,78	11,81	21,37	17,03
18	14,43	19,88	15,77	13,33	8,82	**14,03**	22,77	12,92
19	10,38	15,66	14,87	10,42	6,16	11,36	12,74	8,51
20	7,73	**15,51**	14,31	**6,81**	**6,91**	**9,70**	**6,68**	**6,93**
21	**8,42**	**17,19**	19,06	10,33	6,37	**11,60**	**13,08**	**7,98**
22	**7,17**	**16,98**	17,71	9,94	9,23	9,01	18,01	7,02
23	**7,45**	**11,00**	**9,24**	10,77	6,53	10,36	12,93	7,17
24	**6,30**	**10,48**	10,16	9,03	5,02	17,08	13,43	7,88

Mixed evidence arise on the inclusion of the exogenous variable in the models: it results in better forecasting of day ahead electricity prices only in 50% of combinations between hours of the day and countries irrespective of whether AR and AR-X models or ARI and ARI-X models are compared, while it improves forecasting performance in VEC-X that outperforms VEC model in more than 65% of cases. The same evidence does not hold for VAR model, where the inclusion of an exogenous variable leads to better performance only in less than 30% of the cases.
Also considering pre-filtered data, the analysis reveals that in the ramp up hours in the morning simple time series model outperforms multiple time series model, and the opposite happens in hours 11^{th} , 12^{th} and 20^{th} 21^{st}.

Moreover, considering pre-filtered dataset, when simple time series models outperform multiple time series ones, lower gains are obtained compared to the ones registered with the original dataset (1,2 €/MWh vs almost 3€/MWh), even still higher than the ones got when multiple time series models provide better forecasting performances compared to simple time series ones (**Figure 7.8**). VAR-X model still displays the worst performance compared to the corresponding simple time series model.

Figure 7.8: Hourly average Delta RMSE (Pre-filtered dataset)



7.2.5 Conclusion

Electricity day ahead price exhibits high volatility and electricity price time series displays spikes. There is no a unanimous consensus of how to treat spike in forecasting. One of the technique mainly used in electrical engineering price forecasting literature is pre-filtering the original dataset, removing outliers. In the present section this approach has been adopted and a spike has been identified, through a recursive filter, as a deviation from the mean price greater than three standard deviation. The detected values have been replaced with the threshold itself. Once pre-filtered the original dataset, the same comparison between multiple and simple time series forecasting performance has been proposed.

After applying the filter, electricity time series do not display clear evidence of their stationarity properties, since contradictory results outcome from stationarity and unit root tests. Therefore, as done with the original dataset, models have been specified both under the assumption of stationarity and of unit roots.

For the hours where the corresponding in-sample intervals include extremely marked price spikes in the original dataset, a significant reduction of the SMAPE values has been registered, as Belgian and French loss functions show, varying from 38% to 20% and from 68% to 16% respectively considering the average value regardless of the estimated model.

Despite accounting for the spike allow improving the forecasting performance in such cases, the two datasets lead to the same qualitative results.

7.3 Scenario based conditional forecasting

Multivariate models can be used for forecasting by applying a chain rule as the ones described in the previous sections. These instruments, due to their flexibility can be applied also to obtain forecasts conditional on the potential future trend of a variable included in the models. This condition is possible when there is a different informative set about the variable in the system; for instance, when information about the future trend of a variable are released in advance compared with the ones regarding the other variables considered. Another application of the conditional forecasting is the provision of forecast conditional on several policy scenarios.

Multiple time series models trough conditional forecasting based on different policy scenarios can address the question of how a change in one of the system variable (the one modeled through scenario analysis) can affect the value of the other variable in the system (Zivot and Wang, 2006). These scenario based conditional forecasts are discussed in the present section.

VAR-X and VEC-X models specified in section 6.2 are used to obtain one month ahead forecasting of hourly day ahead electricity prices for the eight countries considered in the analysis, conditioned on a specific trend for each country load. The forecasts have been obtained by a recursive procedure, where the model coefficients have been estimated every day, including in the in-sample also the past forecasted values.

To perform this exercise, the scenario refers to the period 30th July -31st August 2013, and forecasts have been made conditional to the load trend. The reference scenario employs the load real values (from now on “Base” scenario) and nine alternative scenarios have been developed with the increase of 1% of the load of all countries (from now on “All” scenario) and with the increase of 1%

in one country load at time (named with each country name). In such a way, sensitivity values have been computed, that address the question how electricity day ahead prices change when load varies in a specific country. In order to account for the dynamic interdependencies among the analyzed market, only multiple time series models have been implemented for this exercise.

Due to their better forecasting performance compared with VAR model, the forecast exercise obtained with VEC-X models is shown in the following tables, while the results obtained from VAR-X models have been reported in Appendix C. **Table 7.17** displays the forecasted average values for all the countries through VEC-X model.

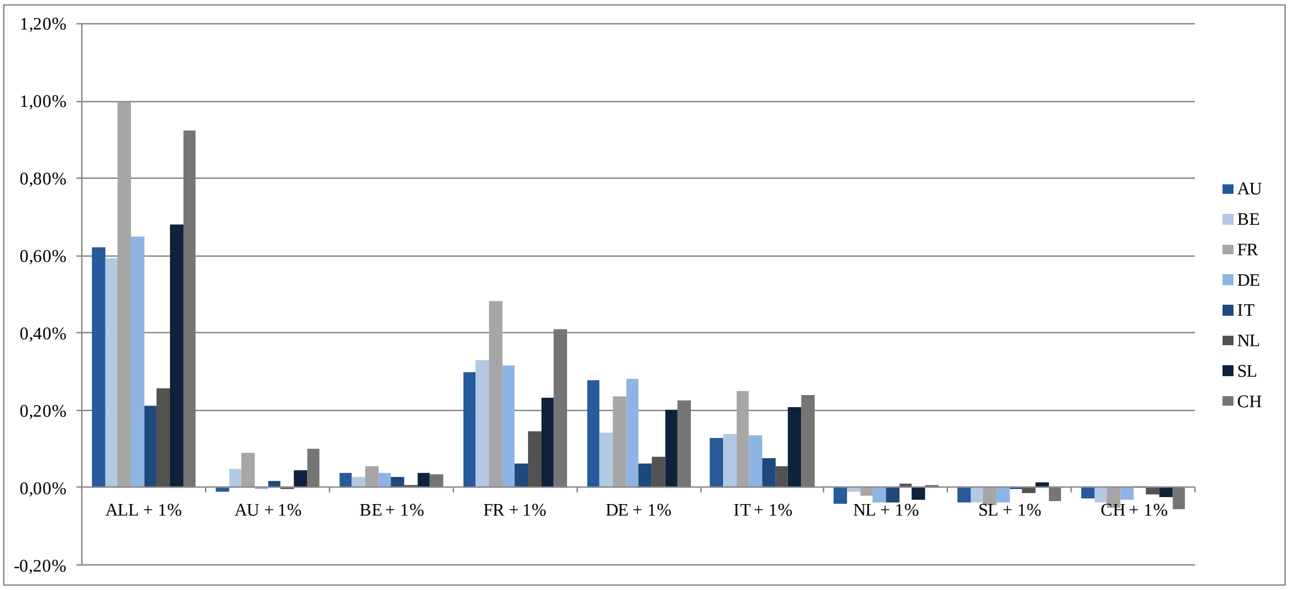
Table 7.17: Average monthly price values (VEC-X model) – August, 2013 (€/MWh)

	EXAA	BELPEX	EPEX FR	EPEX DE	IPEX	APX	BSP	EPEX CH
Base	38,41	37,84	33,96	37,65	67,74	45,74	44,43	37,79
All	38,65	38,06	34,29	37,89	67,88	45,85	44,73	38,14
Austria	38,41	37,86	33,99	37,65	67,75	45,73	44,45	37,83
Belgium	38,43	37,85	33,98	37,66	67,76	45,74	44,45	37,81
France	38,53	37,96	34,12	37,77	67,78	45,80	44,53	37,95
Germany	38,52	37,89	34,04	37,75	67,78	45,77	44,52	37,88
Italy	38,46	37,89	34,04	37,70	67,79	45,76	44,52	37,88
Netherland	38,40	37,84	33,95	37,63	67,71	45,74	44,42	37,80
Slovenia	38,40	37,82	33,94	37,63	67,74	45,73	44,44	37,78
Switzerland	38,40	37,83	33,94	37,63	67,74	45,73	44,42	37,77

Under both the hypotheses of stationarity and unit root, the forecasting highlights the same qualitative dynamics, but sensitivity values obtained through VAR-X models are higher than the ones showed by VEC-X models.

Generally speaking, when the load increases in a "bigger" country, such as Germany or France or Italy, the prices of all the countries show an increase, actually due to the greater load absolute value. When the French load increases, the highest variation is registered in French prices that grows of 0,48%. When the German load increases, the greater variations refer to German and Austrian prices (+0,28%) due to the not clear distinction between the two areas (EXAA day ahead market allows electricity to be physically delivered also in the four German control areas and EPEX Spot allows delivering in the Austrian TSO control area). The load increase in the other countries results in a small price variation (**Figure 7.9** and **Table 7.18**).

Figure 7.9: Price changes across scenarios (VEC-X)



Looking at a country level, Italy and the Netherlands show the lowest variability independently from the scenarios considered. This may be an indication that in price forecasting for these countries the price past values have a greater impact than the load. This may be related to the shape of the supply curve: in Italy the generation mix is mainly based on gas plants that are middle merit plants, so small variation in demand does not imply large price variations because the demand crosses the supply curve not in its steeper part. Analogous considerations hold for Netherland, where fossil fuel plants account for the 84% of the generating capacity.

Table 7.18: Price changes across scenarios (VEC-X)

	EXAA	BELPEX	EPEX FR	EPEX DE	IPEX	APX	BSP	EPEX CH
All	0,62%	0,59%	1,00%	0,65%	0,21%	0,26%	0,68%	0,92%
Austria	-0,01%	0,05%	0,09%	0,00%	0,02%	0,00%	0,04%	0,10%
Belgium	0,04%	0,03%	0,06%	0,04%	0,03%	0,01%	0,04%	0,03%
France	0,30%	0,33%	0,48%	0,32%	0,06%	0,14%	0,23%	0,41%
Germany	0,28%	0,14%	0,24%	0,28%	0,06%	0,08%	0,20%	0,22%
Italy	0,13%	0,14%	0,25%	0,13%	0,08%	0,06%	0,21%	0,24%
Netherland	-0,04%	-0,01%	-0,02%	-0,04%	-0,04%	0,01%	-0,03%	0,01%
Slovenia	-0,04%	-0,04%	-0,05%	-0,04%	0,00%	-0,01%	0,01%	-0,03%
Switzerland	-0,03%	-0,04%	-0,05%	-0,03%	0,00%	-0,02%	-0,03%	-0,06%

Appendix C

This appendix reports:

- the tables with the comparison between MAPE and RMSE computed on multiple and simple time series models on the original dataset for the out-of-sample period, July 1st , 2013 – July 29th, 2013 (**Table C.1**; **Table C.2**; **Table C.3**; **Table C.4**; **Table C.5**; **Table C.6**; **Table C.7**; **Table C.8**). The best results for each hour are in bold.
- the tables of summary statistics for all the day ahead electricity price of the market analyzed, after pre-filtering procedure (**Table C.9**; **Table C.10**; **Table C.11**; **Table C.12**; **Table C.13**; **Table C.14**; **Table C.15**). Prices have been expressed in €/MWh.
- the tables with the comparison between MAPE and RMSE computed on multiple and simple time series models on the pre-filtered dataset for the out-of-sample period, July 1st , 2013 – July 29th, 2013 (**Table C.17**; **Table C.18**; **Table C.19**; **Table C.20**; **Table C.21**; **Table C.22**; **Table C.23**; **Table C.24**). The best results for each hour are in bold.
- The table with the forecasted average values for all the countries through VAR-X model in the scenario analysis (**Table C.25**) and their sensitivity tested trough an increase of each country of 1% (**Table C.26**).

Table C.1: MAPE errors from AR and VAR models (%)

				AR				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**6,06**	21,74	14,19	7,18	**4,81**	19,60	**7,80**	**10,02**
2	**6,78**	21,19	19,04	**10,90**	6,29	12,20	**7,49**	**9,62**
3	**7,18**	22,61	**22,18**	**10,93**	7,34	8,54	**7,26**	**8,40**
4	8,25	**32,75**	**31,65**	**12,12**	9,23	**9,65**	**8,76**	9,32
5	**7,30**	**34,19**	31,51	11,87	9,18	10,96	**9,26**	**7,66**
6	**7,44**	23,13	20,92	15,76	**8,14**	**9,26**	**10,17**	**6,44**
7	**8,61**	**28,03**	24,27	**12,36**	**7,20**	11,09	**10,51**	**8,73**
8	**9,64**	86,71	**22,24**	**12,49**	**6,79**	9,74	13,64	**10,06**
9	10,42	**18,85**	**24,90**	**10,37**	**9,29**	**9,46**	**15,54**	10,58
10	14,58	**62,36**	**30,89**	15,10	9,07	**10,75**	**14,47**	12,34
11	17,81	**74,88**	**37,67**	18,66	9,99	11,11	**13,52**	15,67
12	21,03	**91,68**	**32,50**	20,04	11,51	**8,41**	10,71	16,75
13	22,35	22,38	23,64	20,91	12,49	10,66	**10,13**	18,97
14	**4857,67**	22,88	21,31	20,19	17,78	**10,12**	**12,27**	**18,71**
15	**3491,67**	26,11	22,36	22,06	18,41	**9,38**	**13,44**	**19,18**
16	**3446,18**	22,94	19,55	19,34	15,59	10,02	**16,23**	**19,12**
17	**3904,22**	18,07	15,21	**15,17**	**10,12**	11,44	**18,15**	**18,48**
18	**14,52**	**20,16**	**18,43**	**12,06**	**7,71**	14,38	**18,84**	**13,87**
19	**11,37**	**19,21**	17,92	**9,85**	**5,58**	12,41	15,12	**10,13**
20	8,14	21,03	18,88	8,05	6,83	11,19	7,75	7,72
21	9,38	23,52	21,78	**10,29**	**5,90**	12,49	11,63	8,03
22	**7,11**	**20,84**	20,69	**9,47**	**8,97**	9,64	**16,93**	**6,39**
23	7,91	**11,90**	10,23	**9,71**	**5,80**	**9,99**	**12,16**	6,98
24	**6,36**	**11,06**	**9,47**	**6,91**	**4,27**	17,78	**11,16**	6,82
				VAR				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	6,99	**19,70**	**13,06**	**6,95**	5,62	**19,53**	8,66	11,23
2	7,39	**18,15**	**17,48**	11,87	**6,11**	**11,78**	9,30	10,26
3	8,77	**20,05**	22,55	11,70	**6,99**	**8,02**	7,90	9,25
4	**7,91**	33,69	32,04	14,95	**8,79**	9,82	10,25	**8,28**
5	8,85	36,54	**30,94**	**11,87**	**9,08**	**10,79**	10,09	9,11
6	9,34	**22,60**	**19,31**	**15,70**	8,28	9,38	11,72	6,53
7	9,53	30,78	**23,88**	12,51	7,63	**10,22**	11,66	10,25
8	11,30	**76,35**	23,26	16,84	7,48	**9,69**	**13,14**	13,01
9	**10,14**	19,64	29,92	12,32	10,12	9,77	18,07	**10,00**
10	**13,03**	66,52	60,52	**12,98**	**8,79**	11,15	17,22	**12,28**
11	**13,85**	77,66	64,87	**14,78**	**9,65**	**8,84**	13,86	**14,36**
12	**17,20**	97,23	33,46	**16,89**	**10,45**	8,51	**10,36**	**14,84**
13	**19,06**	**18,92**	**18,22**	**16,74**	**11,64**	**10,53**	11,90	**16,32**
14	5259,05	**20,62**	**18,20**	**17,54**	**15,92**	11,35	12,66	21,98
15	4241,34	**25,60**	**16,82**	**16,16**	**16,24**	10,31	15,57	19,37
16	4508,25	**21,04**	**17,47**	**17,41**	**14,38**	**10,00**	20,62	23,32
17	4906,89	**17,44**	**15,12**	15,86	11,45	**11,16**	21,95	23,18
18	17,73	27,38	20,06	14,41	8,49	**13,48**	22,57	15,90
19	13,06	19,86	**17,84**	10,89	5,65	**11,73**	**13,93**	10,40
20	**7,58**	**19,62**	**17,37**	**6,62**	**5,95**	**9,77**	**6,95**	**6,99**
21	**8,87**	**22,09**	**20,66**	10,99	5,97	**12,00**	**10,59**	**7,78**
22	7,31	21,29	**19,27**	10,16	9,57	**9,55**	17,67	7,54
23	**7,46**	12,32	**9,63**	10,13	6,25	10,25	12,20	**6,55**
24	6,78	11,09	9,58	8,45	4,82	**17,66**	11,32	**6,78**

Table C.2: MAPE errors from AR-X and VAR-X models (%)

				AR-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**5,79**	**18,39**	14,09	**7,11**	**4,74**	19,40	**7,88**	**9,84**
2	**6,03**	19,74	19,49	**11,88**	**6,25**	**11,82**	**7,66**	**9,73**
3	**6,24**	23,82	**22,81**	**11,33**	7,10	**7,83**	8,71	**8,60**
4	**6,96**	**33,30**	**31,11**	14,67	9,26	**9,62**	**9,49**	**9,29**
5	**8,44**	**33,07**	**28,40**	**12,71**	9,22	**10,86**	**9,83**	**7,59**
6	**9,02**	**22,61**	**20,58**	**15,88**	8,05	**8,31**	**10,51**	**6,44**
7	**8,09**	**27,60**	**23,11**	**9,65**	**7,49**	**8,92**	**9,79**	**8,61**
8	**9,39**	**55,93**	**18,95**	**10,97**	**7,05**	**7,64**	**12,38**	**9,47**
9	**10,08**	**17,86**	**15,07**	**9,44**	**9,68**	**8,06**	**14,12**	11,52
10	**12,93**	66,35	**17,34**	14,43	**9,86**	**9,83**	**12,42**	**12,77**
11	**14,82**	74,78	**21,43**	17,12	**9,99**	10,66	**12,48**	16,31
12	**17,64**	**87,98**	**24,48**	18,64	10,66	**8,74**	**10,46**	17,24
13	**19,59**	20,57	19,39	19,40	**11,36**	**10,40**	**10,24**	19,22
14	4666,38	**20,72**	**18,43**	**18,56**	**16,13**	**10,79**	**12,94**	**18,69**
15	**3381,68**	25,04	18,18	20,37	**16,78**	**10,18**	**14,68**	**19,53**
16	**3152,31**	**20,93**	**15,78**	**18,76**	14,69	10,63	**17,05**	**19,80**
17	**3639,49**	**18,65**	**14,44**	**14,98**	**10,34**	11,22	**18,42**	**18,84**
18	**13,04**	**20,13**	**16,34**	**12,61**	8,24	13,42	**19,49**	**14,68**
19	**10,63**	**19,66**	**14,63**	**10,34**	6,24	**11,84**	**14,36**	**10,45**
20	**7,58**	19,70	**16,70**	8,07	7,00	11,08	**9,06**	7,86
21	**8,88**	**22,28**	**20,35**	**10,23**	6,02	**12,27**	13,08	**7,93**
22	**6,80**	**20,47**	**19,24**	**9,32**	**8,97**	**9,52**	**17,40**	**6,37**
23	**7,52**	**11,51**	**9,76**	**9,58**	**5,82**	**9,91**	**12,71**	**7,02**
24	**5,99**	**10,89**	**9,17**	**6,86**	**4,27**	**17,68**	**11,29**	**6,80**
				VAR-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	7,85	19,72	**12,58**	8,24	5,60	**19,31**	8,18	11,74
2	8,15	**19,19**	**17,56**	14,62	6,54	12,01	8,88	12,02
3	10,79	**23,68**	23,18	13,01	**6,66**	9,42	**7,99**	11,86
4	9,49	37,52	36,48	**13,40**	**8,48**	10,31	10,46	10,95
5	10,07	45,00	38,78	13,34	**8,95**	11,37	11,21	12,00
6	9,55	24,78	21,53	16,43	**8,04**	10,04	12,27	8,10
7	11,05	29,55	23,46	10,98	7,69	10,03	11,80	10,53
8	10,92	80,63	21,48	15,07	7,83	8,84	12,79	12,33
9	12,90	20,57	28,89	11,26	10,98	9,25	18,86	**11,36**
10	14,71	**64,27**	57,41	**11,97**	11,30	11,81	18,18	14,94
11	15,87	**72,64**	60,38	**13,81**	10,58	**10,47**	14,39	**15,35**
12	17,65	90,00	30,01	**16,24**	**10,45**	9,36	13,05	**15,02**
13	20,70	**19,59**	**17,91**	**17,78**	11,87	10,76	13,90	**16,50**
14	**4634,98**	21,17	19,41	19,27	17,28	11,47	14,52	21,41
15	4064,50	**24,41**	**17,63**	**17,71**	16,78	11,55	17,32	19,99
16	4532,85	23,78	20,30	19,19	**13,67**	**10,54**	22,84	25,22
17	5124,15	20,85	18,00	16,26	11,11	**10,93**	23,13	25,28
18	17,78	28,11	20,80	14,76	**7,57**	**13,41**	24,76	16,57
19	14,08	20,22	18,49	11,14	**5,64**	12,11	15,03	11,62
20	9,09	**19,05**	17,02	**7,37**	**6,09**	**10,38**	9,91	**7,82**
21	10,52	22,74	20,52	10,85	**5,98**	12,32	**12,35**	10,44
22	8,29	22,70	19,99	10,02	9,38	9,84	18,52	8,65
23	8,46	12,46	10,60	10,21	6,54	10,32	13,43	7,20
24	6,30	11,09	9,50	9,67	5,18	17,75	12,09	8,20

Table C.3: MAPE errors from ARI and VEC models (%)

ARI								
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**6,37**	20,73	15,58	**7,52**	**4,88**	19,93	**8,11**	**8,95**
2	**7,07**	22,01	19,90	**9,85**	6,34	**11,15**	**8,88**	**8,88**
3	**7,37**	22,10	**22,24**	12,02	7,30	**6,93**	8,90	**7,69**
4	8,40	**29,90**	**29,40**	**13,41**	9,07	9,88	**10,08**	8,41
5	**8,24**	**27,43**	**27,85**	12,02	9,24	11,38	10,79	**7,25**
6	**8,10**	**19,22**	18,61	**14,36**	**8,17**	10,34	12,30	6,58
7	**8,88**	**26,16**	24,64	**11,57**	**7,52**	10,86	**10,78**	**8,37**
8	**8,80**	**27,88**	**17,39**	**14,04**	**7,19**	**9,30**	**12,66**	**9,08**
9	**9,67**	**15,05**	**12,55**	**10,29**	**9,36**	**8,90**	**15,11**	**9,48**
10	13,99	**49,53**	**13,88**	13,78	8,92	11,32	**14,39**	**9,65**
11	15,90	**62,82**	**16,38**	17,08	10,42	11,27	**12,99**	**13,22**
12	20,17	**78,10**	**19,14**	18,76	11,76	**8,18**	10,94	**14,87**
13	21,41	19,45	19,30	19,78	12,55	10,86	**10,45**	**15,84**
14	**4382,51**	**18,54**	19,25	18,00	17,80	**10,24**	**12,86**	**16,16**
15	**3021,73**	**21,09**	19,26	18,28	18,29	**9,54**	**13,67**	**15,66**
16	**2979,72**	**16,46**	15,99	**16,02**	16,29	10,15	**16,24**	**15,59**
17	**3457,39**	**13,72**	14,49	**13,35**	**10,71**	11,28	**17,45**	**15,55**
18	**13,28**	**17,96**	**16,76**	**11,46**	**8,13**	14,62	**18,64**	**11,81**
19	**10,64**	**17,25**	**15,96**	**9,81**	**5,82**	12,27	14,35	**9,46**
20	8,46	20,10	17,97	7,22	6,63	11,24	6,58	7,36
21	9,38	22,82	21,28	**9,64**	**5,95**	12,67	11,56	7,59
22	**6,97**	**20,38**	**20,02**	**9,19**	**9,01**	9,62	**16,82**	**6,16**
23	8,10	**11,60**	10,26	**9,72**	**6,07**	10,25	**11,87**	6,48
24	7,05	11,07	9,85	**6,64**	**4,31**	17,88	**11,45**	7,24
VEC								
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	6,75	**19,60**	**13,24**	7,60	5,86	**19,62**	9,57	10,27
2	7,52	**17,91**	**17,48**	11,90	**6,21**	11,68	9,42	10,18
3	8,94	**20,00**	22,54	**11,70**	**6,90**	7,94	**8,02**	9,16
4	**8,10**	32,86	31,70	14,96	**8,70**	**9,86**	10,28	**8,32**
5	8,93	34,81	30,43	**11,90**	**9,11**	**10,79**	**10,19**	9,09
6	9,54	20,72	**18,34**	15,47	8,34	**9,26**	**11,64**	**5,91**
7	9,47	31,35	**24,04**	12,60	7,68	**10,23**	11,60	10,18
8	11,20	77,61	23,25	16,88	7,58	9,70	13,20	12,84
9	10,14	19,62	29,97	12,32	10,31	9,79	18,13	10,02
10	**12,87**	68,43	60,20	**12,96**	**8,75**	**11,24**	16,91	12,34
11	**13,22**	70,79	65,63	**14,79**	**9,83**	**8,82**	14,07	14,58
12	**16,48**	91,51	33,28	**16,93**	**10,77**	8,57	**10,71**	16,78
13	**17,83**	**17,89**	**18,50**	**16,83**	**11,78**	**10,62**	12,10	16,34
14	4742,73	18,61	**17,16**	**16,71**	**15,59**	11,80	13,01	21,87
15	3806,02	24,72	**16,78**	**16,69**	**16,24**	10,53	15,91	19,17
16	3935,18	18,68	**15,78**	16,08	**14,75**	**10,09**	20,26	22,68
17	4434,75	15,62	**13,71**	14,40	11,91	**11,12**	21,66	22,72
18	16,92	26,52	18,19	13,72	9,08	**13,59**	22,24	15,36
19	13,06	19,56	18,39	11,19	5,97	**11,86**	**14,23**	10,82
20	**7,79**	**19,87**	**17,53**	**6,72**	**6,25**	**9,75**	**5,81**	**6,86**
21	**8,19**	**21,99**	**21,06**	11,24	6,11	**12,10**	**10,87**	**6,71**
22	7,16	21,42	20,11	10,14	9,60	**9,56**	17,55	6,72
23	**7,43**	11,81	**9,61**	10,97	6,47	**10,24**	11,91	**6,01**
24	**6,98**	**10,50**	**9,53**	10,78	4,86	**17,69**	11,78	**7,00**

Table C.4: MAPE errors from ARI-X and VEC-X models (%)

				ARI-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	6,27	18,79	15,00	7,22	**4,90**	19,62	**8,22**	**8,94**
2	6,27	20,42	20,26	11,13	6,40	**11,19**	9,13	9,08
3	**6,78**	22,76	23,84	12,15	7,13	**6,87**	9,32	**8,21**
4	7,27	**31,86**	**30,97**	**13,32**	9,11	**10,43**	10,45	8,49
5	8,92	**29,63**	**27,40**	**11,96**	9,29	**11,41**	11,12	**7,29**
6	9,50	21,53	20,45	**14,98**	**7,99**	**9,36**	12,25	6,54
7	8,58	**27,44**	25,63	**10,36**	**7,53**	**8,54**	10,15	**8,13**
8	**9,54**	**27,77**	**18,28**	**12,91**	**6,79**	**7,94**	11,40	**9,08**
9	9,91	**14,88**	**13,03**	**10,09**	**9,55**	**8,20**	**13,77**	**10,28**
10	12,36	**54,42**	**14,26**	14,14	8,50	**10,66**	**12,47**	11,06
11	13,94	64,36	**15,54**	16,61	9,62	11,21	**11,99**	14,11
12	16,85	**75,70**	**16,21**	18,01	10,31	**8,33**	**10,54**	15,80
13	18,47	17,97	16,85	18,83	11,05	**10,85**	**10,79**	16,42
14	4300,94	**16,53**	17,84	17,81	15,38	**10,47**	**13,44**	**16,51**
15	3027,07	**19,20**	**17,33**	**18,23**	16,14	**10,11**	**14,89**	15,92
16	**2794,02**	**16,56**	**15,23**	16,72	14,85	10,39	**16,53**	**15,97**
17	**3268,12**	**14,71**	**14,38**	13,96	**10,59**	**11,13**	**18,17**	**15,83**
18	**11,81**	**17,28**	**15,90**	**12,01**	**8,45**	13,99	**19,26**	**12,45**
19	**9,91**	**16,76**	**13,87**	**10,34**	**5,98**	11,91	**13,44**	**9,85**
20	**7,75**	**18,86**	**16,61**	7,63	6,80	11,05	8,22	7,57
21	8,93	**21,89**	**20,31**	**10,23**	**5,98**	12,40	12,96	7,74
22	7,16	**20,43**	**19,29**	**9,32**	**9,00**	9,39	**17,53**	**6,25**
23	7,84	11,70	9,92	**9,67**	**6,00**	**10,05**	12,39	**6,53**
24	6,48	10,92	**9,28**	**7,07**	**4,30**	**17,58**	**11,59**	7,19
				VEC-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**5,84**	**18,25**	**12,63**	**6,46**	5,82	**19,38**	10,16	9,47
2	**5,81**	**17,35**	**17,13**	**10,51**	**6,35**	12,26	**9,12**	**8,64**
3	7,93	**20,05**	**20,57**	**11,78**	**7,03**	8,70	**8,46**	8,96
4	**6,48**	32,87	32,37	14,54	**9,02**	11,10	**10,44**	**7,81**
5	**7,25**	33,79	28,05	12,26	**9,15**	12,33	**10,68**	8,24
6	**7,44**	**21,02**	**19,51**	16,33	8,13	10,78	**10,22**	**4,70**
7	**6,94**	29,53	**23,52**	16,43	7,75	10,06	**9,52**	8,67
8	9,71	86,09	23,89	16,02	6,95	8,85	**11,29**	12,18
9	**9,17**	18,37	33,97	11,82	9,98	9,01	16,85	10,88
10	**11,13**	59,82	58,29	**12,84**	**7,91**	10,89	16,12	**10,70**
11	**12,94**	**60,76**	66,15	**13,64**	**9,59**	**9,05**	13,25	**12,53**
12	**14,84**	80,12	32,08	**15,45**	**9,63**	9,01	11,13	**14,01**
13	**14,69**	**16,25**	**16,25**	**15,24**	**10,68**	10,92	12,36	**14,27**
14	**3308,09**	17,53	**17,37**	**16,00**	**14,19**	11,54	14,82	18,86
15	**2527,17**	23,23	18,95	18,49	**14,84**	10,66	18,09	**15,79**
16	3008,46	17,76	18,16	**16,34**	**14,53**	**10,36**	20,70	20,21
17	3617,30	15,55	15,99	**13,46**	12,79	11,15	21,45	21,25
18	16,36	23,67	16,22	13,82	9,73	**13,47**	22,21	13,46
19	12,71	18,85	16,57	11,78	6,20	**11,47**	13,88	10,31
20	7,92	19,75	17,51	**7,00**	**6,32**	**9,71**	**6,42**	**6,63**
21	**8,02**	22,45	21,37	11,55	6,11	**11,97**	**12,12**	**6,83**
22	**6,91**	21,10	20,07	9,63	9,67	**9,38**	17,68	6,77
23	**7,40**	**11,61**	**9,41**	10,61	6,53	10,74	**12,19**	6,99
24	**6,45**	**10,32**	9,44	10,75	4,83	17,64	11,92	**7,11**

Table C.5: RMSE errors from AR and VAR models

				AR				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**2,09**	9,19	5,14	2,75	**5,05**	9,78	**3,43**	**3,54**
2	**1,96**	6,65	5,58	**3,55**	6,02	5,36	**2,89**	**3,17**
3	**1,95**	5,39	**5,41**	**3,51**	6,72	3,22	**2,53**	**2,36**
4	**2,10**	**5,54**	**5,45**	**3,84**	7,77	3,87	**2,86**	2,41
5	**1,96**	**5,77**	**5,45**	**3,59**	7,46	4,37	3,06	**2,09**
6	**2,08**	**4,72**	4,41	**4,63**	**7,33**	3,45	**3,56**	1,89
7	**2,94**	**6,13**	**5,37**	**4,35**	5,96	4,45	5,31	**2,84**
8	**4,24**	**21,12**	**6,66**	**5,80**	**5,82**	**5,13**	9,95	**4,19**
9	**4,06**	**6,23**	**7,59**	**5,07**	**9,28**	**6,00**	**11,20**	4,80
10	**4,98**	**6,56**	**9,84**	5,92	7,91	**8,03**	**9,41**	**4,65**
11	6,03	**7,37**	**12,04**	6,95	8,35	7,50	**8,52**	**5,62**
12	7,20	8,73	**10,22**	8,27	9,20	6,26	6,10	6,25
13	6,75	7,86	8,35	7,95	8,43	7,23	**5,85**	**6,98**
14	7,03	**7,76**	7,77	7,68	9,20	**7,08**	**6,04**	**6,17**
15	6,10	**7,88**	**7,22**	**7,67**	9,61	**6,61**	**6,69**	**5,88**
16	5,76	**6,42**	**6,06**	**6,37**	9,61	**6,05**	**10,26**	**5,63**
17	5,77	**5,20**	**4,93**	**4,97**	9,39	**6,61**	**11,19**	**5,54**
18	**5,03**	**6,31**	**5,99**	**4,84**	**7,97**	**9,36**	**13,57**	**4,86**
19	**4,99**	**6,39**	**5,97**	**4,74**	**5,91**	**7,78**	10,19	**4,84**
20	4,40	7,69	7,11	4,24	7,98	7,14	4,12	4,24
21	5,43	8,63	8,17	**5,28**	**7,05**	7,82	8,24	4,79
22	3,87	**7,85**	7,80	**4,76**	**9,71**	5,45	**13,02**	**3,53**
23	4,37	**5,97**	5,11	**5,13**	6,26	6,61	**7,93**	3,80
24	**2,77**	5,27	**4,38**	**3,46**	**4,02**	9,35	**8,65**	**3,05**
				VAR				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	2,56	**8,64**	**4,85**	**2,75**	5,17	**9,66**	3,66	3,86
2	2,30	**5,98**	**5,07**	4,05	**5,72**	**5,06**	3,43	3,41
3	2,39	**5,09**	5,49	3,56	**6,35**	**3,08**	2,64	2,58
4	2,20	5,94	5,79	4,53	**7,36**	**3,70**	3,18	**2,34**
5	2,31	6,39	5,85	3,76	**7,10**	**4,07**	**3,06**	2,36
6	2,63	4,91	**4,36**	4,72	7,70	**3,30**	3,62	**1,75**
7	3,34	6,24	5,54	4,59	**5,95**	**4,24**	**5,22**	2,97
8	4,79	21,95	7,05	7,17	6,32	5,28	**9,59**	4,79
9	4,10	6,60	14,16	5,39	9,88	6,19	12,57	**4,30**
10	5,00	7,16	22,48	**5,66**	**7,50**	8,16	10,94	4,93
11	**5,40**	7,38	23,27	**6,31**	**7,18**	**6,73**	8,94	5,63
12	**6,45**	**8,64**	14,60	**7,91**	**8,35**	**6,05**	**6,06**	**5,84**
13	**6,15**	**7,10**	**7,64**	**7,42**	**7,92**	**7,19**	7,21	7,59
14	**6,46**	7,87	**7,26**	**7,60**	**8,23**	8,06	6,27	6,86
15	**5,64**	8,72	7,30	8,12	**8,91**	7,65	7,19	6,64
16	**5,59**	6,87	6,42	7,17	**8,84**	6,37	11,46	6,96
17	**5,60**	5,59	5,34	5,49	**9,34**	6,67	12,76	7,07
18	5,76	7,69	6,51	5,73	8,44	9,53	13,71	5,94
19	5,42	6,60	6,75	5,08	6,32	7,83	**9,77**	5,07
20	**4,15**	**7,16**	**6,49**	**3,80**	**7,65**	**6,64**	**3,93**	**3,65**
21	**5,15**	**8,40**	**7,71**	5,55	7,29	**7,70**	**7,56**	**4,46**
22	**3,60**	8,05	**7,43**	5,18	9,97	**5,25**	13,14	3,63
23	**3,95**	6,02	**4,78**	5,19	**6,17**	**6,59**	8,47	**3,49**
24	2,92	**5,10**	4,54	4,16	4,19	**9,23**	9,61	3,09

Table C.6: RMSE errors from AR-X and VAR-X models

				AR-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**1,99**	8,64	4,99	**2,88**	**5,04**	9,77	**3,43**	**3,53**
2	**1,73**	6,25	5,33	**3,98**	6,05	5,30	**2,86**	**3,18**
3	**1,78**	5,49	5,49	**3,62**	6,72	**3,04**	**2,66**	**2,44**
4	**1,87**	**5,88**	**5,58**	4,49	7,78	3,85	**2,94**	**2,42**
5	**2,23**	**6,00**	**5,50**	4,25	7,49	**4,27**	**3,09**	**2,11**
6	**2,66**	**5,14**	4,71	4,68	**7,30**	**3,23**	**3,52**	**1,90**
7	**3,44**	6,30	**5,30**	**3,43**	6,06	**3,79**	**4,59**	**2,71**
8	**4,63**	**14,53**	**6,77**	**5,30**	**5,90**	**4,53**	**8,71**	**4,24**
9	**4,23**	**6,79**	**5,50**	**4,90**	**9,49**	**5,20**	**9,84**	5,06
10	**4,61**	**6,91**	**6,27**	**5,96**	**8,08**	**7,39**	**7,99**	**4,80**
11	**5,41**	**7,77**	**7,73**	**6,84**	8,19	7,25	**7,80**	**5,76**
12	**6,45**	**8,65**	**8,52**	**8,17**	8,61	6,54	**5,82**	**6,32**
13	**6,17**	**7,38**	**7,57**	**7,81**	**7,67**	**7,31**	**5,71**	**6,96**
14	**6,72**	**7,82**	7,97	**7,70**	8,60	**7,54**	**6,26**	**6,19**
15	**5,81**	**7,98**	**7,58**	**7,80**	9,14	**7,23**	**7,12**	**5,92**
16	**5,34**	**6,79**	**6,53**	**6,66**	9,48	**6,43**	**10,07**	**5,74**
17	**5,31**	**5,89**	**5,34**	**5,32**	9,21	6,66	**11,11**	**5,64**
18	**4,71**	**6,41**	**6,00**	**5,11**	7,85	**9,20**	**12,72**	**5,07**
19	**4,83**	6,69	**5,42**	**4,91**	**6,01**	**7,11**	**9,04**	**4,97**
20	**4,32**	7,26	6,55	4,27	8,00	**6,61**	**4,84**	4,33
21	**5,44**	**8,55**	7,92	**5,45**	**7,08**	**7,57**	8,98	**4,78**
22	**3,90**	**8,09**	**7,50**	**4,86**	**9,70**	**5,36**	13,20	**3,57**
23	**4,26**	**5,94**	**4,99**	**5,18**	**6,29**	**6,57**	**8,04**	3,80
24	**2,68**	5,19	**4,24**	**3,66**	**3,99**	9,30	**8,71**	**3,04**
				VAR-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	2,72	**8,55**	**4,93**	3,29	5,19	**9,66**	3,45	4,08
2	2,74	**5,96**	**4,94**	4,67	**5,89**	**5,16**	3,38	3,80
3	3,17	**5,40**	**5,39**	4,09	**6,22**	3,44	2,85	3,26
4	2,64	6,09	5,96	**4,46**	**7,22**	**3,84**	3,35	3,01
5	2,71	6,82	6,09	**3,91**	**6,98**	4,29	3,40	3,07
6	2,86	5,18	**4,62**	**4,49**	7,59	3,57	3,71	2,09
7	3,50	**6,27**	5,83	3,96	**5,84**	4,13	5,19	3,00
8	5,54	22,27	7,17	6,45	6,25	4,83	9,58	5,11
9	5,44	7,20	14,08	5,47	9,93	6,15	12,33	**4,80**
10	6,45	7,63	21,37	6,14	8,50	8,29	11,46	6,18
11	7,26	7,83	21,96	7,18	**7,47**	**6,79**	9,59	7,02
12	8,19	9,11	14,08	9,01	**8,11**	**6,51**	7,69	6,87
13	7,80	7,57	7,85	8,84	7,76	7,52	7,99	7,50
14	7,72	8,86	**7,88**	9,09	**8,42**	8,39	7,37	7,18
15	6,75	9,24	8,02	9,61	**8,42**	8,49	8,48	6,67
16	6,56	7,88	7,09	7,99	**8,64**	6,83	12,14	6,97
17	5,95	6,40	5,81	5,75	**8,89**	**6,56**	13,17	6,89
18	5,78	8,07	6,62	6,04	**7,76**	9,55	14,09	5,76
19	5,97	**6,58**	6,33	5,38	6,23	7,79	9,84	5,26
20	4,97	**6,96**	**6,20**	**4,06**	**7,75**	6,73	5,31	**3,91**
21	5,97	8,75	**7,90**	5,79	7,57	7,87	**8,07**	5,09
22	4,10	8,59	7,84	5,29	9,90	5,43	**13,15**	4,07
23	4,36	6,33	5,12	5,64	6,44	6,65	8,41	**3,77**
24	3,02	**5,06**	4,52	5,11	4,44	**9,25**	9,31	3,54

Table C.7: RMSE errors from ARI and VEC models

				ARI				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**2,20**	9,51	5,35	3,04	**5,11**	10,07	**3,69**	**3,60**
2	**2,20**	6,86	5,53	**3,69**	6,07	5,12	**3,25**	**3,30**
3	**2,21**	5,55	5,56	3,75	6,76	**2,93**	2,94	**2,49**
4	2,40	**5,66**	**5,53**	**4,24**	7,80	3,95	3,26	2,52
5	**2,28**	**5,62**	**5,42**	3,92	7,45	4,59	3,42	**2,27**
6	**2,43**	4,72	4,43	**4,81**	**7,44**	3,77	3,91	2,15
7	**3,23**	**6,01**	**5,23**	**4,07**	6,29	4,49	5,49	2,99
8	**4,39**	**11,24**	**6,40**	**5,82**	**6,16**	**5,08**	10,06	**4,35**
9	4,19	**6,13**	**5,60**	**5,10**	**9,73**	**5,82**	**11,27**	4,75
10	5,09	**6,59**	**5,86**	5,96	8,32	**8,16**	**9,54**	**4,48**
11	5,94	7,44	**6,85**	6,97	8,86	7,57	**8,72**	**5,55**
12	7,32	8,78	**8,17**	8,44	9,72	6,19	6,37	**6,28**
13	6,89	7,81	8,02	8,10	8,65	7,29	**6,17**	**6,52**
14	7,17	**7,70**	7,87	**7,88**	9,47	**7,27**	**6,29**	**6,06**
15	6,25	**7,88**	**7,30**	**7,89**	9,96	**6,75**	**6,94**	**5,93**
16	5,93	**6,42**	**6,15**	**6,55**	10,09	**6,10**	**10,53**	**5,62**
17	5,79	**5,32**	**5,03**	**5,18**	9,90	**6,57**	**11,42**	**5,50**
18	**5,03**	**6,57**	**6,17**	**5,05**	**8,39**	**9,50**	13,74	**4,86**
19	**5,04**	**6,33**	**5,81**	**4,87**	**6,21**	**7,72**	10,30	**4,84**
20	4,51	7,82	7,19	4,33	**8,22**	7,17	3,93	4,25
21	5,61	8,82	8,36	**5,36**	**7,19**	7,97	8,37	4,80
22	4,04	**8,16**	7,98	**4,91**	**9,75**	5,47	13,17	3,60
23	4,45	6,17	5,21	**5,20**	6,35	6,74	**8,05**	3,85
24	**2,96**	5,22	**4,35**	**3,53**	**4,07**	9,46	**8,83**	**3,05**
				VEC				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	2,46	**8,64**	**4,89**	**2,86**	5,26	**9,69**	4,03	3,85
2	2,33	**5,97**	**5,07**	4,05	**5,75**	**5,05**	3,43	3,40
3	2,43	**5,08**	**5,49**	**3,55**	**6,32**	3,08	**2,66**	2,57
4	**2,23**	5,91	5,78	4,51	**7,37**	**3,70**	**3,18**	**2,34**
5	2,34	6,35	5,85	**3,75**	**7,13**	**4,08**	**3,08**	2,36
6	2,55	**4,66**	**4,19**	4,93	7,74	**3,28**	**3,60**	**1,67**
7	3,33	6,32	5,56	4,61	**6,10**	**4,23**	**5,21**	**2,96**
8	4,75	22,06	7,05	7,16	6,49	5,29	**9,62**	4,74
9	**4,10**	6,60	14,19	5,39	10,12	6,20	12,58	**4,30**
10	**4,98**	7,29	22,52	**5,66**	**7,64**	8,24	10,83	4,98
11	**5,73**	**7,19**	23,21	**6,85**	**7,39**	**6,70**	9,07	6,57
12	**6,73**	**8,53**	14,63	**8,43**	**8,70**	**6,09**	**6,29**	6,78
13	**6,41**	**6,91**	**7,82**	**8,01**	**8,14**	**7,29**	7,35	8,28
14	**6,49**	7,75	**7,37**	8,06	**8,37**	8,33	6,36	7,19
15	**5,63**	8,62	7,54	8,68	**9,19**	7,84	7,26	6,85
16	**5,61**	6,65	6,54	7,78	**9,05**	6,52	11,53	7,16
17	**5,51**	5,36	5,36	5,73	**9,63**	6,75	12,76	7,19
18	5,77	7,49	6,54	6,00	8,94	9,52	**13,68**	6,19
19	5,81	6,87	7,42	5,62	6,58	8,13	**9,87**	5,50
20	**4,21**	**7,24**	**6,68**	**3,80**	8,25	**6,71**	**3,50**	**3,70**
21	**5,06**	**8,43**	**8,16**	5,74	7,37	**7,71**	**7,77**	**4,41**
22	**3,67**	8,48	**7,97**	5,37	10,01	**5,26**	**13,14**	**3,41**
23	**3,98**	**5,94**	**4,77**	5,52	**6,24**	**6,58**	8,66	**3,47**
24	3,03	**5,03**	4,47	4,93	4,23	**9,24**	9,85	3,28

Table C.8: RMSE errors from ARI-X and VEC-X models

				ARI-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	2,17	9,07	5,26	3,00	**5,13**	10,11	**3,70**	3,58
2	1,90	6,57	5,64	4,03	6,14	**5,15**	**3,26**	3,29
3	**2,02**	5,72	5,86	3,85	6,82	**2,83**	3,05	2,59
4	2,10	6,15	**5,63**	**4,27**	7,81	**4,04**	3,34	2,54
5	2,51	**6,15**	**5,49**	**4,06**	7,48	4,53	3,45	2,28
6	2,97	5,44	4,77	**4,71**	**7,38**	**3,59**	3,88	2,15
7	3,76	6,76	5,64	**3,49**	6,28	**3,81**	**4,78**	2,96
8	4,94	**12,02**	**6,65**	**5,57**	**5,96**	**4,55**	9,03	**4,41**
9	4,52	7,06	**5,92**	**5,23**	**9,63**	**5,22**	**9,96**	**5,03**
10	4,79	7,20	**6,79**	6,18	7,99	**7,61**	**8,13**	4,79
11	5,42	8,11	**7,42**	7,04	8,27	7,37	**7,97**	5,71
12	6,58	8,93	**8,16**	8,41	8,83	**6,38**	**6,04**	6,37
13	6,29	7,52	**7,73**	8,02	7,68	**7,30**	**6,19**	**6,57**
14	6,84	8,07	8,07	**7,91**	8,66	**7,29**	**6,46**	**6,10**
15	5,95	**8,19**	**7,65**	**8,03**	9,12	**6,93**	**7,43**	**5,95**
16	5,49	7,09	**6,68**	**6,84**	9,67	**6,16**	**10,32**	**5,69**
17	5,44	6,19	**5,47**	**5,52**	**9,58**	**6,49**	**11,41**	**5,57**
18	**4,80**	**6,66**	**6,11**	**5,30**	**8,14**	**9,15**	**13,05**	**5,06**
19	**4,91**	**6,41**	**5,48**	**5,07**	**6,09**	**7,19**	**9,13**	**5,01**
20	4,45	7,54	**6,54**	4,51	8,16	**6,69**	4,72	4,37
21	5,59	8,82	**7,95**	**5,62**	**7,17**	7,70	9,08	4,84
22	4,05	8,39	**7,54**	**4,98**	**9,74**	5,35	**13,35**	3,66
23	4,42	6,22	5,01	**5,23**	6,33	**6,58**	**8,17**	3,87
24	2,83	5,44	**4,30**	**3,74**	**4,04**	9,30	**8,88**	**3,05**
				VEC-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**2,15**	**8,49**	**4,86**	**2,55**	5,19	**9,76**	4,22	**3,55**
2	**1,79**	**5,85**	**4,82**	**3,66**	**5,72**	5,35	3,38	**3,13**
3	2,17	**4,90**	**5,00**	**3,63**	**6,41**	3,54	**2,86**	**2,53**
4	**1,85**	**5,91**	5,86	4,79	**7,46**	4,11	**3,19**	**2,29**
5	**1,92**	6,29	5,65	4,19	**7,16**	**4,47**	**3,12**	**2,25**
6	**2,13**	**4,62**	**4,30**	5,29	7,77	3,87	**3,32**	**1,57**
7	**2,59**	**5,93**	**5,36**	5,29	**6,13**	4,24	4,92	**2,50**
8	**4,32**	20,27	7,65	7,03	6,49	4,64	**8,70**	4,53
9	**4,12**	**6,79**	15,02	5,31	10,33	5,79	11,98	5,16
10	**4,63**	**6,93**	22,45	**5,71**	**7,41**	7,83	10,07	**4,30**
11	**5,40**	**7,08**	22,86	**6,59**	**7,08**	**6,74**	8,59	**5,62**
12	**6,10**	**8,29**	14,94	**8,12**	**7,91**	6,39	6,46	**5,88**
13	**5,55**	**6,72**	7,74	**7,44**	**7,39**	7,31	7,75	7,66
14	**5,62**	**7,95**	**7,70**	7,92	**7,88**	8,34	6,99	6,92
15	**5,16**	8,92	7,76	8,43	**8,53**	7,90	7,89	6,79
16	**5,37**	**6,98**	7,00	7,72	**9,08**	6,61	12,01	7,17
17	**5,15**	**5,69**	5,83	5,75	9,89	6,86	12,89	7,27
18	5,56	6,99	6,44	6,14	9,31	9,62	13,95	5,81
19	5,51	6,61	7,14	5,71	6,80	7,95	9,47	5,19
20	**4,13**	**7,35**	6,94	**3,96**	**7,98**	6,70	**3,98**	**3,62**
21	**4,82**	**8,59**	8,34	6,07	7,38	**7,64**	**8,48**	**4,46**
22	**3,48**	**8,27**	7,92	5,04	10,10	**5,21**	13,47	**3,50**
23	**3,91**	**5,89**	**4,67**	5,36	**6,26**	6,87	9,02	**3,57**
24	**2,79**	**5,15**	4,64	4,94	4,23	**9,21**	9,96	3,19

Table C.9: Descriptive statistics EXAA price (Pre-filtered dataset)

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	37,71	11,74	57,58	8,59	-0,58	3,26	0,977***
2	34,30	6,52	53,21	9,26	-0,65	3,23	0,970***
3	31,36	1,55	51,31	10,00	-0,69	3,26	0,966***
4	29,37	0,01	50,00	10,33	-0,58	2,99	0,973***
5	29,62	0,01	50,00	10,44	-0,61	3,04	0,971***
6	33,09	2,08	52,70	10,39	-0,82	3,42	0,953***
7	40,49	2,41	65,60	12,71	-0,96	3,60	0,933***
8	49,08	0,54	97,23	16,20	-0,67	3,56	0,960***
9	52,63	4,89	99,90	15,88	-0,56	3,64	0,967***
10	53,45	11,43	94,89	13,86	-0,52	3,70	0,974***
11	53,35	13,67	92,34	13,02	-0,49	3,53	0,980***
12	53,67	13,59	92,89	13,10	-0,45	3,45	0,984***
13	51,36	11,41	90,34	13,01	-0,57	3,42	0,976***
14	48,60	6,72	87,00	13,66	-0,61	3,32	0,975***
15	46,45	4,42	85,00	13,73	-0,64	3,34	0,973***
16	45,56	4,85	85,40	13,33	-0,63	3,43	0,974***
17	46,46	5,96	86,13	13,33	-0,38	3,61	0,983***
18	51,63	7,12	95,24	14,74	0,25	4,04	0,977***
19	56,42	13,53	99,57	14,58	0,45	3,88	0,978***
20	56,54	20,08	93,29	12,33	0,18	3,14	0,997**
21	52,97	23,37	82,38	9,75	-0,13	2,89	0,998
22	48,52	24,14	72,61	8,06	-0,18	3,22	0,994***
23	47,05	24,30	69,22	7,46	-0,34	3,22	0,989***
24	40,99	17,42	60,60	7,70	-0,51	3,16	0,983***

Table C.10: Descriptive statistics BELPEX price (Pre-filtered dataset)

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	42,57	9,28	77,22	11,64	-0,28	4,00	0,973***
2	38,72	3,02	73,87	11,92	-0,19	3,61	0,979***
3	34,63	0,00	70,37	12,13	-0,25	3,02	0,983***
4	30,01	-6,84	66,21	12,24	-0,21	2,41	0,973***
5	29,05	-7,31	64,74	12,03	-0,23	2,30	0,965***
6	33,14	-3,69	69,37	12,22	-0,48	2,80	0,960***
7	40,40	-4,12	84,28	14,73	-0,50	3,35	0,960***
8	49,27	-4,65	102,44	17,80	-0,40	3,38	0,970***
9	53,36	0,35	105,63	17,51	-0,36	3,87	0,964***
10	56,08	8,13	103,31	15,80	-0,34	4,37	0,960***
11	57,04	12,59	100,73	14,63	-0,47	4,55	0,956***
12	58,10	15,01	100,44	14,16	-0,46	4,61	0,956***
13	56,68	18,48	93,91	12,43	-0,73	4,66	0,947***
14	53,43	12,09	93,78	13,46	-0,80	4,41	0,946***
15	50,89	8,89	92,05	13,73	-0,72	4,31	0,951***
16	48,38	7,33	88,71	13,45	-0,73	4,32	0,946***
17	47,82	6,27	88,71	13,65	-0,63	4,26	0,948***
18	53,18	4,95	100,58	15,94	-0,05	4,23	0,968***
19	59,18	9,57	110,83	17,46	0,40	4,38	0,962***
20	59,13	11,06	106,36	15,92	0,23	4,31	0,972***
21	54,63	17,03	91,92	12,44	-0,37	4,36	0,971***
22	50,42	20,33	80,44	10,00	-0,49	4,49	0,962***
23	52,33	26,92	77,34	8,35	0,14	4,35	0,971***
24	47,88	20,70	74,42	8,87	0,06	4,30	0,977***

Table C.11: Descriptive statistics EPEX Germany price (Pre-filtered dataset)

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	37,43	8,56	57,32	9,56	-0,79	3,53	0,959***
2	34,09	3,12	54,03	10,37	-0,88	3,48	0,945***
3	31,46	-1,05	52,05	10,92	-0,84	3,28	0,946***
4	29,47	-3,47	51,08	11,08	-0,67	2,89	0,959***
5	29,88	-2,71	52,07	10,93	-0,66	2,90	0,961***
6	33,13	0,21	53,46	11,03	-0,92	3,42	0,934***
7	40,20	-0,16	73,31	13,52	-0,99	3,88	0,931***
8	48,90	-1,62	99,07	16,89	-0,58	3,55	0,968***
9	52,35	3,56	100,71	16,27	-0,43	3,69	0,975***
10	52,81	9,48	95,62	14,34	-0,51	3,73	0,976***
11	52,50	10,05	94,26	13,98	-0,52	3,77	0,975***
12	52,96	10,17	94,94	13,99	-0,51	3,65	0,978***
13	50,64	8,34	92,02	13,79	-0,61	3,50	0,972***
14	48,00	4,09	90,96	14,32	-0,59	3,34	0,974***
15	45,93	2,02	88,89	14,36	-0,60	3,42	0,975***
16	45,09	2,87	86,45	13,84	-0,62	3,60	0,972***
17	45,80	4,72	86,08	13,52	-0,42	3,82	0,976***
18	51,29	6,91	94,83	14,69	0,11	4,18	0,977***
19	56,36	11,46	100,37	14,89	0,37	4,01	0,978***
20	56,64	17,06	95,79	13,18	0,21	3,49	0,992***
21	52,50	20,61	84,26	10,61	-0,14	3,12	0,997**
22	48,09	21,46	74,47	8,83	-0,18	3,48	0,993***
23	47,26	22,72	71,18	8,02	-0,39	3,52	0,987***
24	40,94	15,34	60,35	8,42	-0,72	3,72	0,966***

Table C.12: Descriptive statistics IPEX price (Pre-filtered dataset)

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	63,06	30,74	97,65	11,73	0,15	2,85	0,997**
2	55,83	23,57	91,53	12,07	0,18	2,96	0,997**
3	51,48	15,42	88,18	12,32	0,16	2,98	0,997**
4	48,35	11,42	86,06	12,60	0,18	2,77	0,996***
5	47,85	11,05	85,47	12,55	0,17	2,74	0,996***
6	51,00	15,31	86,83	12,21	-0,07	2,91	0,998
7	59,82	23,23	85,53	12,55	-0,72	3,35	0,963***
8	68,73	28,13	108,96	13,80	-0,46	4,05	0,974***
9	77,02	31,18	122,32	15,47	-0,15	3,75	0,989***
10	80,38	34,41	125,17	15,25	0,02	4,25	0,978***
11	78,50	30,74	124,76	15,68	0,08	4,46	0,970***
12	76,39	25,05	126,07	16,77	0,14	4,88	0,953***
13	68,20	28,19	106,56	12,78	-0,66	4,91	0,944***
14	64,98	21,87	106,54	13,92	-0,80	4,92	0,929***
15	67,55	18,98	114,55	15,83	-0,55	4,87	0,942***
16	70,29	23,24	115,92	15,40	-0,36	4,76	0,957***
17	74,23	26,77	120,60	15,79	-0,14	4,47	0,969***
18	81,37	19,44	141,85	20,73	0,91	4,67	0,921***
19	85,10	27,73	141,21	19,25	0,96	3,98	0,934***
20	89,12	49,63	145,46	18,94	0,89	3,63	0,948***
21	90,05	57,58	141,49	17,44	0,97	3,58	0,931***
22	83,64	55,16	124,92	13,98	0,84	3,46	0,945***
23	74,86	51,99	104,24	10,04	0,58	3,00	0,974***
24	67,61	41,07	94,06	9,03	0,41	3,32	0,988***

Table C.13: Descriptive statistics APX price (Pre-filtered dataset)

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	43,65	20,13	67,14	7,81	-0,13	3,81	0,989***
2	39,28	15,83	62,49	7,86	-0,42	3,67	0,983***
3	36,25	10,99	61,34	8,57	-0,56	3,60	0,975***
4	33,55	6,66	59,94	9,18	-0,56	3,26	0,974***
5	33,23	6,37	58,12	9,17	-0,63	3,28	0,970***
6	36,00	9,48	59,96	8,97	-0,84	3,85	0,952***
7	42,34	10,16	70,00	10,80	-0,80	4,08	0,955***
8	51,03	8,38	93,36	14,25	-0,42	3,63	0,981***
9	54,72	13,31	95,85	13,88	-0,23	3,66	0,985***
10	57,01	20,84	92,96	12,13	-0,15	3,63	0,989***
11	58,49	25,46	91,26	11,07	-0,07	3,56	0,991***
12	59,68	27,76	91,45	10,67	-0,04	3,53	0,992***
13	58,06	30,52	85,35	9,19	-0,12	3,39	0,994***
14	55,57	26,78	84,22	9,67	-0,10	3,26	0,996***
15	52,94	24,30	81,53	9,65	-0,12	3,24	0,997**
16	50,61	22,81	78,34	9,38	-0,07	3,56	0,993***
17	50,59	22,98	78,11	9,32	0,16	3,73	0,988***
18	56,33	23,00	90,67	11,66	0,76	3,91	0,959***
19	60,26	27,00	97,57	12,74	0,84	3,94	0,952***
20	59,84	29,41	94,26	11,66	0,62	3,51	0,973***
21	56,67	31,01	82,75	8,61	0,33	3,30	0,991***
22	52,35	30,29	74,95	7,37	0,50	3,48	0,983***
23	51,99	32,62	71,64	6,50	0,45	3,61	0,981***
24	47,37	29,17	65,69	6,08	0,06	3,54	0,993***

Table C.14: Descriptive statistics BSP price (Pre-filtered dataset)

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	39,22	5,95	71,86	11,15	0,08	4,18	0,978***
2	35,51	2,17	68,25	11,21	-0,19	3,89	0,982***
3	32,59	0,00	65,65	11,32	-0,34	3,64	0,982***
4	30,64	0,00	63,80	11,34	-0,24	3,36	0,986***
5	31,00	0,00	63,99	11,29	-0,26	3,35	0,986***
6	34,74	0,00	69,95	12,02	-0,30	3,70	0,979***
7	43,71	0,00	87,60	14,89	-0,27	3,58	0,980***
8	53,90	0,00	107,86	18,31	-0,34	3,37	0,986***
9	58,81	1,97	115,44	19,26	-0,08	3,49	0,993***
10	59,79	5,93	113,31	18,23	0,14	3,63	0,991***
11	59,30	8,42	109,83	17,23	0,07	3,56	0,993***
12	59,29	10,23	107,97	16,57	-0,05	3,52	0,995***
13	56,38	11,88	100,44	14,99	-0,44	3,46	0,984***
14	53,97	6,75	100,76	15,90	-0,41	3,32	0,987***
15	52,97	1,02	104,63	17,55	-0,16	3,30	0,996***
16	52,76	0,00	106,47	18,26	0,06	3,31	0,995***
17	54,50	0,00	111,24	19,30	0,36	3,45	0,984***
18	59,68	0,00	123,73	21,87	0,88	4,32	0,942***
19	63,71	2,17	124,69	20,85	0,88	4,18	0,944***
20	64,21	8,22	120,29	18,95	0,65	3,54	0,968***
21	61,75	9,90	114,48	17,65	0,72	3,61	0,955***
22	57,45	10,15	105,32	16,04	0,69	3,37	0,942***
23	54,27	12,55	95,93	14,11	0,57	3,39	0,952***
24	46,20	7,50	84,58	13,02	0,64	3,96	0,953***

Table C.15: Descriptive statistics EPEX Switzerland price (Pre-filtered dataset)

Hour	Mean	Minumum	Maximum	St. Dev.	Skewness	Kurtosis	W Test
1	44,54	5,56	81,78	12,84	-0,02	3,01	0,996***
2	39,87	1,47	77,19	12,71	-0,05	3,09	0,998
3	35,93	0,00	73,06	12,66	-0,05	3,00	0,999
4	33,09	0,00	70,39	12,73	0,01	2,86	0,999
5	32,45	0,00	69,12	12,51	-0,04	2,92	0,998
6	37,25	0,00	76,54	13,39	-0,15	3,03	0,997**
7	46,13	0,00	94,99	16,58	-0,43	2,88	0,981***
8	53,09	0,00	106,16	17,95	-0,56	3,44	0,963***
9	56,70	3,16	109,23	17,74	-0,45	3,76	0,97***
10	58,02	7,73	107,22	16,60	-0,40	3,89	0,973***
11	58,11	10,96	104,12	15,50	-0,52	3,89	0,968***
12	58,53	13,07	102,79	14,87	-0,65	3,94	0,961***
13	56,00	14,19	96,65	13,62	-0,81	3,97	0,947***
14	54,01	8,91	97,97	14,73	-0,77	3,72	0,948***
15	53,34	4,62	100,85	15,96	-0,68	3,48	0,958***
16	52,89	3,04	101,48	16,36	-0,61	3,37	0,965***
17	53,24	4,77	101,76	16,36	-0,45	3,24	0,978***
18	55,83	5,37	105,04	16,66	-0,06	3,62	0,988***
19	59,13	8,21	108,77	16,84	0,32	3,88	0,979***
20	59,32	13,36	104,28	15,23	0,13	3,45	0,989***
21	57,30	17,63	96,16	13,12	-0,22	2,95	0,989***
22	55,16	17,81	91,53	12,31	-0,25	2,85	0,993***
23	54,90	19,54	89,07	11,54	-0,24	3,09	0,994***
24	48,74	12,19	83,66	11,99	-0,10	2,98	0,995***

Table C.16: Lag selection VAR-X models (Pre-filtered dataset)

Hour 1					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-30554,2		52,4794	52,6754	52,9992
1	-28943,9	3220,6	49,8338	50,1345	50,6309*
2	-28752,1	383,56	49,6152	50,0204*	50,6895
3	-28664,6	174,94	49,5751	50,0848	50,9266
4	-28603,5	122,15	49,5801	50,1944	51,2088
5	-28530,9	145,37	49,5652	50,2841	51,4712
6	-28451	159,73	49,5381	50,3615	51,7213
7	-28373,5	155,1*	49,5149*	50,4429	51,9754

Hour 2					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-30046		51,61	51,8061	52,1298
1	-28445,7	3200,8	48,9814	49,2821	49,7785*
2	-28296,6	298,06	48,836	49,2412*	49,9103
3	-28212,5	168,31	48,8015*	49,3113	50,153
4	-28162,6	99,757	48,8257	49,44	50,4544
5	-28105,3	114,57	48,8371	49,556	50,7431
6	-28033,5	143,67	48,8237	49,6472	51,007
7	-27958,3	150,43*	48,8045	49,7326	51,265

Hour 3					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-30590,9		52,5423	52,7383	53,0621
1	-29000,8	3180,4	49,9312	50,2318	50,7282*
2	-28874,4	252,75	49,8244	50,2296*	50,8987
3	-28795,7	157,31	49,7994	50,3091	51,1509
4	-28732,1	127,34	49,7999	50,4143	51,4287
5	-28679,9	104,35	49,8202	50,5391	51,7262
6	-28602	155,83	49,7964	50,6198	51,9796
7	-28488,5	227,03*	49,7116*	50,6397	52,1721

Hour 4					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-30529,3		52,4368	52,6329	52,9566
1	-28804,4	3449,8	49,5952	49,8958*	50,3923*
2	-28688,6	231,57	49,5066	49,9118	50,5809
3	-28632,2	112,82	49,5196	50,0294	50,8711
4	-28565,7	132,96	49,5154	50,1297	51,1441
5	-28492	147,54	49,4986	50,2175	51,4046
6	-28407,8	168,24	49,4642	50,2877	51,6475
7	-28322,1	171,55*	49,427*	50,355	51,8874

Hour 5					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-30314,4		52,0691	52,2651	52,5889
1	-28680,6	3267,5	49,3834	49,6841	50,1805*
2	-28550,1	260,97	49,2697	49,6749*	50,344
3	-28495,7	108,92	49,286	49,7958	50,6375
4	-28419,5	152,4	49,2651	49,8795	50,8939
5	-28354,6	129,78	49,2636	49,9825	51,1696
6	-28261,5	186,21	49,2138	50,0373	51,3971
7	-28185,4	152,22*	49,1931*	50,1211	51,6536

Hour 6					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-30175,2		51,8309	52,027	52,3507
1	-28582,8	3184,8	49,2161	49,5167	50,0131*
2	-28450,3	265	49,0989	49,5041*	50,1732
3	-28384,3	131,88	49,0955	49,6053	50,4471
4	-28311,9	144,81	49,0812	49,6955	50,7099
5	-28196,5	230,96	48,9931	49,712	50,8991
6	-28084,7	223,57	48,9113	49,7348	51,0946
7	-27961,8	245,81*	48,8106*	49,7386	51,271

Hour 7					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-30781,2		52,8677	53,0638	53,3875
1	-29633,9	2294,5	51,0144	51,315	51,8114*
2	-29434,8	398,25	50,7832	51,1884	51,8575
3	-29287,5	294,56	50,6407	51,1505	51,9923
4	-29211,4	152,25	50,62	51,2343	52,2488
5	-29117,7	187,42	50,5692	51,2881	52,4752
6	-28955,2	324,87	50,4007	51,2242	52,584
7	-28782,3	345,87*	50,2144*	51,1424*	52,6748

Hour 8					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31490,7		54,0817	54,2777	54,6015
1	-30543,4	1894,6	52,5704	52,8711	53,3675
2	-30316,9	452,95	52,2925	52,6977	53,3668*
3	-30127,8	378,23	52,0784	52,5882	53,4299
4	-30051,9	151,82	52,058	52,6724	53,6868
5	-29958,4	187,07	52,0075	52,7264	53,9135
6	-29826	264,75	51,8905	52,714	54,0738
7	-29602	447,99*	51,6168*	52,5448*	54,0773

Hour 9					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31606,4		54,2796	54,4757	54,7994
1	-30683,5	1845,9	52,8101	53,1107	53,6072*
2	-30498,8	369,42	52,6036	53,0088*	53,6779
3	-30387,4	222,88	52,5224	53,0322	53,8739
4	-30305,4	163,97	52,4916	53,106	54,1204
5	-30252,2	106,24	52,5103	53,2292	54,4163
6	-30134,7	235,18	52,4186	53,242	54,6018
7	-29899,5	470,31*	52,1258*	53,0538	54,5862

Hour 10					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31151,3		53,5009	53,6969	54,0207
1	-30078,3	2145,9	51,7747	52,0754	52,5718*
2	-29926,5	303,66	51,6245	52,0297	52,6987
3	-29796,5	259,99	51,5115	52,0213*	52,8631
4	-29702,3	188,43	51,4599	52,0742	53,0886
5	-29627,5	149,58	51,4414	52,1603	53,3474
6	-29505,8	243,41	51,3427	52,1661	53,5259
7	-29388,8	233,9*	51,2521*	52,1801	53,7126

Hour 11					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31339,9		53,8236	54,0196	54,3434
1	-30108,2	2463,4	51,8258	52,1264	52,6228*
2	-29952,5	311,32	51,669	52,0742*	52,7432
3	-29842	220,91	51,5895	52,0992	52,941
4	-29754	176,1	51,5483	52,1627	53,1771
5	-29679,2	149,63	51,5298	52,2487	53,4358
6	-29532,1	294,11	51,3877	52,2112	53,571
7	-29389	286,25*	51,2523*	52,1804	53,7128

Hour 12					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31653,3		54,3598	54,5559	54,8796
1	-30275,8	2755	52,1125	52,4132	52,9096*
2	-30120,3	310,97	51,956	52,3612*	53,0303
3	-30023,6	193,36	51,9001	52,4099	53,2516
4	-29933,1	181,06	51,8547	52,4691	53,4835
5	-29876,9	112,43	51,868	52,5869	53,774
6	-29743,6	266,62	51,7495	52,5729	53,9327
7	-29630,2	226,8*	51,6649*	52,593	54,1254

* Selected lag

Hour 13					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-30960,3		53,1741	53,3702	53,694
1	-29603,2	2714,3	50,9618	51,2624	51,7588*
2	-29436,7	332,99	50,7864	51,1916*	51,8607
3	-29312,9	247,56	50,6841	51,1939	52,0357
4	-29210,7	204,37	50,6188	51,2331	52,2476
5	-29129,1	163,1	50,5888	51,3077	52,4948
6	-28991,3	275,62	50,4625	51,286	52,6457
7	-28820,9	340,87*	50,2804*	51,2084	52,7409

Hour 14					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31187,8		53,5634	53,7594	54,0832
1	-29884	2607,5	51,4423	51,7429	52,2394*
2	-29703,8	360,42	51,2435	51,6487	52,3178
3	-29536,3	334,97	51,0664	51,5762	52,418
4	-29436,2	200,36	51,0045	51,6189	52,6333
5	-29356,9	158,57	50,9784	51,6973	52,8844
6	-29145,2	423,29	50,7258	51,5493	52,909
7	-29005,9	278,56*	50,597*	51,525*	53,0575

Hour 15					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31866,6		54,7247	54,9207	55,2445
1	-30530,2	2672,6	52,5479	52,8485	53,345*
2	-30334,1	392,23	52,3219	52,7271	53,3962
3	-30113,8	440,61	52,0544	52,5642	53,406
4	-30023,3	181,1	52,009	52,6234	53,6378
5	-29903,1	240,29	51,913	52,6319	53,819
6	-29729,9	346,53	51,726	52,5495	53,9093
7	-29562,9	334,01*	51,5498*	52,4778*	54,0103

Hour 16					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31203,7		53,5906	53,7866	54,1104
1	-29878,1	2651,1	51,4322	51,7328	52,2293*
2	-29672,7	410,89	51,1902	51,5954	52,2645
3	-29523,2	299,03	51,0439	51,5537	52,3954
4	-29427,2	191,9	50,9892	51,6036	52,618
5	-29327,5	199,32	50,9282	51,6471	52,8342
6	-29127,8	399,59	50,6959	51,5194	52,8791
7	-28974,1	307,32*	50,5425*	51,4705*	53,003

Hour 17					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31291		53,74	53,9361	54,2598
1	-29841,3	2899,4	51,3692	51,6699	52,1663*
2	-29648,8	385,04	51,1494	51,5546	52,2237
3	-29521,3	254,96	51,0408	51,5505	52,3923
4	-29430,6	181,45	50,995	51,6094	52,6238
5	-29316,9	227,42	50,91	51,6289	52,816
6	-29128,9	375,97	50,6979	51,5213	52,8811
7	-28983,3	291,17*	50,5583*	51,4863*	53,0188

Hour 18					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31911,6		54,8018	54,9978	55,3216
1	-30340,4	3142,5	52,223	52,5237	53,0201
2	-30110,7	459,25	51,9397	52,3449*	53,014*
3	-30009,2	203,11	51,8754	52,3852	53,227
4	-29930,8	156,76	51,8508	52,4652	53,4796
5	-29842	177,66	51,8083	52,5272	53,7143
6	-29724,3	235,36	51,7165	52,54	53,8997
7	-29613,6	221,37*	51,6366*	52,5647	54,0971

Hour 19					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31806,9		54,6226	54,8187	55,1424
1	-30393,1	2827,6	52,3133	52,6139	53,1103*
2	-30208,7	368,82	52,1073	52,5125*	53,1816
3	-30116,3	184,77	52,0587	52,5685	53,4103
4	-30028,6	175,42	52,0182	52,6325	53,6469
5	-29927,8	201,56	51,9552	52,6741	53,8612
6	-29830,9	193,89	51,8989	52,7223	54,0821
7	-29708,5	244,88*	51,7989*	52,7269	54,2594

Hour 20					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31833		54,6672	54,8633	55,187
1	-30312,1	3041,7	52,1747	52,4753	52,9717*
2	-30171,9	280,41	52,0443	52,4495*	53,1186
3	-30054,8	234,2	51,9535	52,4632	53,305
4	-29969,1	171,39	51,9163	52,5307	53,5451
5	-29900,8	136,57	51,909	52,6279	53,815
6	-29765,1	271,39	51,7864	52,6098	53,9696
7	-29628,1	273,98*	51,6615*	52,5895	54,122

Hour 21					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-31597,2		54,2639	54,46	54,7837
1	-29790,4	3613,7	51,2821	51,5827	52,0792*
2	-29595,2	390,37	51,0577	51,4629	52,132
3	-29461,3	267,91	50,938	51,4478*	52,2895
4	-29382,8	156,88	50,9133	51,5276	52,5421
5	-29302,6	160,48	50,8855	51,6044	52,7915
6	-29154,5	296,17	50,7416	51,5651	52,9249
7	-29052,9	203,25*	50,6773*	51,6053	53,1377

Hour 22					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-30852,8		52,9903	53,1864	53,5101
1	-28834,3	4037,1	49,6463	49,9469	50,4434*
2	-28638,8	390,93	49,4214	49,8266	50,4957
3	-28505,6	266,42	49,303	49,8128*	50,6545
4	-28412,8	185,67	49,2537	49,868	50,8824
5	-28331,7	162,03	49,2245	49,9434	51,1305
6	-28225,8	211,91	49,1528	49,9762	51,336
7	-28129,2	193,1*	49,0971*	50,0251	51,5576

Hour 23					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-29671,9		50,9699	51,166	51,4897
1	-27622	4099,8	47,5723	47,8729	48,3693*
2	-27426,9	390,1	47,3481	47,7533*	48,4223
3	-27304,9	244,02	47,2488	47,7586	48,6003
4	-27215	179,92	47,2044	47,8187	48,8332
5	-27134,9	160,14	47,1769	47,8958	49,0829
6	-27033,6	202,61	47,1131	47,9365	49,2963
7	-26940,6	185,91*	47,0635*	47,9916	49,524

Hour 24					
Lag	LL	LR	Information Criteria		
			Akaike	Hannan-Quinn	Schwarz
0	-29570,3		50,796	50,992	51,3158
1	-27415,3	4309,9	47,2187	47,5193	48,0157*
2	-27231,7	367,34	47,0139	47,4191	48,0882
3	-27078,8	305,7	46,8619	47,3717*	48,2135
4	-26990,9	175,86	46,821	47,4353	48,4498
5	-26892,3	197,09	46,7619	47,4808	48,6679
6	-26802,1	180,56	46,7169	47,5404	48,9002
7	-26720,7	162,66*	46,6873*	47,6153	49,1478

* Selected lag

Table C.17: MAPE errors from AR and VAR models (%) (Pre-filtered dataset)

				AR				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**6,10**	21,71	13,80	6,22	**4,82**	19,48	**7,78**	**9,96**
2	**6,81**	21,15	18,51	**9,42**	6,27	12,10	**7,56**	**9,54**
3	**7,16**	22,60	**22,30**	**9,75**	7,35	8,30	**7,33**	**8,35**
4	8,19	**32,58**	**31,83**	**10,70**	9,26	**9,53**	**8,86**	9,30
5	**7,24**	**31,68**	31,60	11,22	9,17	10,84	**9,27**	**7,66**
6	**7,51**	21,55	20,01	13,37	**8,12**	**9,08**	**10,20**	**6,41**
7	**8,57**	**24,31**	20,98	**11,21**	**7,27**	10,81	**10,48**	**8,69**
8	**9,55**	25,01	**20,98**	**12,25**	**6,41**	9,46	13,35	**9,94**
9	10,38	**18,64**	**16,97**	**10,09**	**8,90**	**9,13**	**15,88**	9,02
10	13,52	**19,12**	**18,14**	14,66	9,06	**10,05**	**14,62**	10,14
11	14,95	**19,29**	**19,03**	17,79	9,74	10,82	**13,23**	12,41
12	17,74	**21,32**	**20,86**	19,87	11,36	**8,27**	10,17	13,33
13	18,08	19,64	20,11	20,82	13,39	10,72	**9,99**	13,82
14	**24,36**	21,84	20,89	20,29	18,07	**10,17**	**12,22**	**15,84**
15	**23,11**	24,88	22,47	22,44	19,43	**9,65**	**13,15**	**17,75**
16	**20,80**	22,79	19,70	19,64	13,56	10,16	**15,91**	**17,43**
17	**21,07**	17,93	15,17	**15,35**	**9,41**	11,80	**17,57**	**16,82**
18	**14,46**	**19,51**	**18,21**	**11,99**	**7,63**	14,63	**19,00**	**13,11**
19	**11,10**	**18,63**	16,48	**9,47**	**5,38**	11,85	15,10	**10,39**
20	8,22	20,19	18,43	7,90	6,51	10,67	7,34	7,84
21	9,66	20,96	21,82	**10,05**	**5,97**	12,52	11,58	7,91
22	**7,34**	**17,40**	19,04	**9,36**	**8,87**	9,64	**16,45**	**6,40**
23	8,05	**11,36**	10,17	**9,54**	**5,83**	**9,89**	**12,09**	7,05
24	**6,49**	**10,82**	**9,52**	**6,64**	**4,27**	17,64	**11,10**	6,84
				VAR				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	6,98	**17,00**	**11,17**	**7,44**	5,53	**19,17**	8,01	10,93
2	7,51	**18,05**	**16,86**	10,02	**6,18**	**11,75**	8,60	10,23
3	8,37	**19,77**	21,74	10,19	**6,94**	**7,70**	7,51	8,65
4	**7,67**	32,35	31,35	10,85	**8,65**	9,67	9,64	**8,86**
5	8,89	35,30	**32,80**	**10,56**	**8,93**	**10,88**	10,55	8,94
6	8,96	**21,07**	**19,33**	**11,97**	8,27	8,93	11,33	6,81
7	8,72	28,55	**23,66**	11,35	7,79	**9,94**	11,44	11,12
8	10,91	**28,80**	23,98	13,68	7,05	**8,78**	**12,28**	11,79
9	**11,30**	22,32	18,48	12,41	10,03	9,49	18,33	**9,27**
10	**12,96**	20,07	17,90	**13,50**	**10,56**	10,04	17,28	**11,84**
11	**12,00**	18,78	16,82	**15,74**	**9,92**	**8,90**	14,80	**11,58**
12	**15,10**	20,99	19,35	**17,90**	**11,01**	8,84	**10,09**	**11,65**
13	**16,31**	**18,23**	**18,49**	**18,35**	**13,16**	**10,79**	10,66	**13,24**
14	25,78	**20,64**	**19,60**	**19,70**	**16,58**	10,42	13,06	18,64
15	24,77	**25,04**	**20,43**	**19,73**	**17,76**	10,02	15,70	18,16
16	21,23	**21,26**	**18,35**	**18,15**	**12,40**	**10,25**	19,14	19,91
17	22,62	**18,91**	**16,48**	16,89	10,02	**11,81**	19,98	20,27
18	16,67	25,90	18,71	13,08	7,58	**14,07**	21,96	15,47
19	11,11	18,97	**17,09**	9,94	5,41	**11,59**	**13,36**	9,52
20	**7,78**	**17,59**	**16,11**	**7,15**	**6,55**	**9,46**	**6,97**	**7,13**
21	**9,02**	**19,10**	**20,06**	10,69	6,30	**12,02**	**11,42**	**8,01**
22	7,72	17,61	**17,80**	10,19	9,38	**9,24**	17,67	7,59
23	**7,51**	11,50	**10,17**	10,10	6,48	10,11	11,79	**6,36**
24	6,44	10,62	9,81	7,43	5,10	**17,47**	11,47	**7,41**

Table C.18: MAPE errors from AR-X and VAR-X models (%) (Pre-filtered dataset)

AR-X								
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**5,90**	**18,69**	13,51	**6,50**	**4,76**	19,29	**7,85**	**9,76**
2	**6,09**	19,68	19,40	**10,18**	**6,24**	**11,82**	**7,74**	**9,64**
3	**6,27**	23,86	**22,53**	**10,07**	7,16	**7,75**	8,69	**8,54**
4	**6,89**	**33,02**	**31,21**	12,49	9,27	**9,58**	**9,47**	**9,27**
5	**8,32**	**31,71**	**28,47**	**11,01**	9,21	**10,75**	**9,84**	**7,60**
6	**9,01**	**21,27**	**19,41**	**13,40**	8,03	**8,19**	**10,51**	**6,41**
7	**8,07**	**24,77**	**21,46**	**9,12**	**7,56**	**8,71**	**9,78**	**8,59**
8	**9,59**	**25,82**	**19,93**	**11,07**	**6,70**	**7,64**	**12,18**	**9,63**
9	**10,40**	**17,07**	**13,73**	**9,21**	**9,24**	**8,19**	**14,26**	10,45
10	**11,99**	18,75	**15,51**	13,83	**9,82**	**9,31**	**12,63**	**11,52**
11	**12,36**	18,55	**15,78**	16,64	**9,85**	10,41	**12,03**	12,88
12	**15,06**	**19,63**	**16,85**	18,45	10,50	**8,62**	**9,74**	13,69
13	**15,82**	18,20	17,14	19,27	**12,02**	**10,41**	**10,21**	14,62
14	21,82	**20,07**	**18,24**	**18,81**	**16,61**	**10,47**	**13,14**	**16,01**
15	**20,83**	23,95	18,98	20,93	**17,63**	**10,22**	**14,42**	**18,87**
16	**17,55**	**21,04**	**16,53**	**19,01**	12,86	10,75	**16,78**	**18,83**
17	**18,31**	**18,41**	**14,27**	**15,15**	**9,46**	11,62	**17,96**	**17,39**
18	**12,88**	**19,24**	**16,28**	**12,52**	8,11	13,87	**19,48**	**13,89**
19	**10,18**	**18,59**	**14,14**	**10,05**	5,75	**11,64**	**14,27**	**10,77**
20	**7,47**	19,09	**16,79**	8,05	6,70	10,72	**9,03**	7,68
21	**9,06**	**19,77**	**20,06**	**10,14**	6,06	**12,30**	13,07	**8,00**
22	**7,00**	**17,07**	**17,65**	**9,23**	**8,87**	**9,49**	**16,89**	**6,38**
23	**7,78**	**11,00**	**9,90**	**9,49**	**5,85**	**9,81**	**12,62**	**7,09**
24	**6,04**	**10,83**	**9,15**	**6,76**	**4,25**	**17,53**	**11,22**	**6,82**
VAR-X								
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	8,08	16,66	**11,10**	8,34	5,59	**19,03**	7,78	11,24
2	8,60	**20,62**	**18,08**	12,08	6,50	12,28	8,83	11,76
3	10,36	**23,44**	23,01	11,35	**6,85**	8,95	**7,65**	10,70
4	8,81	35,45	35,49	**10,98**	**8,55**	10,03	10,15	10,33
5	9,58	40,16	37,33	12,14	**8,88**	11,61	11,45	11,86
6	9,64	23,45	21,28	12,42	**8,08**	9,67	12,04	8,64
7	10,84	31,70	24,27	9,97	7,89	9,89	11,17	12,38
8	13,06	33,89	26,86	12,94	7,43	8,09	13,53	13,47
9	15,10	24,38	20,74	12,05	11,04	9,59	19,58	**12,35**
10	15,00	**20,54**	19,24	**12,82**	12,73	10,56	18,67	14,40
11	13,78	**19,05**	16,82	**15,28**	10,87	**9,87**	15,30	**12,27**
12	15,62	20,54	18,07	**16,94**	**11,21**	9,48	11,83	**11,84**
13	17,86	**18,47**	**18,89**	**19,19**	13,09	10,90	12,30	**13,48**
14	**25,26**	21,52	20,31	21,58	17,17	11,05	14,84	17,91
15	24,17	**24,27**	**20,75**	**20,78**	18,15	10,75	17,55	17,87
16	21,69	22,72	20,42	19,40	**12,50**	**10,78**	21,02	20,81
17	22,31	21,69	18,99	17,50	10,02	**11,52**	21,25	22,13
18	16,32	25,68	19,20	13,48	**7,28**	**13,48**	23,43	15,72
19	11,78	19,06	17,20	9,80	**5,60**	11,96	14,42	10,42
20	8,98	**17,75**	15,81	**7,64**	**6,77**	**9,98**	9,56	**7,77**
21	10,52	19,73	19,96	10,07	**6,34**	12,20	**12,91**	9,59
22	8,61	18,53	18,31	9,76	9,15	9,46	18,36	8,56
23	8,33	11,67	10,76	10,26	6,60	10,20	12,42	6,79
24	6,09	10,87	9,79	7,58	5,40	17,65	11,82	8,34

Table C.19: MAPE errors from ARI and VEC models (%) (Pre-filtered dataset)

				ARI				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**6,37**	20,74	15,03	**7,14**	**4,90**	19,79	**8,10**	**8,94**
2	**7,09**	22,08	19,93	**8,86**	6,33	**11,31**	**8,84**	**8,81**
3	**7,35**	22,01	**22,12**	10,71	7,32	**6,91**	8,88	**7,67**
4	8,32	**30,00**	**29,55**	**12,02**	9,09	9,79	**10,17**	8,41
5	**8,17**	**28,68**	**29,88**	11,64	9,24	11,27	10,83	**7,26**
6	**8,09**	**18,58**	18,43	**12,84**	**8,18**	10,15	12,27	6,56
7	**8,78**	**21,76**	21,99	**10,59**	**7,60**	10,60	**10,71**	**8,36**
8	**8,83**	**19,48**	**18,41**	**13,11**	**6,57**	**9,04**	**12,32**	**9,31**
9	**9,89**	**14,49**	**14,69**	**9,82**	**8,91**	**8,72**	**15,94**	**8,71**
10	12,73	**16,46**	**16,51**	13,42	8,79	10,47	**14,66**	**9,30**
11	13,55	**17,79**	**17,92**	16,74	10,07	10,95	**13,08**	**11,05**
12	17,06	**19,36**	**19,07**	18,64	11,53	**8,13**	10,61	**12,06**
13	17,25	17,27	18,88	19,66	13,43	10,99	**10,22**	**12,98**
14	**22,54**	**18,27**	19,23	18,36	18,11	**10,50**	**12,75**	**14,15**
15	**21,54**	**20,93**	20,05	19,59	19,43	**9,67**	**13,53**	**15,55**
16	**18,91**	**17,39**	17,06	**16,89**	14,04	10,28	**15,94**	**15,28**
17	**19,56**	**14,05**	14,65	**13,85**	**9,98**	11,64	**16,70**	**14,93**
18	**13,43**	**17,68**	**16,65**	**11,51**	**8,11**	14,82	**18,75**	**12,36**
19	**10,69**	**17,67**	**15,60**	**9,85**	**5,66**	11,99	14,36	**10,39**
20	8,30	19,72	17,93	7,36	6,38	10,73	6,33	7,61
21	9,63	20,46	21,06	**9,64**	**6,04**	12,67	11,45	7,87
22	**7,16**	**17,09**	**18,50**	**9,05**	**8,90**	9,56	**16,36**	**6,20**
23	8,31	**11,07**	10,38	**9,68**	**5,85**	10,18	**11,76**	6,49
24	7,20	10,95	9,82	**6,88**	**4,30**	17,60	**11,29**	7,27
				VEC				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	6,79	**16,84**	**11,40**	7,84	5,94	**19,27**	8,79	10,53
2	7,54	**17,86**	**16,84**	10,02	**6,39**	11,65	8,66	10,10
3	8,38	**19,72**	21,67	**10,18**	**6,85**	7,55	**7,55**	8,57
4	**7,74**	31,32	30,82	10,82	**8,67**	**9,73**	9,68	**8,83**
5	8,91	33,82	32,25	**10,61**	**9,02**	**10,87**	**10,63**	8,86
6	9,28	19,62	**18,30**	11,47	8,29	**9,11**	**11,11**	**6,98**
7	8,71	27,83	**23,55**	11,36	7,94	**9,94**	11,60	11,12
8	10,83	29,06	24,04	13,70	7,12	8,83	12,09	11,69
9	11,18	21,85	18,11	12,38	10,25	9,53	18,34	9,01
10	**12,96**	20,40	18,11	**13,51**	**10,55**	**10,12**	17,20	12,24
11	**11,76**	18,10	16,82	**15,48**	**9,60**	**8,96**	14,69	11,27
12	**14,67**	19,74	18,08	**17,33**	**10,79**	8,91	**10,54**	11,95
13	**15,40**	**17,32**	**17,89**	**18,07**	**12,85**	**10,86**	11,09	13,51
14	24,02	18,85	**18,82**	**18,73**	**16,07**	10,64	13,31	18,51
15	22,73	24,02	**19,62**	**18,34**	**17,75**	10,11	16,18	17,90
16	20,82	21,86	**18,49**	17,91	**12,49**	**10,26**	18,88	19,97
17	20,71	17,32	**14,57**	14,62	10,28	**11,76**	19,49	19,37
18	15,51	25,22	17,30	12,54	7,97	**14,29**	21,38	14,53
19	10,93	18,39	16,68	9,82	5,86	**11,56**	**12,96**	8,95
20	**7,86**	**17,46**	**16,02**	**7,03**	**6,44**	**9,45**	**6,16**	**6,98**
21	**8,38**	**18,62**	**20,17**	10,36	6,30	**11,97**	**11,51**	**7,64**
22	7,40	17,82	18,47	10,06	9,30	**9,22**	17,37	7,18
23	**7,65**	11,36	**10,19**	10,77	6,62	**10,10**	11,70	**6,34**
24	**6,71**	**10,54**	**9,82**	8,84	5,09	**17,49**	11,90	**7,71**

Table C.20: MAPE errors from ARI-X and VEC-X models (%) (Pre-filtered dataset)

				ARI-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	6,35	18,84	14,34	6,93	**4,92**	19,60	**8,19**	**8,90**
2	6,35	20,34	20,02	9,64	6,36	**11,33**	8,92	9,02
3	**6,79**	22,75	23,58	10,67	7,17	**6,87**	9,33	**8,18**
4	7,19	**31,81**	**31,13**	**11,90**	9,13	**10,36**	10,41	8,49
5	8,78	**29,34**	**28,91**	**11,06**	9,28	**11,33**	11,16	**7,30**
6	9,49	20,10	19,11	**12,96**	**8,13**	**9,15**	12,22	6,52
7	8,52	**23,79**	22,88	**9,54**	**7,60**	**8,37**	10,15	**8,11**
8	**9,76**	**22,36**	**19,71**	**12,73**	**6,49**	**7,88**	11,26	**9,30**
9	10,24	**15,15**	**13,45**	**9,78**	**8,84**	**8,18**	**14,36**	**9,58**
10	11,57	**17,10**	**15,46**	13,62	8,58	**9,94**	**12,43**	10,60
11	12,01	17,62	**15,71**	16,30	9,26	10,87	**11,71**	11,82
12	14,42	**18,56**	**16,74**	17,81	10,30	**8,31**	**9,74**	12,58
13	14,93	16,05	17,07	18,67	11,66	**10,95**	**10,36**	13,50
14	20,84	**16,38**	17,64	17,94	16,01	**10,93**	**13,34**	**14,38**
15	19,62	**19,55**	**18,54**	**19,35**	17,31	**10,17**	**14,80**	16,02
16	**16,42**	**17,61**	**16,01**	17,48	12,82	10,50	**16,55**	**15,93**
17	**17,11**	**14,92**	**14,15**	14,38	**9,36**	**11,49**	**17,66**	**15,28**
18	**12,06**	**16,89**	**15,85**	**11,99**	**8,24**	14,24	**19,14**	**12,82**
19	**9,95**	**17,08**	**14,00**	**10,37**	**5,70**	11,59	**13,36**	**10,70**
20	**7,68**	**18,42**	**16,77**	7,78	6,57	10,51	8,57	7,94
21	9,14	**19,48**	**20,09**	**10,19**	**6,08**	12,34	12,88	8,02
22	7,37	**17,21**	**17,72**	**9,24**	**8,90**	9,34	**16,99**	**6,28**
23	8,08	11,06	10,07	**9,60**	**5,87**	**9,99**	12,29	**6,56**
24	6,58	10,90	**9,29**	**7,08**	**4,28**	**17,28**	**11,41**	7,23

				VEC-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**6,03**	**16,14**	**10,51**	**7,13**	5,82	**19,01**	9,28	9,51
2	**5,92**	**19,90**	**18,30**	**8,74**	**6,27**	12,77	**9,33**	**9,41**
3	7,37	**19,66**	**19,91**	**9,38**	**6,91**	8,39	**8,19**	8,93
4	**6,19**	31,16	31,33	11,59	**8,91**	10,83	**9,91**	**7,41**
5	**7,48**	31,29	29,40	10,54	**9,06**	12,07	**10,96**	8,05
6	**7,82**	**18,74**	**17,23**	11,55	8,20	10,27	**10,23**	**5,66**
7	**6,30**	26,99	**22,56**	11,90	7,91	9,70	**9,80**	10,18
8	8,63	26,94	22,37	13,79	6,74	8,60	**11,25**	10,81
9	**9,53**	19,79	16,58	11,50	9,12	8,72	16,81	9,03
10	**10,69**	17,69	15,79	**12,76**	**8,82**	9,52	16,53	**8,10**
11	**11,20**	**17,87**	15,66	**14,56**	**9,50**	**9,13**	14,72	**9,08**
12	**13,04**	19,21	16,33	**15,95**	**9,97**	9,25	10,98	**9,49**
13	**12,85**	**15,45**	**16,40**	**16,38**	**10,58**	11,19	11,10	**12,90**
14	**19,58**	17,86	**17,80**	**18,07**	**13,83**	10,90	14,27	15,89
15	**18,92**	22,80	17,52	17,35	**14,91**	10,52	18,07	**15,16**
16	17,33	18,07	16,03	**15,35**	**12,43**	**10,60**	19,34	17,91
17	19,21	16,16	16,20	**14,37**	10,24	11,62	19,73	18,03
18	15,87	24,01	16,44	13,16	8,38	**14,17**	22,01	13,22
19	10,80	18,18	15,68	10,55	5,93	**11,13**	12,09	8,62
20	7,79	17,36	15,56	**6,90**	**6,67**	**9,59**	**6,78**	**6,93**
21	**8,46**	19,33	20,32	10,31	6,29	**11,92**	**12,46**	**7,99**
22	**7,21**	17,60	18,25	9,76	9,31	**9,05**	17,65	7,11
23	**7,44**	**11,06**	**9,41**	10,47	6,61	10,42	**12,06**	7,10
24	**6,19**	**10,13**	9,88	8,57	5,06	17,40	12,15	**7,62**

Table C.21: RMSE errors from AR and VAR models (Pre-filtered dataset)

				AR				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**2,08**	9,23	4,98	2,56	**5,06**	9,72	**3,43**	**3,52**
2	**1,98**	6,66	5,35	**3,16**	6,02	5,36	**2,92**	**3,14**
3	**1,95**	5,37	**5,40**	**3,19**	6,72	3,17	**2,54**	**2,35**
4	**2,09**	**5,56**	**5,51**	**3,46**	7,78	3,84	**2,88**	2,40
5	**1,95**	**5,64**	**5,57**	**3,44**	7,45	4,31	3,07	**2,09**
6	**2,09**	**4,61**	4,44	**4,02**	**7,32**	3,40	**3,55**	1,89
7	**2,92**	**5,42**	**4,93**	**3,86**	5,98	4,38	5,29	**2,83**
8	**4,23**	**6,66**	**6,43**	**5,46**	**5,48**	**4,94**	9,80	**4,21**
9	**4,06**	**6,17**	**5,89**	**4,93**	**8,95**	**5,90**	**11,10**	4,39
10	**4,92**	**6,28**	**6,18**	5,76	7,71	**7,47**	**9,35**	**4,34**
11	5,72	**7,03**	**6,92**	6,76	8,08	7,28	**8,41**	**5,09**
12	6,90	8,17	**8,10**	8,25	8,83	6,23	5,88	5,80
13	6,49	7,63	7,74	7,95	8,37	7,29	**5,58**	**6,03**
14	6,73	**7,74**	7,66	7,71	9,13	**7,37**	**6,02**	**6,00**
15	5,92	**7,77**	**7,32**	**7,76**	9,51	**6,79**	**6,65**	**5,63**
16	5,54	**6,42**	**6,16**	**6,44**	8,47	**6,15**	**10,25**	**5,31**
17	5,52	**5,22**	**4,99**	**5,07**	8,60	**6,84**	**11,14**	**5,13**
18	**5,12**	**6,28**	**6,07**	**4,96**	**7,97**	**9,19**	**13,41**	**4,87**
19	**4,97**	**6,34**	**5,76**	**4,81**	**5,83**	**7,33**	10,09	**4,99**
20	4,40	7,48	6,95	4,26	7,85	6,74	3,91	4,30
21	5,53	8,25	8,17	**5,27**	**7,30**	7,85	8,17	4,83
22	3,97	**7,47**	7,62	**4,72**	**9,75**	5,47	**12,88**	**3,55**
23	4,42	**5,81**	5,09	**5,06**	6,23	6,57	**7,84**	3,81
24	**2,80**	5,07	**4,33**	**3,47**	**4,02**	9,21	**8,65**	**3,06**
				VAR				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	2,47	**8,19**	**4,45**	**2,82**	5,12	**9,59**	3,51	3,82
2	2,19	**6,04**	**4,83**	3,51	**5,73**	**5,11**	3,11	3,38
3	2,25	**5,07**	5,27	3,31	**6,40**	**3,03**	2,46	2,51
4	2,13	5,75	5,60	3,43	**7,34**	**3,58**	3,03	**2,33**
5	2,43	6,25	5,95	3,41	**7,09**	**3,96**	**3,12**	2,39
6	2,56	4,45	**4,21**	3,60	7,57	**3,24**	3,51	**2,00**
7	3,10	5,69	5,03	4,17	**5,89**	**4,21**	**5,00**	3,33
8	4,54	6,97	6,80	6,10	5,68	4,80	**9,24**	4,66
9	4,24	7,07	6,41	5,55	9,40	6,16	12,47	**4,04**
10	4,83	6,78	6,06	**5,67**	**8,24**	7,06	10,75	4,43
11	**5,24**	7,13	6,29	**6,43**	**7,59**	**6,45**	9,25	4,66
12	**6,36**	**8,16**	7,78	**7,97**	**8,23**	**6,18**	**6,16**	**5,30**
13	**6,23**	**7,41**	7,17	**7,62**	**8,12**	**7,30**	6,55	6,88
14	**6,40**	7,85	**7,50**	**7,93**	**8,39**	7,51	6,36	6,96
15	**5,65**	8,37	7,39	7,81	**8,96**	7,10	7,40	6,49
16	**5,21**	6,42	6,15	6,30	**8,03**	6,37	11,45	6,74
17	**5,19**	5,82	5,46	5,48	**8,48**	6,90	12,40	6,35
18	5,51	7,43	6,14	5,25	7,57	9,33	14,04	5,54
19	4,89	6,20	5,81	4,48	6,21	7,42	**9,45**	4,66
20	**4,22**	**6,66**	**6,12**	**4,09**	**8,05**	**6,42**	**3,83**	**3,83**
21	**5,23**	**7,82**	**7,51**	5,31	7,78	**7,57**	**8,21**	**4,61**
22	**3,75**	7,55	**7,27**	5,14	10,01	**5,19**	13,23	3,71
23	**3,99**	5,68	**4,96**	5,15	**6,32**	**6,53**	8,32	**3,51**
24	2,78	**4,96**	4,56	3,74	4,38	**9,12**	9,37	3,30

Table C.22: RMSE errors from AR-X and VAR-X models (Pre-filtered dataset)

AR-X								
Hour	Austria	Belgium	France	Germany	Italy	Netherland	Slovenia	Switzerland
1	**1,99**	8,71	4,84	**2,61**	**5,06**	9,72	**3,43**	**3,51**
2	**1,75**	6,27	5,28	**3,36**	6,05	5,31	**2,89**	**3,16**
3	**1,78**	5,48	5,43	**3,25**	6,72	**3,03**	**2,66**	**2,43**
4	**1,85**	**5,89**	**5,60**	3,83	7,78	3,82	**2,94**	**2,41**
5	**2,20**	**5,88**	**5,50**	3,72	7,47	**4,23**	**3,10**	**2,11**
6	**2,64**	**5,02**	4,68	4,01	**7,29**	**3,20**	**3,53**	**1,90**
7	**3,42**	5,95	**5,17**	**3,14**	6,09	**3,74**	**4,58**	**2,71**
8	**4,75**	**7,53**	**6,78**	**5,12**	**5,53**	**4,53**	**8,61**	**4,25**
9	**4,33**	**6,74**	**5,92**	**4,82**	**9,07**	**5,24**	**9,78**	4,90
10	**4,61**	**6,58**	**6,25**	**5,77**	**7,82**	**6,92**	**7,96**	**4,66**
11	**5,21**	**7,39**	**6,84**	**6,70**	7,87	7,04	**7,61**	**5,26**
12	**6,24**	**8,16**	**7,98**	**8,14**	8,18	6,50	**5,55**	**5,86**
13	**5,95**	**7,27**	**7,58**	**7,80**	**7,53**	**7,36**	**5,49**	**6,47**
14	**6,44**	**7,85**	7,89	**7,71**	8,47	**7,60**	**6,28**	**6,07**
15	**5,66**	**7,89**	**7,58**	**7,86**	8,96	**7,19**	**7,11**	**5,96**
16	**5,16**	**6,73**	**6,58**	**6,71**	8,12	**6,50**	**10,05**	**5,73**
17	**5,11**	**5,90**	**5,41**	**5,39**	8,32	6,88	**10,95**	**5,47**
18	**4,82**	**6,34**	**6,10**	**5,22**	7,73	**9,02**	**12,53**	**5,05**
19	**4,78**	6,41	**5,59**	**4,96**	**5,82**	**6,88**	**8,85**	**5,09**
20	**4,30**	7,13	6,49	4,34	7,85	**6,33**	**4,81**	4,36
21	**5,56**	**8,19**	7,86	**5,48**	**7,31**	**7,62**	8,89	**4,85**
22	**4,02**	**7,70**	**7,33**	**4,83**	**9,75**	**5,36**	13,05	**3,59**
23	**4,35**	**5,78**	**5,05**	**5,14**	**6,25**	**6,52**	**7,97**	3,82
24	**2,71**	5,01	**4,24**	**3,64**	**3,98**	9,17	**8,71**	**3,04**
VAR-X								
Hour	Austria	Belgium	France	Germany	Italy	Netherland	Slovenia	Switzerland
1	2,66	**8,13**	**4,55**	3,28	5,15	**9,60**	3,34	4,03
2	2,65	**6,65**	**5,14**	3,73	**5,66**	**5,18**	3,32	3,90
3	3,01	**5,37**	**5,28**	3,51	**6,41**	3,40	2,70	3,04
4	2,47	5,81	5,78	**3,53**	**7,26**	**3,73**	3,21	2,86
5	2,68	6,36	5,93	**3,67**	**7,00**	4,22	3,37	3,04
6	2,81	4,66	**4,28**	**3,59**	7,49	3,54	3,58	2,28
7	3,42	**6,19**	5,48	3,83	**5,90**	4,07	4,93	3,53
8	5,54	7,56	6,97	5,76	5,70	4,38	9,09	5,21
9	5,75	8,00	7,01	5,88	9,76	6,13	12,36	**5,09**
10	6,22	7,49	6,70	6,02	9,48	7,27	11,28	5,56
11	6,78	7,79	6,65	7,10	**8,00**	**6,45**	9,72	5,51
12	7,83	8,91	8,06	8,81	**8,25**	**6,56**	7,51	6,22
13	7,68	7,96	7,44	8,89	8,08	7,57	7,31	7,03
14	7,63	8,94	**8,18**	9,20	**8,49**	7,68	7,35	7,35
15	6,74	9,02	8,15	8,86	**8,82**	7,54	8,60	6,65
16	6,25	7,50	6,92	7,15	**7,92**	6,71	11,91	6,60
17	5,50	6,60	6,02	5,86	**8,39**	**6,83**	12,59	6,18
18	5,52	7,56	6,19	5,57	**7,32**	9,27	14,18	5,43
19	5,37	**6,32**	5,80	4,87	6,34	7,53	9,39	4,88
20	4,88	**6,52**	**5,90**	**4,23**	**8,26**	6,51	5,01	**4,08**
21	6,00	8,21	**7,70**	5,52	7,91	7,73	**8,43**	5,09
22	4,24	7,99	7,61	5,22	9,90	5,36	**13,19**	4,14
23	4,35	5,96	5,21	5,44	6,47	6,62	8,20	**3,76**
24	2,89	**5,00**	4,60	3,99	4,58	**9,20**	9,08	3,58

Table C.23: RMSE errors from ARI and VEC models (Pre-filtered dataset)

				ARI				
Hour	Austria	Belgium	France	Germany	Italy	Netherland	Slovenia	Switzerland
1	**2,20**	9,51	5,35	3,04	**5,11**	10,07	**3,69**	**3,60**
2	**2,20**	6,86	5,53	**3,69**	6,07	5,12	**3,25**	**3,30**
3	**2,21**	5,55	5,56	3,75	6,76	**2,93**	2,94	**2,49**
4	2,40	**5,66**	**5,53**	**4,24**	7,80	3,95	3,26	2,52
5	**2,28**	**5,62**	**5,42**	3,92	7,45	4,59	3,42	**2,27**
6	**2,43**	4,72	4,43	**4,81**	**7,44**	3,77	3,91	2,15
7	**3,23**	**6,01**	**5,23**	**4,07**	6,29	4,49	5,49	2,99
8	**4,39**	**11,24**	**6,40**	**5,82**	**6,16**	**5,08**	10,06	**4,35**
9	4,19	**6,13**	**5,60**	**5,10**	**9,73**	**5,82**	**11,27**	4,75
10	5,09	**6,59**	**5,86**	5,96	8,32	**8,16**	**9,54**	**4,48**
11	5,94	7,44	**6,85**	6,97	8,86	7,57	**8,72**	**5,55**
12	7,32	8,78	**8,17**	8,44	9,72	6,19	6,37	**6,28**
13	6,89	7,81	8,02	8,10	8,65	7,29	**6,17**	**6,52**
14	7,17	**7,70**	7,87	**7,88**	9,47	**7,27**	**6,29**	**6,06**
15	6,25	**7,88**	**7,30**	**7,89**	9,96	**6,75**	**6,94**	**5,93**
16	5,93	**6,42**	**6,15**	**6,55**	10,09	**6,10**	**10,53**	**5,62**
17	5,79	**5,32**	**5,03**	**5,18**	9,90	**6,57**	**11,42**	**5,50**
18	**5,03**	**6,57**	**6,17**	**5,05**	**8,39**	**9,50**	13,74	**4,86**
19	**5,04**	**6,33**	**5,81**	**4,87**	**6,21**	**7,72**	10,30	**4,84**
20	4,51	7,82	7,19	4,33	**8,22**	7,17	3,93	4,25
21	5,61	8,82	8,36	**5,36**	**7,19**	7,97	8,37	4,80
22	4,04	**8,16**	7,98	**4,91**	**9,75**	5,47	13,17	3,60
23	4,45	6,17	5,21	**5,20**	6,35	6,74	**8,05**	3,85
24	**2,96**	5,22	**4,35**	**3,53**	**4,07**	9,46	**8,83**	**3,05**
				VEC				
Hour	Austria	Belgium	France	Germany	Italy	Netherland	Slovenia	Switzerland
1	2,42	**8,21**	**4,51**	**2,90**	5,24	**9,61**	3,89	3,86
2	2,21	**6,04**	**4,83**	3,51	**5,81**	**5,11**	3,10	3,37
3	2,26	**5,09**	**5,30**	**3,30**	**6,43**	3,03	**2,46**	2,51
4	**2,14**	5,76	5,61	3,42	**7,37**	**3,59**	**3,03**	**2,33**
5	2,44	6,25	5,98	**3,41**	**7,12**	**3,96**	**3,13**	2,37
6	2,48	**4,42**	**4,29**	3,64	7,61	**3,25**	**3,51**	**2,12**
7	3,10	5,69	5,05	4,17	**5,98**	**4,21**	**5,01**	**3,34**
8	4,51	7,00	6,80	6,07	5,78	4,81	**9,23**	4,63
9	**4,20**	7,02	6,39	5,54	9,58	6,17	12,46	**3,99**
10	**4,83**	6,87	6,11	**5,67**	**8,25**	7,11	10,73	4,54
11	**5,37**	**7,07**	6,52	**6,65**	**7,39**	**6,46**	9,43	4,88
12	**6,58**	**8,01**	7,97	**8,30**	**8,20**	**6,19**	**6,40**	5,86
13	**6,57**	**7,34**	**7,41**	**8,18**	**8,11**	**7,38**	6,72	7,32
14	**6,65**	7,80	**7,70**	8,42	**8,48**	7,58	6,44	7,38
15	**5,92**	8,28	7,57	8,17	**9,16**	7,18	7,52	6,87
16	**5,24**	6,51	6,17	6,32	**8,07**	6,36	11,53	6,74
17	**5,18**	5,59	5,36	5,52	**8,64**	6,96	12,41	6,59
18	5,45	7,28	6,16	5,36	8,00	9,40	**14,01**	5,59
19	4,92	6,18	6,06	4,55	6,58	7,54	**9,44**	4,66
20	**4,24**	**6,65**	**6,19**	**4,05**	8,31	**6,44**	**3,49**	**3,83**
21	**5,18**	**7,92**	**8,03**	5,49	7,87	**7,62**	**8,40**	**4,65**
22	**3,83**	8,01	**7,91**	5,47	9,99	**5,23**	**13,36**	**3,72**
23	**4,04**	**5,69**	**4,96**	5,42	**6,35**	**6,52**	8,51	**3,55**
24	2,91	**4,98**	4,55	4,29	4,40	**9,13**	9,58	3,45

Table C.24: RMSE errors from ARI-X and VEC-X models (Pre-filtered dataset)

				ARI-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	2,16	9,10	5,07	2,80	**5,14**	10,10	**3,69**	3,56
2	1,92	6,56	5,53	3,46	6,13	**5,23**	**3,24**	3,26
3	**2,02**	5,70	5,79	3,48	6,81	**2,85**	3,04	2,58
4	2,09	6,11	**5,66**	**3,82**	7,82	**4,02**	3,32	2,52
5	2,49	**6,03**	**5,51**	**3,77**	7,47	4,49	3,45	2,27
6	2,95	5,22	4,71	**4,17**	**7,42**	**3,53**	3,87	2,14
7	3,74	6,20	5,36	**3,26**	6,31	**3,77**	**4,76**	2,95
8	5,03	**7,76**	**6,74**	**5,40**	**5,57**	**4,54**	8,90	**4,57**
9	4,59	7,06	**5,90**	**5,16**	**9,13**	**5,22**	**10,20**	**4,84**
10	4,79	6,91	**6,28**	6,00	7,61	**7,01**	**8,09**	4,72
11	5,37	7,70	**6,89**	6,91	7,90	7,13	**7,76**	5,43
12	6,37	8,40	**8,04**	8,36	8,29	**6,35**	**5,75**	6,01
13	6,06	7,35	**7,65**	8,01	7,52	**7,37**	**5,67**	**6,25**
14	6,56	8,01	7,98	**7,91**	8,44	**7,57**	**6,45**	**6,03**
15	5,79	**8,11**	**7,68**	**8,07**	8,92	**7,05**	**7,42**	**6,03**
16	5,30	7,03	**6,69**	**6,91**	8,14	**6,24**	**10,31**	**5,71**
17	5,24	6,20	**5,54**	**5,58**	**8,52**	**6,70**	**11,27**	**5,48**
18	**4,92**	**6,61**	**6,16**	**5,43**	**8,02**	**8,99**	**12,65**	**5,23**
19	**4,93**	**6,63**	**5,63**	**5,22**	**5,93**	**6,92**	**8,94**	**5,23**
20	4,44	7,43	**6,52**	4,59	8,01	**6,35**	4,92	4,49
21	5,70	8,45	**7,90**	**5,65**	**7,40**	7,71	9,00	4,95
22	4,16	7,98	**7,37**	**4,95**	**9,78**	5,36	**13,19**	3,69
23	4,50	6,04	5,07	**5,20**	6,29	**6,54**	**8,09**	3,88
24	2,86	5,21	**4,31**	**3,73**	**4,04**	9,15	**8,90**	**3,06**
				VEC-X				
Hour	**Austria**	**Belgium**	**France**	**Germany**	**Italy**	**Netherland**	**Slovenia**	**Switzerland**
1	**2,17**	**8,04**	**4,44**	**2,62**	5,20	**9,64**	3,96	**3,61**
2	**1,80**	**6,52**	**4,98**	**3,04**	**5,37**	5,42	3,24	**3,40**
3	2,05	**5,00**	**5,03**	**3,24**	**6,41**	3,45	**2,73**	**2,60**
4	**1,80**	**5,88**	5,82	3,59	**7,48**	3,92	**3,07**	**2,20**
5	**2,03**	6,12	5,84	3,29	**7,13**	**4,25**	**3,22**	**2,25**
6	**2,21**	**4,22**	**4,14**	3,42	7,66	3,74	**3,26**	**1,92**
7	**2,36**	**5,81**	**5,29**	4,15	**5,98**	4,19	4,80	**3,23**
8	**4,01**	7,23	7,23	5,97	5,83	4,40	**8,69**	4,51
9	**3,85**	**7,02**	6,67	5,32	9,35	5,76	11,82	4,27
10	**4,40**	**6,56**	6,20	**5,66**	**7,45**	6,92	10,28	**3,73**
11	**5,12**	**7,26**	6,59	**6,44**	**7,17**	**6,57**	9,18	**4,30**
12	**5,96**	**8,04**	7,95	**8,02**	**7,45**	6,49	6,63	**4,91**
13	**5,66**	**7,22**	7,16	**7,62**	**7,14**	7,49	6,96	6,56
14	**5,69**	**7,90**	**7,87**	8,12	**7,58**	7,67	6,64	6,99
15	**5,28**	8,50	7,51	7,81	**8,17**	7,29	8,02	6,53
16	**5,15**	**6,45**	6,43	6,47	**7,92**	6,52	11,92	7,01
17	**4,87**	**5,89**	5,79	5,57	8,58	7,09	12,58	6,32
18	5,27	7,04	6,13	5,56	8,32	9,41	14,16	5,13
19	4,65	6,14	6,16	4,82	6,58	7,31	9,03	4,27
20	**4,13**	**6,64**	6,20	**4,09**	**8,22**	6,53	**3,85**	**3,74**
21	**4,93**	**8,00**	7,99	5,67	7,82	**7,53**	**9,01**	**4,68**
22	**3,61**	**7,68**	7,71	5,07	10,00	**5,13**	13,52	**3,71**
23	**3,93**	**5,67**	**4,86**	5,32	**6,32**	6,75	8,87	**3,68**
24	**2,63**	**5,13**	4,78	4,17	4,40	**9,10**	9,71	3,36

Table C.25: Average monthly price values (VAR-X model) – August, 2013 (€/MWh)

	EXAA	BELPEX	EPEX FR	EPEX DE	IPEX	APX	BSP	EPEX CH
Base	34,27	36,30	30,57	33,33	66,42	42,87	38,30	35,31
All	34,94	36,89	31,43	34,04	66,92	43,23	39,48	36,35
Austria	33,95	36,21	30,43	32,95	66,56	42,74	38,18	35,36
Belgium	34,26	36,42	30,63	33,33	66,22	42,92	38,21	35,32
France	34,33	36,49	30,87	33,41	66,39	42,94	38,25	35,45
Germany	35,36	37,07	31,67	34,51	66,63	43,23	39,08	36,32
Italy	34,30	36,25	30,64	33,41	66,74	42,84	38,64	35,42
Netherland	34,12	36,02	30,16	33,13	66,42	42,88	38,34	35,05
Slovenia	34,21	36,31	30,56	33,30	66,43	42,93	38,54	35,34
Switzerland	34,28	36,21	30,47	33,33	66,48	42,81	38,31	35,28

Table C.26: Price changes across scenarios (VAR-X)

	EXAA	BELPEX	EPEX FR	EPEX DE	IPEX	APX	BSP	EPEX CH
All	1,97%	1,63%	2,82%	2,12%	0,75%	0,86%	3,09%	2,92%
Austria	-0,92%	-0,24%	-0,47%	-1,15%	0,21%	-0,30%	-0,30%	0,14%
Belgium	-0,01%	0,33%	0,19%	0,01%	-0,31%	0,13%	-0,22%	0,02%
France	0,17%	0,53%	0,98%	0,22%	-0,05%	0,17%	-0,12%	0,40%
Germany	3,18%	2,11%	3,58%	3,52%	0,32%	0,84%	2,05%	2,86%
Italy	0,11%	-0,15%	0,24%	0,24%	0,48%	-0,06%	0,91%	0,30%
Netherland	-0,43%	-0,75%	-1,33%	-0,62%	0,00%	0,04%	0,11%	-0,76%
Slovenia	-0,18%	0,04%	-0,04%	-0,08%	0,01%	0,15%	0,63%	0,08%
Switzerland	0,05%	-0,25%	-0,34%	-0,01%	0,09%	-0,12%	0,03%	-0,10%

Conclusion and further developments

From a theoretical perspective, the present work attempts to fill the gap between the two strands of the empirical literature on electricity prices which have so far developed independently of each other.

Including evidence of market integration in forecasting electricity prices enlarges the information set on which forecast are based: this can lead to an improvement of the forecasting performance, also delivering a great aid to regulators and market agents. Indeed, Power Exchanges prices forecasting and especially day ahead price forecasting has become essential for electricity market players, not only for long term capital budgeting but also for short term bidding optimization. From the methodological point of view the present work aims to propose a multiple time series approach for day ahead electricity markets, in order to account for the interdependencies existing between the analyzed eight European countries.

In this work, the presence of cointegration in the electricity day ahead time series has been confirmed, for all the hours of the day, supporting the evidence coming from the empirical literature. At present, the implemented forecasting exercise does not allow us to state that estimating multiple time series models, and especially including potential cointegration relationship between day ahead electricity price time series, greatly improve their forecasting performance compared to estimating simple time series models.

The more general literature on macroeconomic forecasting is already familiar with this result, even if macroeconomic time series and day ahead electricity prices have quite different features. Within this literature, indeed, Elliott (2006) notes that the inclusion of cointegrating relationship does not necessarily improve the forecasting performance of VAR models, as this depends on “almost all the parameters in the design, including the covariance matrix of the errors” (Anderson and Vahid, 2011, p. 17).

The analysis shows that including long term relationships seems to lead to better forecasting performance only in certain hours of the day, especially 11th, 12th, and 20th and 21st, while in ramp up hours in the morning simple time series models seem to provide more accurate forecasting. This result may be further investigated analyzing possible link with other variables. For instance, it may be linked to the level of cross border exchanges in different hours, and in future developments of the study it could be possible to try a match between these results and a detailed analysis of hourly cross border flows amongst all the considered countries to verify if multiple time series models outperform simple time series ones when cross border flows are higher.

Moreover, the performed study shows that the presence of marked price spikes in the in-sample time series impacts on the coefficients estimation in the model. Indeed, the evaluation of the forecasting performance of all estimated models performed after applying a pre-filtering procedure to remove at least their more pronounced spikes, highlights an increase of forecasting accuracy. A slightly improvement is registered especially in the case of VEC-X model, probably because spikes may represent a short term deviation from the common long term trend.

The present work shows some limitations. Indeed, forecasting electricity price is very challenge and the peculiar features of day ahead electricity prices are only partially captured by the implemented models.

First of all, this work relies on two strong hypotheses about the time series stationarity properties; the implementation of both simple and multiple time series models allowing for fractional integration may result in better forecasting performance. Furthermore, another explanation for the result may be precisely the presence of heteroskedasticity in all or part of the time series analyzed that is not captured in the models estimated. Accordingly, future developments include heteroskedasticity modeling, through estimating ARCH/GARCH components in the proposed framework. Finally, further analyses are needed in order to verify whether or not the results are robust to not only different in-sample and out-of-sample periods, but also to the inclusion of different countries in the estimated models.

In order to address the former issue, some developments already in progress include an in depth investigation on the stationarity properties of day ahead electricity price time series. In recent years a growing literature has emerged on the integration properties of energy variables. The focus has been on both aggregate and disaggregate consumption and production, but to best of my knowledge no study are fully dedicated to the assessment of the integration properties of electricity day ahead prices. Instead, a better knowledge of these properties could be important for correctly represent time series behavior. In detail, a fractional integration approach can be adopted, in order to overcome the knife-edge distinction between I(0) and I(1) processes. Indeed, the fractionally differenced process can be regarded as a halfway house between the two paradigms (Baillie, 1996).

Moreover, it could also be interesting to deepen the analysis of the level of integration in Europe, through an examination at hourly level allowing for fractional cointegration. An interesting development is to check if the level of cointegration, if any, is the same across all the hours of the day. These further researches not only may provide contribution at the present literature, but also could provide further knowledge that may be able to improve the forecasting performance of the proposed models.

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