EVALUATION OF THE CARBON MARKET IMPACT ON THE POLISH POWER EXCHANGE

Aneta Włodarczyk

Częstochowa University of Technology, 69 Dąbrowskiego Street, 42-201 Częstochowa, Poland

Abstract

Significant reduction of CO2 emissions, the increase of energy production from renewable sources and the increase of energy efficiency are the key priorities of EU's energy and climate policy. All these factors have significant impact on the development of the Polish Power Exchange (PPE), what is reflected among others in the electricity prices volatility. Therefore, in this article the behavior of the CO2 emission allowance prices from ECX and ICE Future Europe is examined and compared to the behavior of electricity prices quoted on the PPE. Empirical analysis is connected with the construction of Markov switching models in order to make a comparison between average duration of each variables in high- and low- volatility regimes. These findings allow toevaluate the synchronization of occurrence of higher price risk periods on the carbon market and on the Polish Power Exchange.

Key words: *Polish Power Exchange, CO2 emission allowance, electricity prices, Markov switching model, environmental management*

1. INTRODUCTION

Growing degradation of natural environment and the greenhouse effect, being a derivative of increased emission of greenhouse gases into the atmosphere are priority problems of the European Union gradually solved by means of new instruments of energy and climate policy. Since the year 2008 the EU has intensified on the international arena its activity that are supposed to lead to concluding a new agreement on fighting climate changes, which would replace the Kyoto Protocol that expired in 2012 (UN Climate Conference in Copenhagen (2009), Cancun (2010), Durban (2011), Lima (2014)) (Dyduch 2013). Eventually, on 24 October 2014 a meeting of the Council of the European Union took place, where frameworks of the European Union's energy and climate policy until the year 2030 were agreed on. In the response to the reports presenting degradation level of the natural environment as a result of excessive emission of greenhouse gases into the atmosphere the European Union committed itself to reduce their amount by 40% until the year 2030 compared to the year 1990. Moreover, the EU policy in the scope of energy and environment protection was not unified as disproportion in economic development of individual member states was taken into consideration while defining the general framework of the functioning of the greenhouse gases emission reduction system. This means that the less wealthy member states with the GNP not exceeding 60% of the average for the whole European Union will still be able to use the option of providing energy companies with free CO2 emission allowances until the year 2030. Financial resources saved in this way on the purchase of allowances should be used for investments modernizing the energy sector, among others, through creation of modern coal plants, nuclear power stations and a greater use of Renewable Energy Sources (Zasuń 2014).

Therefore, achieving the goals of energy and climate package of the EU to carbon dioxide emission decrease and increase of the share of renewable energy sources will be possible thanks to application of market and price mechanisms. They are used by the EU system of trading allowances for greenhouse gasses emission (EU ETS – The European Union Emissions Trading System), created in 2005 so as to fulfill in a cost effective way commitments resulting from ratifying the Kyoto Protocol by the EU. Within the EU ETS functioning the price of permission for emitting 1 tone of CO2 emission, and thus, each saved tone of CO2 emission was given a financial value, which was supposed to be the cheapest way to reduce greenhouse gases emission. EU ETS is the first and until the present day biggest market in the world for trading CO2 emission allowances. However, this market is

characterized by high price volatility of contracts for CO2 emission quoted on it (Daskalakis, Psychoyios & Markellos 2009; Benz & Trück 2008). Another researcher focused on the investigation of the price drivers of the carbon market and divided them into the economic and energy factors. It was shown that carbon prices are significantly affected by such fundamental variables as industrial production, energy spreads for electricity production, equity prices, prices of primary energy commodities (coal, crude oil, natural gas or electricity) (Keppler & Mansanet-Bataller 2010; Bredin & Muckley 2011; Balciar et all. 2014). Carbon emission allowance prices are also sensitive to the impact of such risk factors as weather conditions, changes in the rules of energy policy and economic crisis (Hintermann 2010; Włodarczyk &Zawada 2014).

Therefore, the aim of this article is to examine and compare the behavior of the CO2 emission allowance prices quoted on the European Climate Exchange (ECX) or Intercontinental Exchange Future Europe (ICE Future Europe) to the behavior of electricity contract prices quoted on the Polish Power Exchange (PPE). Empirical analysis is connected with the construction of Markov switching models in order to make a comparison between average duration of each variables in high- and low-volatility regimes. These findings allow to evaluate the synchronization of occurrence of higher price risk periods on the European carbon market and on the Polish Power Exchange over the period 2006-2013. This is the period characterized by intensive changes in the energy law and regulations concerning environment protection in the EU member states in connection with development of the CO2 emission allowances market, striving for diversification of energy sources due to the energy security issues and the 2007 subprime economic crisis and the 2009 euro zone crisis. The rest of the paper is organized as follows. Section 2 provides a brief description of market mechanism incorporated into carbon emission allowance trade. Section 3 describes the data and gives some explanation of untypical behavior of carbon emission allowance prices and electricity prices in analyzed period. Methodology and empirical results are presented in Section 4. And finally, Section 5 concludes the paper.

2. MARKET MECHANISMS IN CO2 EMISSION ALLOWANCE TRADE

Execution of the Kyoto Protocol required implementation of market solutions in the process of gradual limitation of greenhouse gases emission in emission-intensive economy sectors: energy and heat protection production sector, energy-intensive industry sectors. A brief characteristics of each mechanism is presented in Table 1.

Table 1. Market mechanisms in greenhouse gases reduction process

Characteristics	**Mechanism type**		
	Joint Implementation Mechanism	**Clean Development Mechanism**	**Emission Trading Mechanism**
Mechanism nature	Individual project consisting in financing or implementing an environmentally-friendly technology in the territory of an authorized [1], resulting in reduction or avoidance of	Investment measures undertaken by the authorized country in the territory of an unauthorized country consisting in reduction, avoidance or sequestration of greenhouse gases. Reforms improving	The cap-and-trade principle is valid, what means that total emission level (cap) is set for the group of enterprises/sectors (polluters) and then they are proportionally granted emission allowances, which cover in full determined limits. Enterprises may use

[1] An authorized country is the one mentioned in the Annex I to the Climatic Convention. The framework UN convention on climate changes drawn up in New York on 9 May 1992, Journal of Laws of 1996 no. 53, pos. 238.

	greenhouse gases emission or carbon dioxide sequestration.	CDM mechanism functioning that concern, among others, the issue of regional distribution of projects and enabling execution of CCS technology projects (Carbon Capture and Storage).	allowances to realize their reduction goals, sell them (within internal or international trade), or leave for the next settlement period. This is a mechanism working within a determined emission level, not creating new units but used only for the turnover of granted AAU units.
Reduction unit	Emission Reduction Unit (ERU) - represents one tonne of CO2 equivalent reduced; these units do not change the AAU number, only their allocation among authorized countries.	Certified Emission Reduction (CER) – subject of turnover on the primary and secondary market and the options market. CER attractiveness results from their relatively lower value compared to EUA.	Assigned Amount Unit (AAU) - is a tradable "'Kyoto unit" or "carbon credit" representing an allowance to emit greenhouse gases comprising one metric tonne of carbon dioxide equivalents calculated using their Global Warming Potential. The turnover unit applied in ETS is European Allowance Unit (EAU) entitling to emit one tonne of carbon dioxide. In the period 2008-2012 the units may be the subject of trade between countries, they cannot be exchanged for the EUA units.
Parties participating in the mechanism	Only authorized countries.	Investor – an authorized country. Host - an unauthorized country.	Only authorized counties, possessing reduction goals included in Annex B to the Kyoto Protocol.
Benefits	Investor - reduces the costs of emission reduction and increases its own emission limit. Host - gains modern environmentally-friendly technologies and decreased emission of greenhouse gases.	Investor - receives CER which can be used to surrender actual emission from the national installation or sell it on the secondary market. Host - gains modern, environmentally friendly technologies and decreased emission of greenhouse gases.	Enterprises of high cost of reduction CO2 emission purchase the allowances from enterprises of lower reduction costs instead reducing emission on their own, which would be connected with the necessity to invest in modern production technologies or limit their production. Enterprises of low cost of emission reduction may limit emission below limits which have been imposed on them and sell the allowances which they have not used.
Types of projects in the	Fuel change, renewable energy	Increase in the energy efficiency (in buildings,	ET is not a project mechanism. Parties

energy sector	production, improved energy efficiency, decrease in fugitive emissions from fuels.	industry; change of fuel to the ones emitting less greenhouse gases), co-generation, hydro engineering projects.	participating in this mechanism can on the national level establish the project mechanism which would support implementation of ET. For example, a lot of countries which possess excessive AAU units (including Poland) started such support systems giving the beginning for internal Green Investment Schemes.
Use of the mechanism by Poland in the period (2008-2012)	The Ministry of Environment in Poland approved 22 projects for which the maximum number of ERU units to be generated in the first settlement period is approximately 22.5 mln.	Until now Poland has not been involved in CDM. This is a mechanism commonly used by the richer member states of the European Union-Great Britain (30,5%), Switzerland (20,8%) of registered projects. The host of investment measures conducted within CDM are China (50,3%) and Indie (19,4%) of implemented projects.	In the Kyoto Protocol Poland committed itself to decrease emission of greenhouse gases by 6% in the period 2008-2012 compared to the state from the year 1998, and it achieved over 28% of emission reduction as a result of environmentally friendly investments and industry restructuring - especially in emission-intensive trades. As a result the surplus of AAU units in Poland in the period 2008-2012 is estimated to be 558 million. Poland conducts transactions of AAU units sale within the GIS system and obtained financial resources are spent on priority projects connected with commissioning biomass heat and power plants or building electro-energy networks in order to connect wind energy production sources.

Source: Own elaboration on the basis of Andrzej Graczyk and A. M. Graczyk, Implementation of market mechanisms in environment protection, PWE, Warsaw 2011, pp. 79-11 http://www.kobize.pl/materialy/opracowania/listopad2012/Opracowanie_Mechanizmy_rynkowe_po_2012.pdf (accessed on 22 February 2015).

Implementation of Clean Development Mechanism (CDM) and Joint Implementation Mechanism, (JI), makes it possible to obtain so called reduction units and use them in the Emission Trading, (ET). It is worth emphasizing that the system of emission allowances trading covers the area of the European Union. However, JD and CDM mechanisms made it possible to include into it also countries from outside this area.

Evolution of the European Union's allowances for greenhouse gasses emission was connected with (Dyduch 2013):

- extended duration of subsequent reference periods:

a) I period (2005 – 2007), the aim of which was to "learn in practice" the principles of allowances trade and improving financial and organizational infrastructure of the market lasted only 3 years;

b) II period (2008-2012) characterized by trading emission allowances in the period of turbulent changes on financial markets lasted 5 years (the period when the Kyoto Protocol was in force);

c) III period (2013-2020) connected with emission allowances trading and introducing vital changes in the scope of allowances allocation will last 8 years (the post Kyoto period);

- extension of the activity scope comprised by EU ETS: in the first period system comprised installations from 11 types of activity, in the second period installations from the aviation sector were included, in the third period installations from 17 other types of activity were added;

- modification of the greenhouse gases comprised by EU ETS: in the third period allowances for emission of nitrous oxide and perflourocarbons were allowed to be traded (chosen sectors) more - ICE exchange;

- increased share of allowances granted in return for payment in the total number of allocated allowances: I period - 95% of granted allowances were free of charge, II period - at least 90% allowances for stationary installations and 85% for aviation installations were free of charge, III period - transition from free of charge distribution of allowances to a chargeable auctioning system, with the derogation for the power stations sector from 10 EU countries, excluding civil aviation (82% of free of charge allowances);

- change of the criteria of granting free of charge allowances: replacing dominant in the I and II period grandfathering (historical emission) by a benchmarking based system maintaining the historical emission criterion weighed by the type of fuel used in the power stations sector;

- decrease in the number of allocated allowances, which resulted from the tightening of greenhouse gases emission limits in particular periods of emissions trading.

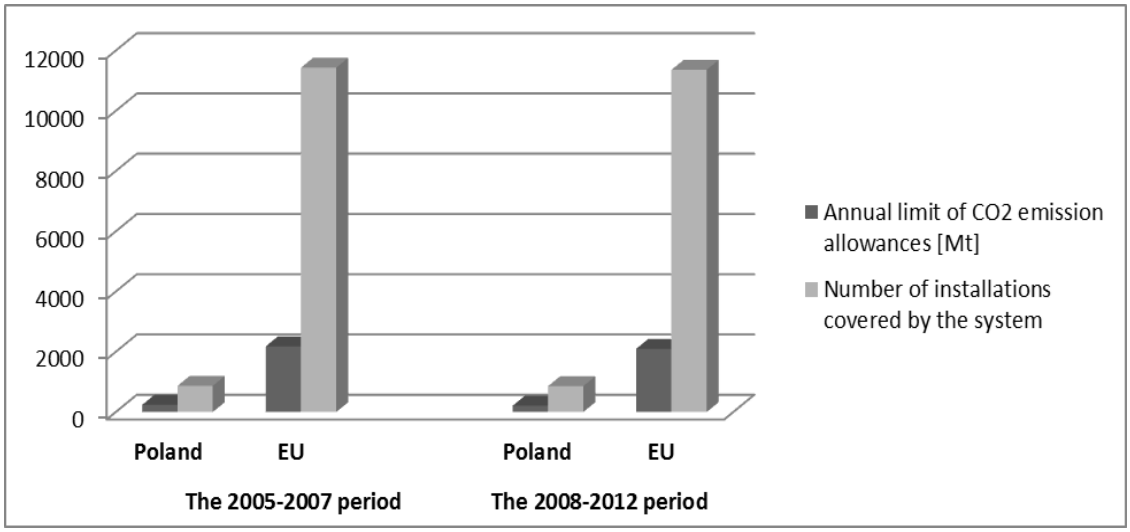


Fig.1 CO2 emission allowance allocation for Poland in the EU ETS system

Source: Own elaboration based on Justyna Dyduch, Trading of the air pollution emissions allowances, PWE, Warsaw 2013 (Polish), pp. 148-149.

In the first reference period (2005-2007) the size of allowed emission was determined at the level of 2180 million tonnes of CO2 annually, which constituted about 45% of the total emission of the European Union. Poland obtained 10,6% of allocated allowances for 869 installations, taking third

position in the Union ranking of established allowances to emit greenhouse gases (Germany (22,1%), Great Britain (10,9%)). In the second reference period (2008-2012) annual size of allowed CO2 emission was decreased by about 3,8% to the level of 2097,7 million tonnes annually, and Poland obtained 10% of allocated allowances for 858 installations (Germany (21,6%), Great Britain (9,3%)). It is also worth emphasizing that in accordance with the arrangements of the EU member states concerning the new frameworks of the climate and energy policy (Brussels, 23 10 2014) Poland will still be able to provide its own power stations with free of charge CO2 emission allowances until the year 2030. Altogether, Poland is to receive free of charge CO2 emission allowances worth 31 billion PLN. Moreover, a special reserve will be created from 2% of emission allowances in favour of restructuring the energy sector in the countries of Middle and Eastern Europe. Poland will receive a half of these resources. Thus, Poland will receive until 2030 the total sum of 7.5 billion PLN for investments in the energy sector.[2]

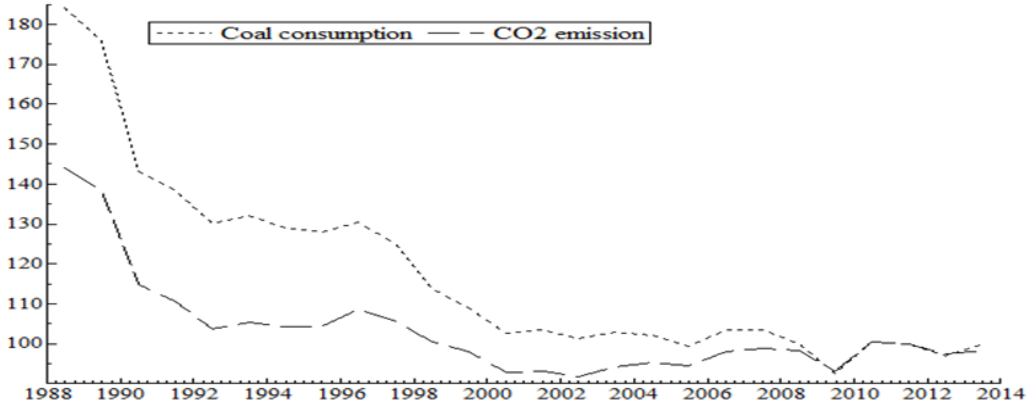


Fig. 2 One-base indexes of coal consumption by Polish economy and CO2 emission in the period 1988-2913 (1988 = 100%)

Source: Own elaboration based on British Petroleum Europe & EU Members database, obtained from Thompson Datastream, accessed December 2014.

Since 2013 EU limits of CO2 emission have been established on the basis of one benchmark determined on the basis of CO2 emission from10% of most efficient EU installations in the years 2007-2008, using natural gas as a fuel (Grudziński 2012). This is an unfavourable benchmark for Polish energy sector despite the already mentioned restructuring of Polish economy and environmentally-friendly investments (Mesjasz-Lech 2010; Nitkiewicz 2012) about 92% of electricity produced in Poland still comes from burning hard coal and lignite (see Fig. 2). That is why Polish electricity producers and purchasers worry about the influence of the coal market and EU energy and climate policy on electricity prices volatility in Poland.

3. CHARACTERISTICS OF TIME SERIES OF CO2 EMISSION ALLOWANCES AND ELECTRICITY PRICES

Polish enterprises from the energy sector may sell or buy CO2 emission allowances (EUR, CER) among others on the exchange. trading on exchanges is allowed only for accredited participants, therefore enterprises need to bear additional costs connected with their possible membership in the exchange or use intermediation of brokerage houses. The advantage of the exchange trading of CO2 allowances is limiting the credit risk and exemption from VAT tax for the investors. The most important European exchanges where transactions of purchasing or selling CO2 allowances took place

[2] http://www.chronmyklimat.pl/ (accessed on 10 February 2015)

in the I and II EU ETS period include: the European Climate Exchange (ECX) with the seat in London, which was taken over by the Intercontinental Exchange (ICE) in 2010; the European Energy Exchange (EEX) with the seat in Lipsk; The Nordic Power Exchange (Nord Pool ASA, currently NASDAQ OMX Commodities) and the BlueNext exchange with the seat in Paris (in December 2012 the exchange ceased its activity). As Polish enterprises from the energy sector participate in the coal market below the author presents a short characteristics of two most important for them exchanges trading CO2 emission allowances.

EEX has also fulfilled the role of the common auction platform and helps in the allocating allowances (EUA, EUAA) within EU ETS, in particular EEX conducts emissions auctions for Poland during a transitional periods. In the framework of the secondary market EEX offers both the spot trading in EU Allowances (II and III EU ETS trading phases), EU Aviation Allowances, Certified Emission Reductions (since December 2012) and derivative market with the possibility of sale or purchase of EUA, EUAA, CER, ERU futures. In 2013, over 40 percent of all allowances were already auctioned on the EEX platform. During the period of the functioning of Phase III of the EU-ETS the Polish Trading Participants on the EEX Carbon Market are: DUON Marketing and Trading SA, Energa-Obrót SA, GAZ-System SA, Metro Group Energy Production Sp. z o.o., PGE Polska Grupa Energetyczna SA, PGNiG SA, PKP Energetyka SA, Tauron Polska Energia SA. Moreover, The Instytut Ochrony Środowiska is the Polish representative of the auctioneers, that is mandated by the European Commission for the primary allocation of emission allowances and it has been admitted for the third trading period to EEX.[3]

The most liquid derivatives market where derivatives for CO2 emission allowances are traded is the European Climate Exchange (ECX) - almost 77% of total allowances turnover in 2009 was recorded on this exchange. Since 2005 trade on the ECX exchange has taken place on the platform ICE Futures Europe in London, which is a part of the capital group Intercontinental Exchange (ICE). Currently, this market participants may efficiently manage risk by means of the following derivatives: CER Futures, ERU Futures, EUA Futures, EUAA Futures, EUA Futures Options, EUA Phase III Daily Futures, EUAA UK Auction Daily Futures, CER Daily Futures, CER Futures Options, ERU Futures Options, EUA UK Auction Daily Futures. Products offered by ICE constitute price benchmarks for other places where CO2 emission allowances are traded and they guarantee emission market transparency, in accordance with requirements of the EU emission trade system (EU ETS). ICE adjusts itself to changing legislative regulations and customer needs through introduction of innovative financial instruments for the need of CO2 emission risk management, the example of which is introducing in 2012 to the exchange turnover EUAA Futures or the presented above list of derivatives that are available on this exchange. Advantages of this market have been appreciated also by Polish enterprises that received the status of a Trade Participant of the ICE Futures Europe (Energa-Obrót SA, PGNiG SA, Tauron Polska Energia SA). Other enterprises may take advantage of this exchange through among others Consus Brokerage House being a General Participant of the ICE Futures Europe.[4]

In order to obtain a representative carbon price for derivatives transaction I follow Chevallier (2009) and Lutz et all. (2013) and consider annual EUA futures, which expire in December, for 2006 up to 2015. I construct the EUA price series (denoted as EUA_ICE) based on the daily ICE EUA Futures Contract Emissions Index (EUR/tCO2e) obtained from ICE Future Europe[5], which correspond to the contract with the closest maturity date. The specificity of CO2 emission allowances trade is connected with obligatory referencing of CO2 emission allowances at the end of each calendar year is the main reason for the greatest popularity of December contracts among the market participants. Additionally, I investigated the time series of the daily spot EUA prices (EUR/tCO2e) obtained from the European Energy Exchange (denoted as EUA_EEX) as a benchmark for EUA transaction conducted on the spot

[3] www.eex.com/en/trading/list-of-trading-participants#/list-of-trading-participants (accessed on 11 February 2015).
[4] www.theice.com/futures-europe/membership (accessed on 11February 2015).
[5] www.theice.com/marketdata/reports/ReportCenter.shtml?reportId=10&contractKey=20#report/82(accessed on 18 March 2014) .

carbon market (Hammoudeh, Nguyen & Sousa 2014). I convert these prices from Euros to Polish zloty using the closing spot EUR-PLN exchange rate obtained from Forex market. It is necessary in the case of making the comparison between the electricity price volatility on the Polish Power Exchange and EUA prices volatility on European carbon markets. The sample period ranges from January 9, 2006 to December 31, 2014, resulting 2343 daily observation.



Fig. 3 Shaping of the daily EUA prices from January 9, 2006 to December 31, 2014 (derivatives market – upper panel; spot market – lower panel)

Source: Own elaboration based on European Energy Exchange database, obtained from Thompson Datastream, accessed December 2014 and ICE Futures Europe database, obtained from www.theice.com, accessed February 2015.

It is worth noting that due to the arbitration activity, the carbon emission allowances prices quoted on the different exchanges are very similar to each other (Daskalakis, Psychoyios &Markellos 2009). The similar observation concerns the EUAs prices behavior quoted on the spot and derivative markets (Trück, Härdle & Weron 2014). The Phase I of the EU-ETS functioning was characterized by the uncertainty regarding the actual EUAs prices settlement and the information shock following the announcement of the first external verified reports regarding each EU member state's actual emissions during the previous compliance year (April and May 2006). The Phase I of the EU-ETS functioning was characterized by the uncertainty regarding the actual EUAs prices settlement and the information shock following the announcement of the first external verified reports regarding each EU member state's actual emissions during the previous year (April and May 2006). Thus EUAs spot prices increased up to 30 EUR in April 2006, and after that under the impact of the mentioned above events and the banking prohibition from 2007 to 2008 the prices for EUAs dropped up to nearly 0 EUR in 2007-2008 (see Fig.3) (Daskalakis, Psychoyios &Markellos 2009). At the beginning of Phase II EUA prices started to increase from the level of about 25,5 EUR in April 2008 and they reached the level of about 30 EUR in July 2008. Next they decreased in the response to the global financial crises and lower expectations about economic output in the Euro zone due to the subprime crisis, so the lowest price of the EUAs was observed (about 8 EUR) in February 2009. After that the carbon emission allowances prices were shaping in the range between 13 and 16 EUR until the mid-2011. In turn, the EUAs prices dropped to the level of about 6.5 EUR in December 2012 what might be explained by the European Debt crisis consequences and the expectations of the market participants regarding the

relatively high allocation of allowances (Trück, Härdle & Weron 2014). This decreasing tendency in the EU GAs prices level was observed up to the middle of April 2013, when the carbon allowances prices reached the lowest point (below 3 EUR). It may be caused the investors' uncertainty associated with the ending of the Kyoto commitment period. Next, the EUAs prices increased up to the level of approximately 7 EUR in March 2014. Carbon allowances prices decreased again to a level of about 4.5 EUR in April 2014 and they remained in a range between 4.5 and almost 7.5 EUR up to December 2014 (see Fig.3). In addition, one should also consider the importance of the Russia-Ukraine conflict for shaping world crude oil and gas prices as they constitute an important energy resource for numerous EU member states and thus, the influence of these fundamental variables on the European carbon market. Also arrangements concerning a common EU policy in the scope of reduction of greenhouse gases emission (Brussels 2014) have had a stabilizing effect on the shaping of CO2 emission allowances prices.

Polish enterprises involved in CO2 emission allowances trading are also active participants of Polish Power Exchange (PPE). The Polish Power Exchange was established in Poland at the end of 1999 and half a year later the Day-Ahead Market was started. The Day Ahead Market enables an initial adjustment of electricity volume to the changing demand of wholesale market subjects and determines benchmark electricity prices for other contracts concluded on the wholesale electricity market in Poland. This market participants include among others electricity producers and sellers, electricity turnover partnerships, non-tariff energy buyers trading it directly on the spot market or through brokerage houses. The electricity prices are strongly influenced by such determinants as: the level of turnover volume, fuel prices, weather conditions, the CO2 emission allowance prices, political situation, the changeability of the energy demand level, available power in the National Electricity System (Włodarczyk & Zawada 2009). Due to the necessity to limit environmental risk accompanying activity of energy sector enterprises, the PPE started a register of certificates of origin for electricity produced in Renewable Energy Sources (2005) and for co-generations (2007), started the Property Rights Market (2007) and enabled its participants to trade EUA units (2006). Unfortunately, investors show no interest in the RUE market and no transactions are conducted on it at present. Electricity Trading Platform in turn is connected with the EEX exchange enabling its users to trade CO2 emission allowances on the spot market and the Nord Pool exchange in the scope of EUA trade on the spot market as well as forward contracts on EUA and CER. Additionally, it should be stressed that the importance of the Polish Power Exchange for Polish energy market development grew in the year 2010, when the statutory obligation, concerning all Polish producers, to sell 15% of energy on the power exchange or regulated market was introduced and subjects receiving compensations for terminating long-term contracts must additionally sell on a competitive basis all electricity that they produce. The above mentioned legislative changes, macroeconomic situation in Poland and weather factors, demand-supply ones influence volatility of electricity prices on the Day-Ahead Market of the Polish Power Exchange (see Fig.4).

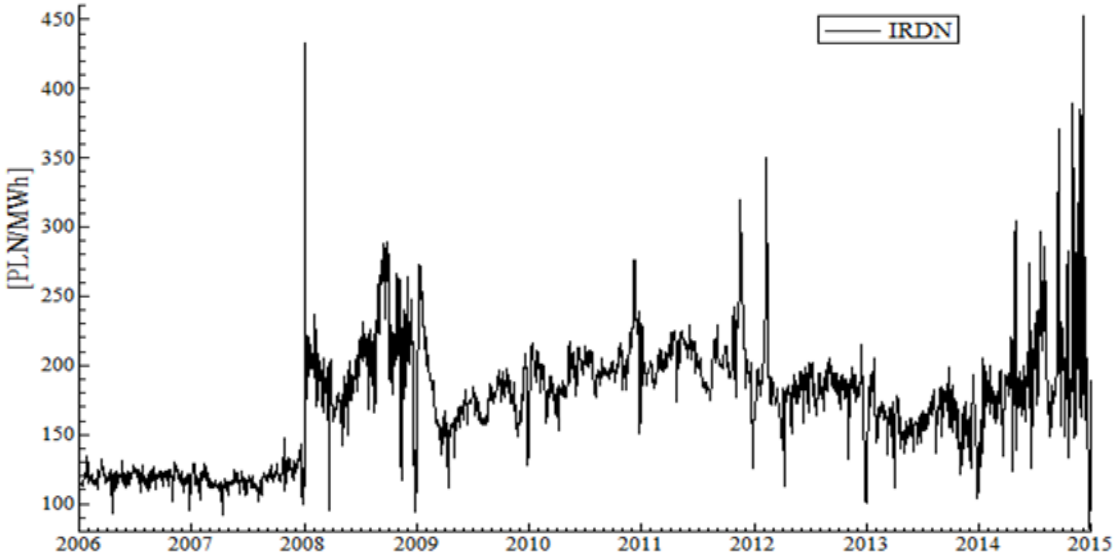


Fig. 4 Shaping of the daily IRDN prices from January 9, 2006 to December 31, 2014

Source: Own elaboration based on the data obtained from the Polish Power Exchange, www.tge.pl, accessed January 2015.

IRDN is the Day-Ahead-Market Index (PLN/MWh) representing the weighted average price of all transactions on the trading session, calculated for particular delivery date. The highest price change on the Day-Ahead Market was observed on January 2, 2008 (daily price increase of about 202%), December 3, 2014 (daily increase of almost 133%), November 25, 2014 (daily increase of about 127%). Moreover, on November 12, 2008, April 28, July 28, August 4, September 18 and October 30, 2014, the IRDN index value increased by more than 80% a day and the next day IRDN returned to the previous level. The high volatility of electricity prices on the DAM corresponds to such events as: the inclusion of costs of carbon emissions into the electricity prices in Poland, the subprime crisis in the United States, the debt crisis in Europe, the Russian-Ukrainian crisis, the beginning of the III Phase of the EU ETS and the accompanying it changes in the regulatory mechanisms of CO2 reduction, the EU climate summit in Brussels.

4. IDENTIFICATION OF HIGH-RISK PERIODS FOR THE CARBON MARKET AND ELECTRICITY MARKET IN POLAND

In empirical research Markov switching heteroskedasticity models were implemented in order to identify the high-risk periods on carbon market and electricity market (Hamilton 1994). This class of econometric models allows for the capturing of the regime changes in volatility process. The general form of p-th order Markov –switching autoregression model (MS-AR(p)) is given by the following equations (Doornik & Hendry 2009):

$$r_t - \mu(s_t) = \varphi_1(r_{t-1} - \mu(s_{t-1})) + ... + \varphi_p(r_{t-p} - \mu(s_{t-p})) + \varepsilon_t, \quad \varepsilon_t \sim N(0, \sigma^2(s_t)) \tag{1}$$

where: r_t – logarithmic returns on EUA prices or electricity prices , s_t – non-observable variable modelled as homogenous Markov chain of N states and the matrix of transition probabilities $P = \lfloor p_{i|j} \rfloor_{i,j\in\{0,1,2,...,N-1\}}$, determining the probability of moving endogenous variable from state j in period t into state i in period t+1,fulfilling the following stochastic assumptions:

$$\sum_{i=0}^{N-1} p_{i|j} = 1, \qquad p_{i|j} \geq 0 \quad \text{for i, j} = 0,1,...N-1, \tag{2}$$

$\mu(s_t)$ - conditional mean of the process, which is dependent on the regime variable s_t, φ_i – regime-dependent parameters (Doornik & Hendry 2009).

It is worth to underline that P matrix elements fulfil the following Markov property:

$$P(s_{t+1} = i \mid s_t = j, s_{t-1} = k, ..., r_t, r_{t-1}, ..., r_0) = P(s_{t+1} = i \mid s_t = j) = p_{i|j}. \tag{3}$$

Due to the presence of the volatility clustering effect in analysed returns series the GARCH structure was incorporated into Markov switching model, which enables for different behaviour of the volatility process in particular regimes (Hamilton & Susmel1994; Gray 1996; Klaassen 2002; Davidson 2004, Haas, Mittnik & Paolell 2004). In this paper the following specification of the MS-GARCH(1,1) was estimated (Doornik 2013):

$$\varepsilon_t = \sqrt{h_t(S_t)} \cdot \nu_t, \quad \nu_t \sim \text{N}(0,1), \tag{4}$$

$$h_t(S_t) = \sigma^2(S_t) + \alpha_1(S_t)\varepsilon_{t-1}^2 + \beta_1(S_t)h_{t-1}(S_t), \quad \sigma^2(S_t) > 0, \alpha_1(S_t) \geq 0, \beta_1(S_t) \geq 0, \tag{5}$$

where: $h_t(S_t)$ - regime dependent conditional variance of the error term; $\alpha_1(S_t)$ – regime dependent ARCH parameter depicting the reaction of volatility process on new market information; $\beta_1(S_t)$ - regime dependent GARCH parameter measuring the persistence of volatility process.

In particularly a simpler version of the MS-GARCH model was also estimated, in which only sigma parameter ($\sigma^2(S_t)$) is subject to switching among different regimes, while the others are not time-varying (Doornik 2013):

$$\alpha_1(0) = \alpha_1(1) = ... = \alpha_1(N-1) = \alpha_1 \text{ and } \beta_1(0) = \beta_1(1) = ... = \beta_1(N-1) = \beta_1. \tag{6}$$

The most frequently used method of parameter estimation in Markov-switching model is the maximum likelihood method (Hamilton 1994; Klassen 2002; Doornik 2013):

$$\ell(\theta) = \sum_{t=1}^{T} \ln\left[\sum_{i_0}^{N-1} \cdots \sum_{i_p=0}^{N-1} f\left(r_t \middle| s_t = i_0, \ldots, s_{t-p} = i_p, \Phi_{t-1}; \theta\right) \cdot P\left(s_t = i_0, \ldots, s_{t-p} = i_p \middle| \Phi_{t-1}; \theta\right)\right], \tag{7}$$

where the estimation of the model parameters was performed using Sequential Quadratic Programming Feasible (SQPF) optimization algorithm in PcGive package (Lawrence & Tits 2001).

Moreover, on the basis of estimated transition probabilities to particular volatility states (elements of the stochastic matrix P) one can determine expected further duration of the system in i regime: (Hamilton 1994):

$$d_i = \frac{1}{1 - p_{i|i}} \quad (\text{i} = 0,1,..., \text{N} - 1) \tag{8}$$

where: d_i – average time of economic variable's duration in i-th regime.

For both EUA prices and electricity prices time series daily continuously compounded rates of return were computed, according to rules: $r_t = 100 \cdot \ln(p_{i,t}/p_{i,t-1})$, where $p_{i,t}$ is daily closing price for i-th variable at t moment. According to "industrial approach" (Jong 2006, Janczura et all 2013, Nowotarski, Tomczyk & Weron 2013) the returns series were decomposed into the long-term seasonal component (monthly dummies), the short-term periodic component ("average week" approach) and stochastic component, which was the subject of further modelling. Due to the presence of volatility clustering and the autocorrelation effects in stochastic components the author proposed the MS(N)-ARMA(P,Q)-GARCH(1,1) specification for capturing different volatility regimes in analysed returns series, with N=2 or N=3. The sample period was limited to the Phase II and Phase III functioning the EU ETS system because of immaturity of the carbon market in the Phase I (see Fig. 3).The values of estimated

parameters of MS(N)-ARMA(P,Q)-GARCH(1,1) models with Gaussian innovations distribution are presented in Table 2.

Table 2. Estimation of Markov switching model with GARCH structure[6]

Parameter/Statistic	EUA_ICE (N=2)	IRDN (N=2)	EUA_ICE (N=3)	IRDN (N=3)
Constant (0)	0.0627 [0.078]	0.0138 [0.812]	0.1412 [0.037]	0.2875 [0.259]
Constant (1)	-0.5191 [0.166]	-2.2690 [0.047]	-0.1636 [0.337]	-0.0748 [0.866]
Constant (2)	-	-	0.0120 [0.982]	-5.0920 [0.293]
AR-1 (0)	-0.2708 [0.008]	0.4743 [0.000]	0.2722 [0.256]	0.5329 [0.000]
AR-1 (1)	-0.4723 [0.001]	0.2282 [0.006]	0.2724 [0.308]	-0.0687 [0.219]
AR-1 (2)	-	-	-0.0589 [0.815]	0.4934 [0.000]
AR-2 (0)	-	-0.3832 [0.000]	-0.1694 [0.000]	0.0396 [0.338]
AR-2 (1)	-	-0.5489 [0.000]	-0.0470 [0.484]	-0.1955 [0.000]
AR-2 (2)	-	-	-0.2004 [0.041]	-0.0325 [0.645]
MA-1 (0)	0.4544 [0.000]	-0.6711 [0.000]	-0.1035 [0.675]	-0.7288 [0.000]
MA-1 (1)	0.5933 [0.000]	-0.2441 [0.005]	-0.0754 [0.779]	-0.0637 [0.446]
MA-1 (2)	-	-	0.1947 [0.481]	-0.9433 [0.000]
MA-2 (0)	-	0.3150 [0.000]	-	-
MA-2 (1)	-	-0.6589 [0.000]	-	-
MA-2 (2)	-	-	-	-
sigma (0)	0.2488 (0.055)	1.3947 (0.149)	1.4662 (0.352)	0.8734 (0.156)
sigma (1)	1.3855 (0.356)	8.0177 (1.030)	2.8148 (0.699)	2.5674 (0.477)
sigma (2)	-	-	6.7982 (1.694)	7.1642 (1.226)
ARCH-1	0.0318 (0.015)	0.1642 (0.021)	0.0588 (0.037)	0.0104 (0.004)
GARCH-1	0.9378 (0.022)	0.7067 (0.031)	-	0.9096 (0.028)
$p_{0\|0}$	0.9799 (0.006)	0.9142 (0.015)	0.9835 (0.005)	0.9045 (0.017)
$p_{1\|1}$	0.8036 (0.081)	0.000	0.9577 (0.013)	0.7649 (0.046)
$p_{2\|2}$	-	-	0.9236 (0.037)	0.9011 (0.036)
AIC	4.4698	6.6433	4.4663	6.6209
Regime 0 duration (in days)/ fraction of observation	77.4 / 93.21%	23.0 /95.89%	88.4 / 58.14%	15.5 / 72.16%
Regime 1 duration /	5.90 / 6.79%	1 / 4.11%	37.71 / 5.12%	4.3 / 19.73%

[6] Different specifications of MS(N)-ARMA(P,Q)-GARCH(1,1) models were estimated (P,Q = 0,1,2; N=2,3) and the best ones are presented in Table 3 (the selection was made on the basis of Akaike criterion, residuals diagnostic tests, regime classification measure and the value of transition probabilities).

fraction				
Regime 2 duration / fraction	-	-	20.50 / 6.74%	12.3 / 8.11%
Jarque-Bera test	5.0778 [0.079]	1.8443 [0.398]	1.6170 [0.446]	8.7198 [0.013]
Box-Pierce(40) test	39.395 [0.586]	203.59 [0.000]	40.240 [0.548]	247.11 [0.000]
ARCH(3) test	1.4191 [0.242]	0.6406 [0.589]	2.1065 [0.098]	7.6312 [0.000]

Source: Own calculations in PcGive 14. p-value in brackets and standard errors in parentheses.

In the case of MS(2)-ARMA(2,2)-GARCH(1,1) model (see Table 2), the high – volatility regime is transitory ($p_{1|1}$ =0) what means that if the electricity return is assigned to it in 't' time, the next return will be generated by low-volatility regimes with certainty. On the one hand, this model specification allows for capturing the "spiky behaviour" of electricity returns series. On the other hand, this two-regimes Markov- switching model did not identify the periods of high-risk of electricity prices on the DAM in the proper way because of the occurrences of the extreme changes in electricity prices (around 80%), which were characterized in the Section 3. This causes that Markov-switching model was able to assign only such extreme behaviour of electricity prices to the high volatility regimes. This implies the need of the introduction the third volatility regime to the analysis. Finally, three volatility regimes have been distinguished in the modelling: low volatility regime -0, moderate volatility regime -1, high volatility regime -2. As one can see in Table 2, Markov-switching model with 3 volatility regimes outperforms MS-model with two regimes for electricity returns. Moreover, each of the three regimes is rather stable, as estimated transition probabilities from one to another regime are rather low (below 0.2). The high volatility regime duration is about 21days (EUA_ICE) and 12 days (IRDN). However only 6.74% of carbon returns and 8.11% of electricity returns were assigned to this volatility state. For both EUA futures contacts and electricity spot prices the highest number of observations was assigned to the low volatility regime (58.14% - EUA; 72.16% - IRDN), in which the process remained on average respectively 88 days and 72 days.

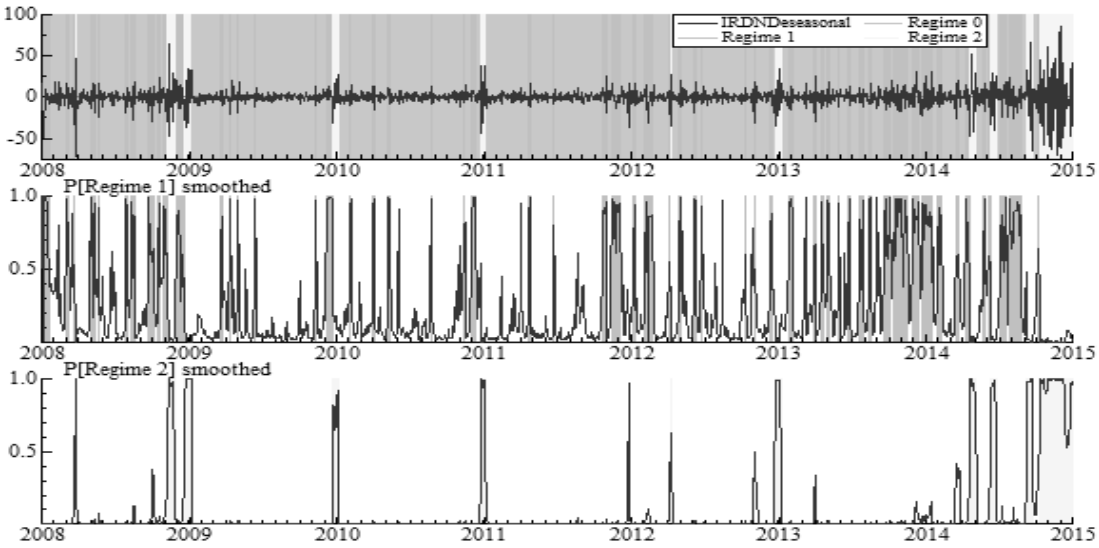


Fig. 5 Electricity returns and smoothed probabilities of high- and moderate- volatility regimes- MS-GARCH approach

Source: Own elaborations in PcGive 14.

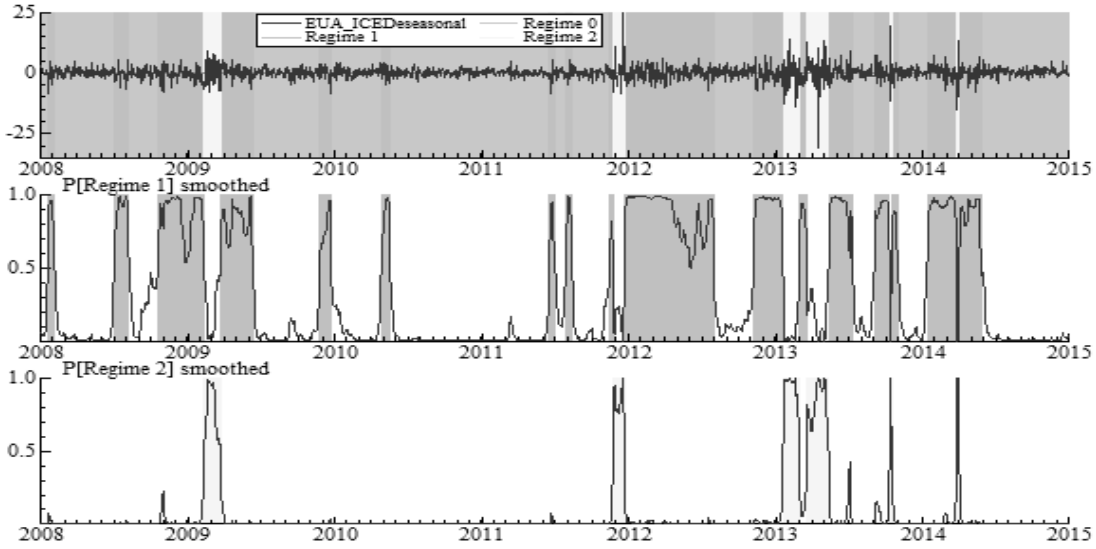


Fig. 6 EUA returns and smoothed probabilities of high- and moderate- volatility regimes- MS-GARCH approach

Source: Own elaborations in PcGive 14.

Comparing the moments when the high volatility regime began and finished for each of the returns series (see Fig. 5-6) one can indicate some similarities of their occurrence, connected with the impact of subprime financial crisis (August/September 2008) or EU debt crisis (October 2009). Moreover, uncertainty, that was accompanied by the carbon market participants at the beginning of III Phase of EU ETS, is also illustrated as the spiky prices behaviour on both commodity exchanges. It is worth stressing that this is the preliminary stage of author's research and all presented models should be subjected to calibration.

5. CONCLUSION

Emission trading uses the demand-supply relations on the coal market to determine the cheapest ways of reducing natural environment pollution. Within this system enterprises may purchase and resale CO2 emission allowances according to their needs, not exceeding permissible limits of pollution emission. Costs of controlling the risk of exceeding permissible limits of CO2 emission are high, which causes growth of interest of enterprises from high greenhouse emission sector, including the ones from the energy sector, in investments into clean, low-emission technologies. A distressing signals for this market participants are proposals of the European Commission aiming at conducting backloading, being a form of a controlled intervention on the market of emission allowances (2013-2015 period), which on assumption was supposed to develop using only the demand-supply mechanisms. Such signals may cause consternation of decision-makers managing a complex risk profile of energy sector enterprises as on the one hand the EU supports energy efficiency and RES technologies that limit the emission and on the other hand it attempts to manage these emissions through maintaining their high prices. It is also worth emphasizing that the dynamic development of EU ETS has drawn the attention of investors, who have noticed a possibility to make profits on trading CO2 emission allowances and green certificates.

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