Modeling Dynamics of the Carbon Market: A System Dynamics Approach on the CO_2 Emissions and its Connections to the Oil Market

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Abstract. Global warming poses a real threat to the sustainable development. The temperature data shows that unless the greenhouse gas emissions are controlled, the global temperature can rise critically by the end of the century. The Emission Trading System (ETS) has been introduced to control the emissions in the participating countries by providing economic incentives to the industries and manufacturers to shift towards cleaner energy resources and technologies. In this paper, we study the main variables and causes behind the emissions, and investigate the mechanisms on the carbon market, particularly the European Union ETS. We also provide an updated oil market model to include the recent data and developments in the global oil market. We connect the two models to each other so that the effects of the oil price on the climate change can be investigated. Next, we train our model with the historic data and simulate it to show the capability of the proposed model in predicting the trends of the historic data. Finally, we provide simulation results to support our model.

1 Introduction

Climate change is real. During the past century the average temperature of our planet has increased significantly. According to the temperature data, the global average temperature has increased from -0.375 Celsius degrees in 1850 to an estimate value of 0.894 Celsius degrees in 2016 [1]. The land-surface air temperature indicates even a higher change from -0.496 degrees to 1.345 degrees between 1850 and 2016 [2]. Moreover, a similar data set shows that the northern hemisphere's temperature has increased more than that of the southern hemisphere. Fig. 1 shows the average global land-ocean temperature index between 1880 and 2012. The overall message is that human activities leading to greenhouse gas (GHG) emissions should be controlled heavily.

An initial global attempt towards recognizing the climate change was in 1997, which led to the establishment of the Kyoto Protocol (KP) [3]. Through the the

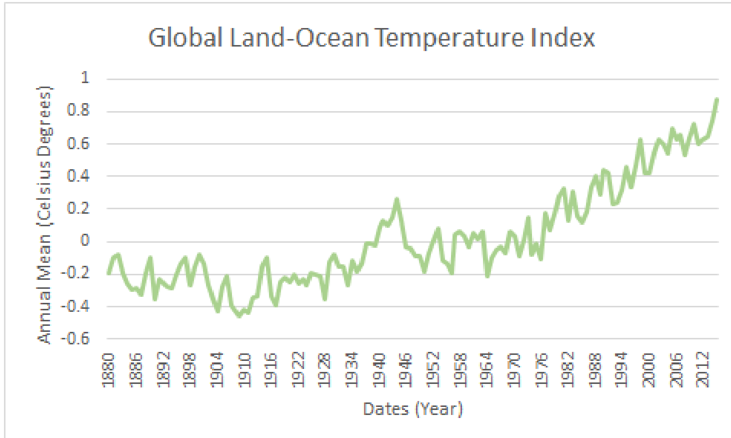

Fig. 1. Average global land-ocean temperature index between 1880 and 2012.

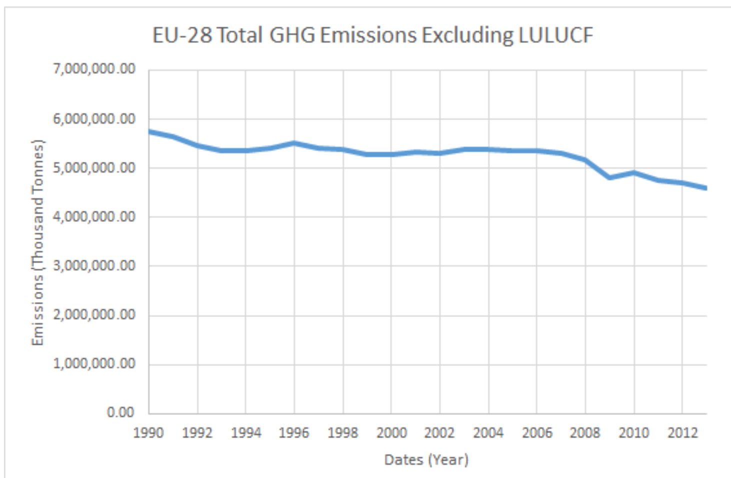

Fig. 2. Historic total EU GHG emissions, excluding Land Use, Land Use Change, and Forestry (LULUCF) and including international aviation.

Kyoto mechanisms, the KP enabled the participating 37 industrialized countries to set goals in reducing their carbon emissions by 5% between 2008 and 2012 compared to the Kyoto base year of 1990 [4]. One of the mechanisms was the introduction of an Emission Trading System (ETS). A successful implementation of an ETS is in the EU zone, which we refer to as the EU ETS. Another mechanism, which also provides financial incentives for industries, is providing means of investment in low-carbon projects in the developing countries, and transferring cleaner technologies to those countries [5–7]. These methods, have all been adapted and integrated in the EU ETS system. Figure 2 shows the overall EU emissions excluding the Land Use, Land Use Change, and Forestry (LULUCF) and including international aviation.

In this paper, we provide a model on the main parameters and variables that play a role in an emission trading system. Particularly, we consider the European implementation of this approach. We utilize the system dynamics methodology in our modeling [8, 9], and provide our model based on the variables extracted through a literature study on the main sources of carbon emissions. Then, we build a casual model between the derived factors and parameters. For our simulation, we build a stock and flow model in which the stock variables and their rate variables are related through differential equations. The overall model is reduced to a system of ordinary differential equations with variable coefficients, and is solved numerically using methods such as Runge-Kutta method [10–13]. The mathematical relations between the main variables are derived using regression analysis on the available historic data which are used to train the model. For the set of variables where analytic relations cannot be derived, we use look-up tables. A main loop of the oil market is also provided, and the relations between the oil market variables and the carbon market are explained. Our simulations support our results.

2 A System Dynamics Model

In this section, we elaborate the main causal loops, and identify the type of the variables and relations between them. The model consists of two main parts. The first part of the model provides the governing relations in the carbon market, whereas the second part systematically models the global oil price which is the main energy resource in the world. We will explain the carbon market model first, and then elaborate the oil model in the second part. Lastly, we explain how these two parts connect to each other and interact.

General modeling strategies: Our model is a system dynamics [14–16] based model. Like any other system dynamics model, first, the main variables and parameters are extracted and the casual relations among them are established. Then, the mathematical relations between each two variable that are connected through a causal line are developed. The stock variables represent the variables whose values have a momentum with respect to time accumulating values over time, and are generally the outcome of an integral whose relations are modeled through a first order ordinary differential equation that is numerically solved. The change rates of the stock variable is the variable that controls the stock variable over the course of time. The other variables which lack the characteristics of accumulation, and take instantaneous values are modeled as flow variables.

Main loop in carbon market: The main loop consists of three main variables. The Emission Allowances Price (EAP), Emission Allowances Demand (EAD) and the Emission Allowances Supply (EAS) [17–19]. The supply for emission allowances is considered to be constant over a year. The only way it can change is through the regulatory policies of the ETS. For instance, in the third period of the EU ETS implementation the supply for allowances is reduced by 1.74% each

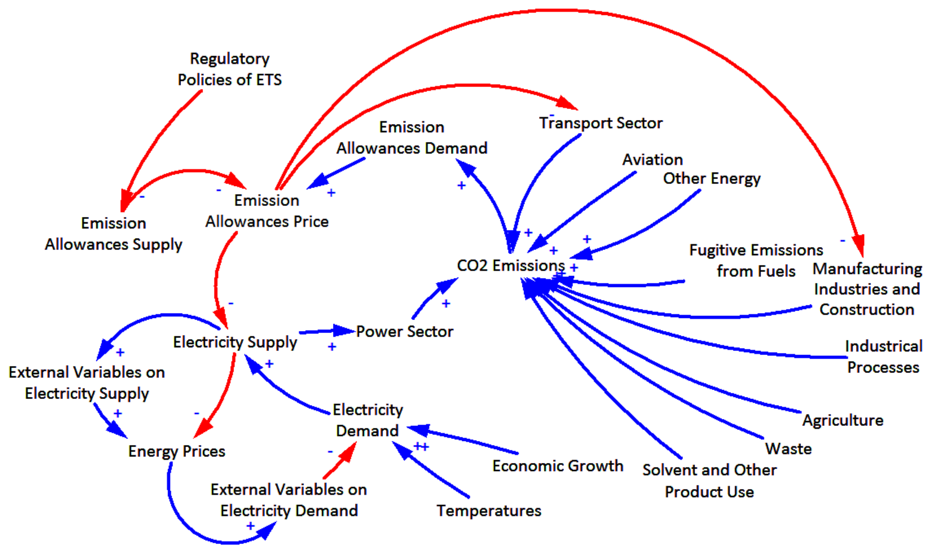

Fig. 3. Carbon market main loop.

year [19]. The overall causal loop is shown in Fig. 3. The External Variables on Demand summarize the variables that model the demand side. Similar to any other economic system, the price of the EU Allowances (EUAs) emerges from the balance between the supply and demand forces. In our model, the price and demand of allowances are stock variables [20–22].

Carbon allowances demand loop: On the demand side, the main factor is the electricity consumption. This is mainly due to the fact that the power sector, which is mainly affected by the electricity consumption, is the biggest CO_2 emitter, and thus it has the largest demand for the allowances [23]. Therefore, it is important to analyze the main factors that determine the electricity demand and supply. Generally, the electricity demand changes with the economic activity, temperature and the amount of daylight (the latter two depend on the time of the year). On the other hand, it is indeed the electricity supply that generates the emissions. Even though it is mainly the electricity demand that drives the electricity supply, the electricity supply itself can also affect the demand through its external imposing factors such as the fuel prices [24, 25]. Based on these, we have modeled the demand for allowances to be affected by the main four factors of the economic growth, fuel prices, weather conditions, and regulatory policies of the ETS. It has been previously investigated that the deviations from the predicted (or expected) values of each of these variables are the main reasons for big changes in the EUA prices. For instance, a harsh weather such as extreme cold in winter or extreme high temperatures in summer time (which are above the average or expected value of the variables) increase the electricity demand, thus, increasing the fuel consumption and subsequently increasing the demand for carbon allowances due to the predicted increase in the emissions [26–30].

Oil market main loop: The main factors behind the oil market are the Global Oil Supply and Global Oil Demand which determine the Global Oil Price. In the oil market, other than the aggregated oil demand and supply, there are other factors that determine the oil price, most of which we refer to as the expectational or anticipated behavioral parameters [10,31]. These factors are generally formed by the predicted trends of the variables other than the supply and demand. For instance, in the occurrence of a conflict or riot in an oil producing country, the oil prices usually react to the events immediately [8]. In such a situation, usually it is expected that the (short-run or long-run depending on the intensity of the events) oil supply of that country will face volatility, adding to the volatility of the whole market [32]. Although in many situations, the actual supply does not change as much as expected (or at least as much as the reaction of the oil price), the predicted trend reflects its influence on the price much earlier than the real data. Therefore, prediction of the market trends in the oil market is crucial in determining the future price. The oil market part of the model utilizes previous work, [32] where we have updated the modeling approach and incorporated the latest market data and events as occurred in 2015. The main loop is shown in Fig. 4.

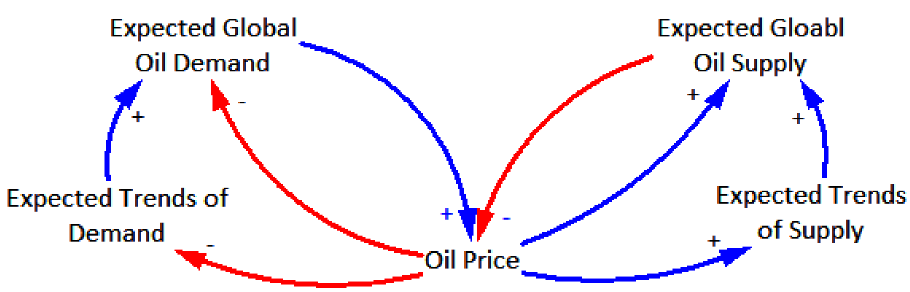

Fig. 4. Oil market main loop.

Effects of the oil market on the carbon emissions: Finally, we connect the two parts of the model by connecting the economic growths from two parts and relating the energy prices of the carbon market to the oil prices. In the carbon market, we assume that the energy prices is a portfolio of the oil price, natural gas, and coal which are the main carbon emitting resources. However, we provide the dynamics of oil price from the oil market part of the model, and assume a linear change of the natural gas and coal prices based on 2015 price data.

3 Simulation Results

In this section, we provide our simulation results to support our model. First, we provide an analysis of the predicted changes on the average global temperature. Then we provide our Vensim [33] simulation results. In the simulation

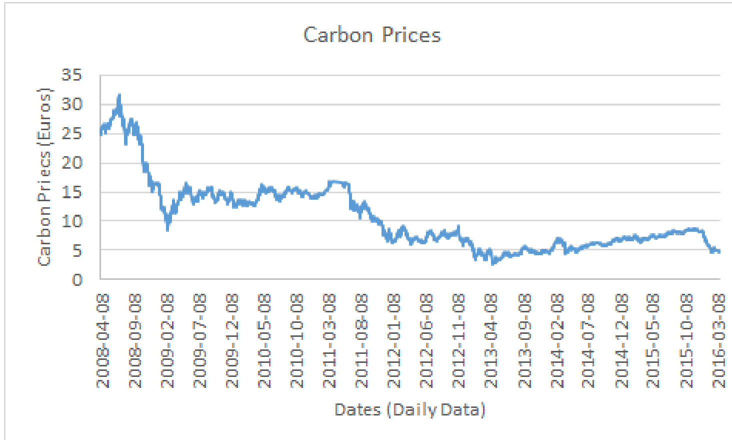

Fig. 5. Historic carbon prices for EUAs.

scenario, we train our model to reproduce the trends for the historic changes of the carbon prices. We use the EUA price data from [34] beginning from the 2013 year. A historic data of EUA prices is depicted in Fig. 5.

Climate change: As shown in figures 6, 7 and 8, we have performed first, second and third order analyses of the temperature changes, respectively. Using the analysis of these figures, it is conjectured that by the end of the 21st century, the mean temperature of the earth can increase to 1.0494, 2.7952, and 3.7518 degrees Celsius as a result of first, second and third order analyses, respectively. This is compliant with the data of the Intergovernmental Panel on Climate Change (IPCC) which has reported that the projected increase of temperature in the current century can be anywhere between 0.3 degrees to 4.8 degrees [35]. These analysis confirms that the global warming can be a threatening event for the sustainable development, unless the GHG emissions are controlled more seriously.

Historic data fit: In this scenario, we train our model and its variables according to the historic data of the oil and carbon market. Particularly, we consider the WTI oil price data taken from [36], economic growth data from [37], oil supply data from [38], oil demand data from [39], CO_2 emissions data from [40], EUA price data from [34], temperature data from [1], and all the other data in carbon market from [41]. Figure 9 reflects our simulation results for the period between 1st of Feb. 2013 and 1st of Feb. 2016. As it is shown in the figure, the EUA price starts from 5.8 Euros, which we have chosen to be the starting value in our simulations, as well. The prices drop during April 2014 period and have a trend of growth until the end of 2015, and start to fall sharply in the beginning of 2016. As shown in the Fig. 9, our results follow the historic data's trend.

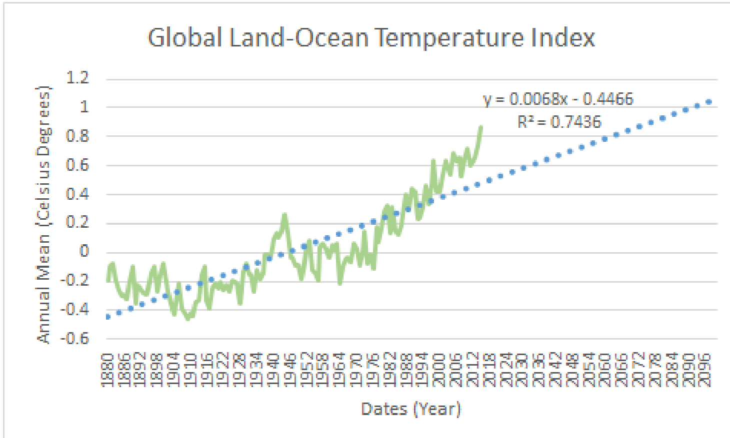

Fig. 6. A first order analysis on the global temperature data, with prediction of the temperature for the rest of the 21st century.

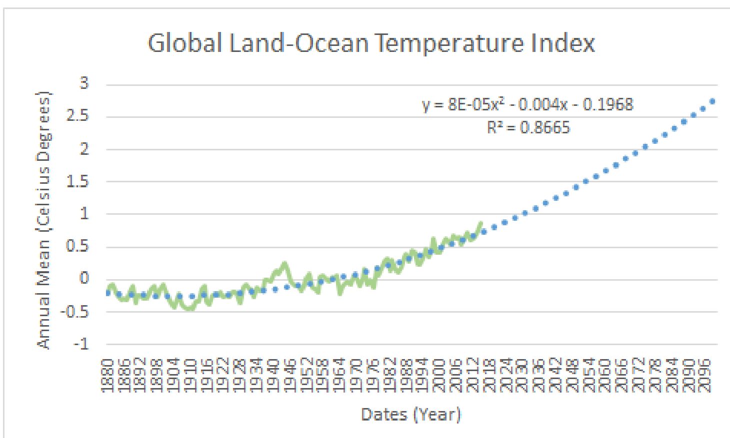

Fig. 7. A second order analysis on the global temperature data, with prediction of the temperature for the rest of the 21st century.

4 Conclusion and Future Work

In this paper, we provided a model of the carbon market, and connected it to the oil market through a system dynamics approach. We investigated the main factors and variables involved in the carbon market, particularly, the major emission resources. We also provided a stock and flow model on the cap-and-trade market mechanisms that provides an incentive to the industries to move forward towards the least costly solutions regarding their emissions. By connecting the oil market model to the carbon market, we could model the effects of oil price on

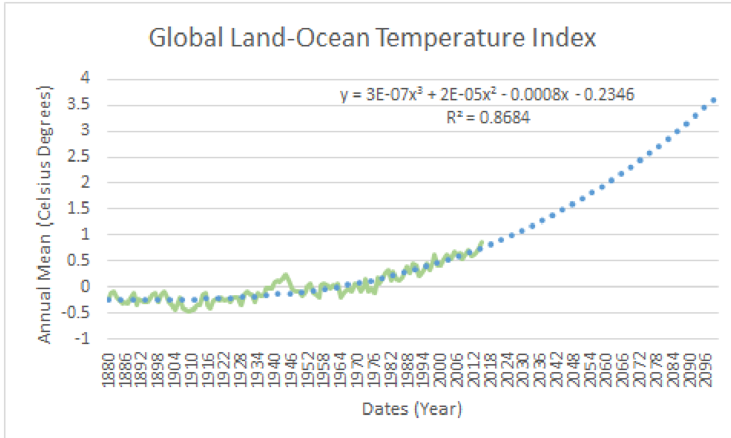

Fig. 8. A third order analysis on the global temperature data, with prediction of the temperature for the rest of the 21st century.

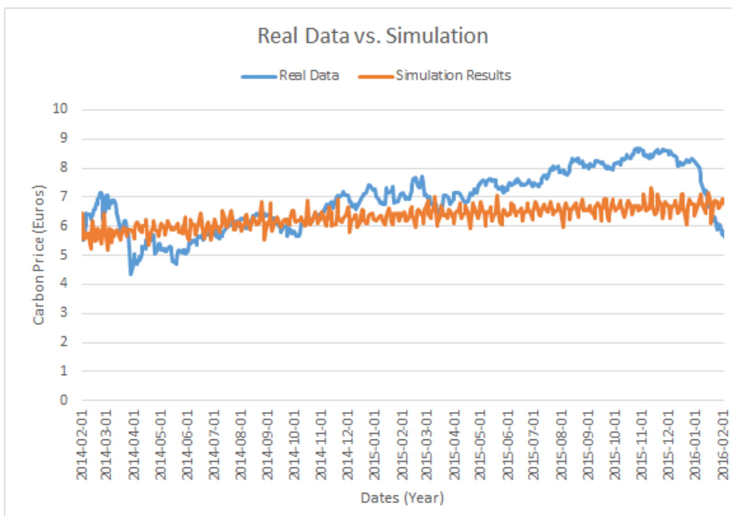

Fig. 9. Emission allowance price simulation result.

the carbon emissions. Our simulations showed that our trained model is capable of providing a historic fit on the data. Our future works, will extend the model to include sub-models of the electricity market, as well as a better modeling of the other energy markets such as natural gas and coal. Moreover, we will provide more analysis on the sensitivity of the model of the changes of different factors to study the effects of policies on those parameters.

References

[1] Metoffice.gov.uk (2016)

[2] Climate Change: Vital Signs of the Planet, http://climate.nasa.gov/vital-signs/global-temperature/ (2015)

[3] Shrestha, R.M., Timilsina, G.R.: The additionality criterion for identifying clean development mechanism projects under the kyoto protocol. Energy Policy **30**(1) (2002) 73–79

[4] Wara, M.: Is the global carbon market working? Nature **445**(7128) (2007) 595–596

[5] Lele, S.M.: Sustainable development: a critical review. World development **19**(6) (1991) 607–621

[6] Jacobson, M.Z., Delucchi, M.A.: Providing all global energy with wind, water, and solar power, part i: Technologies, energy resources, quantities and areas of infrastructure, and materials. Energy Policy **39**(3) (2011) 1154–1169

[7] Yilmaz, L., Chan, W.V., Moon, I., Roeder, T., Macal, C., Rosetti, M.: A system dynamics model on the reasons of car price shocks after economic sanctions

[8] RafieiSakhaei, M., Jabbari, M.: Modeling the impacts of middle east and north africa unrest on the global oil price. In: Proceedings of the international system dynamics conference. St. Gallen, Switzerland. (2012)

[9] Barazandeh, B., Rafieisakhaei, M.: A system dynamics model on the reasons of car price shocks after economic sanctions. In: 2015 Winter Simulation Conference (WSC), IEEE (2015) 3220–3221

[10] Rafieisakhaei, M., Barazandeh, B., Bolursaz, M., Assadzadeh, M.: Modeling dynamics of expectations on global oil price. In: The 33rd International Conference of the System Dynamics Society. (2015)

[11] Azadeh, A., Fekri, M., Asadzadeh, S., Barazandeh, B., Barrios, B.: A unique mathematical model for maintenance strategies to improve energy flows of the electrical power sector. Energy Exploration & Exploitation (2016) 0144598715623665

[12] Butcher, J.C.: The numerical analysis of ordinary differential equations: Runge-Kutta and general linear methods. Wiley-Interscience (1987)

[13] Barazandeh, B., RafieiSakhaei, M., Moosavi, A., Bastani, K.: Effect of localization on the car market under intense sanctions; a system dynamics approach. In: The 34rd International Conference of the System Dynamics Society. (2016)

[14] Sterman, J.D.: Business dynamics: systems thinking and modeling for a complex world. Volume 19. Irwin/McGraw-Hill Boston (2000)

[15] Rafieisakhaei, M., Barazandeh, B.: The effects of oil market events on carbon emissions: A 2016 case study. In: SPE Health, Safety, Security, Environment, & Social Responsibility Conference North America, Society of Petroleum Engineers (2017 (accepted))

[16] Rafieisakhaei, M., Barazandeh, B.: The efficacy of marketbased emission control systems: A system dynamics approach. In: SPE Health, Safety, Security, Environment, & Social Responsibility Conference North America, Society of Petroleum Engineers (2017 (accepted))

[17] Grubb, M., Neuhoff, K.: Allocation and competitiveness in the eu emissions trading scheme: policy overview. Climate Policy **6**(1) (2006) 7–30

[18] Ellerman, A.D., Convery, F.J., De Perthuis, C.: Pricing carbon: the European Union emissions trading scheme. Cambridge University Press (2010)

[19] Commission, E., et al.: Sustainable development in the european union. 2009 monitoring report of the EU sustainable development strategy, Luxembourg: Office for Official Publications of the European Communities (2009)

[20] RafieiSakhaei, M., Barazandeh, B., Moosavi, A., Fekri, M., Bastani, K.: Supply and demand dynamics of the oil market: A system dynamics approach. In: The 34rd International Conference of the System Dynamics Society. (2016)
[21] Rafieisakhaei, M., Barazandeh, B.: Modeling dynamics of a Market-Based emission control system: Efficacy analysis. In: 2016 IEEE Conference on Technologies for Sustainability (SusTech) (SusTech 2016), Phoenix, USA (October 2016)
[22] Barazandeh, B., Rafieisakhaei, M.: Effect of localization on the sustainable development in iran's car industry. In: 2016 IEEE Conference on Technologies for Sustainability (SusTech) (SusTech 2016), Phoenix, USA (October 2016)
[23] Peters, G.P., Marland, G., Le Quéré, C., Boden, T., Canadell, J.G., Raupach, M.R.: Rapid growth in co2 emissions after the 2008-2009 global financial crisis. Nature Climate Change **2**(1) (2012) 2–4
[24] Chiodi, A., Gargiulo, M., Rogan, F., Deane, J., Lavigne, D., Rout, U.K., Gallachóir, B.P.Ó.: Modelling the impacts of challenging 2050 european climate mitigation targets on irelands energy system. Energy Policy **53** (2013) 169–189
[25] Bel, G., Joseph, S.: Emission abatement: Untangling the impacts of the eu ets and the economic crisis. Energy Economics **49** (2015) 531–539
[26] Klassen, R.D., Whybark, D.C.: The impact of environmental technologies on manufacturing performance. Academy of Management journal **42**(6) (1999) 599–615
[27] Daskalakis, G., Psychoyios, D., Markellos, R.N.: Modeling co 2 emission allowance prices and derivatives: evidence from the european trading scheme. Journal of Banking & Finance **33**(7) (2009) 1230–1241
[28] Afra, S., Nasr-El-Din, H., Socci, D., Cui, Z., et al.: A novel viscosity reduction plant-based diluent for heavy and extra-heavy oil. In: SPE Improved Oil Recovery Conference, Society of Petroleum Engineers (2016)
[29] Schobeiri, M.T., Ghoreyshi, S.M.: The ultrahigh efficiency gas turbine engine with stator internal combustion. Journal of Engineering for Gas Turbines and Power **138**(2) (2016) 021506
[30] Ghoreyshi, M., Saidi, M.S., Navabi, M.A., Firoozabadi, B.D., Shabanian, R.: Numerical investigation of antegrade flow effects on flow pulsations in fontan operation. International Journal of Biomedical Engineering and Technology **10**(3) (2012) 221–238
[31] Rafieisakhaei, M., Barazandeh, B., Tarrahi, M.: A system dynamics approach on oil market modeling with statistical data analysis. In: SPE Middle East Oil & Gas Show and Conference, Society of Petroleum Engineers (2017 (accepted))
[32] Rafieisakhaei, M., Barazandeh, B., Tarrahi, M.: Analysis of supply and demand dynamics to predict oil market trends: A case study of 2015 price data. In: SPE/IAEE Hydrocarbon Economics and Evaluation Symposium, Society of Petroleum Engineers (2016)
[33] Eberlein, R.L., Peterson, D.W.: Understanding models with vensim. European journal of operational research **59**(1) (1992) 216–219
[34] : Ice eua futures (c) - data from quandl. Quandl.com (2016)
[35] Stocker, T.F.: Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press (2014)
[36] Company, D.J..: Spot oil price: West texas intermediate (discontinued series) (oilprice). `https://research.stlouisfed.org/fred2/series/OILPRICE/downloaddata` (2015) [Online; accessed 13-July-2015].
[37] Databank.worldbank.org: The world bank databank — explore . create . share (2015)

[38] Eia.gov: International energy statistics - eia. http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=50&pid=53&aid=1 (2015)
[39] IEA: Iea - oil market report public. Iea.org (2015)
[40] : Greenhouse gas emissions (source: Eea). Appsso.eurostat.ec.europa.eu (2016)
[41] : Statistics of the basque country. En.eustat.eus (2016)