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Department of Economics, Management and Humanities

The Impact of CO_2 Emission Allowance Market on the Czech Economy

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Study program: Electrical Engineering, Power Engineering and Management

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Analyzujte současné a očekávané nastavení systému EU ETS, scénáře predikce cen povolenek
Analyzujte dopady různých scénářů cen povolenek na vybrané sektory národního hospodářství
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Seznam doporučené literatury:

Jones, Charles I. Macroeconomics. Fourth. New York;London: W.W. Norton & Company, 2018.
Isard, W., Azis, I., Drennan, M., Miller, R., Saltzman, S., Thorbecke, E. Methods of Interregional and Regional Analysis. London: Routledge, 1998.
Ellerman, A. D. , Buchner, B. K. , and Carraro, C. , Eds., Allocation in the European Emissions Trading Scheme: Rights, Rents and Fairness. Cambridge: Cambridge University Press, 2007.

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In Prague 20.5.2019 …..…………..………………........

Bc. Filip Bělský

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ABSTRACT

The recent increase in the price of the European emission allowance (EUA) raises questions pertaining to its impact on the sectors of the national economy. This thesis studies the impacts of the set price change on sectoral turnover and employment. The functions and mechanisms of the EU ETS along with all its market phases were first described. Furthermore, two scenarios each featuring a different approach to the EUA free allocation process were analyzed using symmetrical input-output (I-O) tables methodology. The first scenario was based on a business-as-usual (BAU) allocation model, while the second scenario utilized full auctioning (FA) approach. The analysis showed that the most severe impact (decrease) was in electricity and heat production sector, while several other sectors benefited from the current environmental policy. These include the production of paper, water supply, sewage treatment, and public administration sectors. The abovementioned sectors showed a net increase in turnover. The results imply a moderate redistribution impact on the total turnover, however this leads to a strong impact on employment redistribution due to differences in sectoral labor productivity.

Keywords

EU ETS, EUA pricing, Input-Output model, National and sectoral impact analysis

ABSTRAKT

Současný růst ceny Evropských emisních povolenek (EUA) vyvolává otázky související s dopady změny cen na sektory národního hospodářství. Tato práce je zaměřená na studium dopadů změn v ceně povolenek na obrat a zaměstnanost v jednotlivých odvětvích. Teoretická část práce nejprve vysvětluje funkce a mechanizmy EU ETS a dále pak popisuje všechna aukční období. V praktické části jsou za pomoci symetrických input-output tabulek (I-O) analyzovány dva různé scénáře bezplatné alokace EUA. První analyzovaný scénář je na základě alokačního přístup typu business-as-usual (BAU), načež druhý scénář pracoval s myšlenkou prodeje všech (FA) povolenek v rámci aukcí. Z provedené analýzy vyplynulo, že největší dopad (pokles) je v odvětví produkce elektřiny a tepla, zatímco ze současné environmentální legislativy nejlépe vychází sektory výroby papíru, zdroje pitné vody, čističky odpadních vod a veřejné správy. Tyto zmíněné sektory naopak vykázaly čistý nárůst obratu. Konečné výsledky naznačují mírný redistribuční efekt v celkovém obratu, které však mají výrazný dopad na redistribuci zaměstnanosti vzhledem k rozdílné sektorové produktivitě práce.

Klíčová slova

EU ETS, EUA cena, Input-Output model, Dopadová analýza národní hospodářství a odvětví

TABLE OF CONTENTS

GLOSSARY

List of abbreviations

Abbr.	Full Text Description
AAU	Assigned Amount Unit
BAT	Best Available Technology
BAU	Business as Usual
BSA	Burden Sharing Agreement
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
COP	Conference of Parties
CZSO	Czech Statistical Office
DSGE	Dynamic Stochastic General Equilibrium
ECCP	European Climate Change Program
EEA	European Environment Agency
EEX	European Energy Exchange
EP	European Parliament
ERU	Emission Reduction Unit
ETS	Emissions Trading Scheme
FA	Full Auctioning
GHG	Greenhouse Gas
I-O	Input-Output
IMI	Induced Market Impact
IRI	Induced Redistribution Impact
IPCC	International Panel on Climate Change
JI	Joint Implementation
LULUCF	Land-Use, Land-Use Change, and Forestry
MAC	Marginal Abatement Cost
MSR	Market Stability Reserve
MZP	Ministry of the Environment of the Czech Republic
NACE	Nomenclature Générale des Activités Économiques dans les Communautés Européennes
NAP	National Allocation Plan
NGO	Non-Governmental Organization
OECD	Organization for Economic Co-operation and Development
PA	Paris Agreement
PPM	Parts Per Million
PMI	Primary Market Impact
PRI	Primary Redistribution Impact
RMU	Removal Unit
TII	Total Induced Impact
UNCED	United Nations Conference of Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change

List of symbols and units

Symbol	Unit	Full Text Description
$\mathbf{A}$	n.a.	Direct requirements matrix
a_{ij}	n.a.	Elements of **A** matrix
$\mathbf{B}$	n.a.	Leontief inverse matrix
b_{ij}	n.a.	Elements of **B** matrix
C	CZK	Total household expenditure
c_i	CZK	Household expenditure in sector i
E	CZK	Total export
$\mathbf{e}$	per/CZK	Employment vector
e_i	CZK or per/CZK	Export from sector I or elements of employment vector
$\mathbf{F}$	CZK	Final demand matrix
$\mathbf{f}$	CZK	Final demand vector
$\mathbf{f^*}$	CZK	Shifted final demand vector
f_i	CZK	Elements of **F** matrix or **f** vector
G	CZK	Total governmental purchase
g_i	CZK	Governmental purchase in sector i
I	CZK	Total corporate investment
$\mathbf{i}$	n.a.	Identity vector
$\mathbf{I}$	n.a.	Identity matrix
i_i	CZK	Corporate investment in sector i
L	CZK	Total labor payment
l_j	CZK	Labor payment in sector j
M	CZK	Total import payment
ME_j	per/CZK	Employment multiplier for sector j
m_j	CZK	Import payment in sector j
MO_j	n.a.	Output multiplier for sector j
n	n.a.	Number of sectors or dimensions
OV	CZK	Total other value-added payment
ov_j	CZK	Other value-added payment in sector j
$\mathbf{X}$	CZK	Total production matrix
$\mathbf{x}$	CZK	Total production vector
$\mathbf{x^*}$	CZK	Shifted total production vector
x_i	CZK	Total monetary value of sector i
x_j	CZK	Total monetary value of sector j
$\mathbf{Y}$	CZK	Primary input matrix
$\mathbf{Z}$	CZK	Interindustry demand matrix
z_{ij}	CZK	Elements of **Z** matrix
$\mathbf{\Delta f}$	CZK	Change in final demand vector
$\mathbf{\Delta x}$	CZK	Change in total production vector

1 INTRODUCTION

Since the dawn of the industrial revolution, mankind has been producing more and more carbon emissions than ever before. This increase in atmospheric pollution has sped up in recent years, due to many varying factors such as the large increase in global trade and the economic growth in third world countries. Furthermore, humanity has been witnessing dramatic changes across local biomes and global landscapes. Nearly all places on Earth have been struck by this sudden change in climate, local temperature fluctuations, varying amounts of rain precipitation and many more unfavorable events happening on a global scale. However, this change does not tell the whole story. While the recent annual averages for temperature might be slightly higher than the historical ones, the precipitation average values remain the same, what changed is the distribution of both. We can clearly observe extreme weather conditions with varying heavy rains and thunderstorms, followed by seasons of severe drought, while the world's population is growing at a significant pace and thus producing even more carbon emissions.

Mankind is without a doubt responsible for the aforementioned changes in climate, and thus several nations and countries decided that it is time to act and make changes that might not benefit the current generation as much but could save the world for future generations to come. One such effort is the EU ETS, its primary goal is to curb carbon emissions, while in the long run trying to achieve carbon neutrality, power efficiency, and increase power reliability and safety. The EU ETS is thus far the largest effort to mitigate the adverse effects of carbon emissions in the entire world. Similar projects albeit on a smaller scale were launched in the past and failed, but the EU ETS prevailed and is presently the trendsetter for all other governmental bodies, which goal is to reduce carbon emissions.

The beginning of this thesis intends to give a brief foreword on the origins of climate protection and how intergovernmental bodies came to existence, while stating the most important events that led to the inception of carbon markets.

The following chapter should explain to the reader how and why the EU ETS works, further detail its mechanism and functions, with individual subchapters focusing on the basis of each trading phase strictly followed by EUA price analysis, and finally concluding with a discussion about the key aspects of the given phase, changes made and outcomes to be taken into the next trading phase.

The two last subchapters provide a brief overview of all significant and important events during all trading periods and act as a summary, while the latter subchapter introduces the reader to ins and outs of the national environmental policy of the Czech Republic, with laws and treaties, which govern the local emission allowance allocation and trading itself.

Chapter Four focuses on macroeconomic methods used in the evaluation of shock impacts on national economies and their sectors. Several commonly used methodologies are discussed and evaluated based on data availability and their relevance to the primary objective of this thesis, while the I-O methodology is further described in detail.

This thesis aims to fill the knowledge gap between the newly made changes to the functioning of the EU ETS and its impacts on national and sectoral changes in turnover and employment, while the recent increase in EUA price furthers this cause by providing supporting feedback for EUA pricing scenarios used in the impact analysis more than ever before.

This leads to the primary objectives of this thesis, which are:

- Analyzing the past, present and future functioning of the EU ETS.
- Accessing a shock impact caused by a sudden change in EUA pricing on the national economy of the Czech Republic and its sectors, as depicted by the total induced change in turnover and employment.
- Discussing the aforementioned impacts on a specific industrial sector in more detail.

The first bullet point is presented throughout Chapter Three, while the following two bullet points are evaluated based on the methodology introduced in Chapter Four and the reader can find them in Chapter Five and Chapter Six respectively.

2 PRECURSORS OF THE EU ETS

2.1. ORIGINS OF CLIMATE PROTECTION

In the past several decades CO_2 concentration in the atmosphere has been steadily rising as indicated by measurements at the Mauna Loa Observatory in Hawaii, USA. Atmospheric concentration has increased from 315 PPM in 1960 to 410 PPM in late 2018. Same data suggests that not only the absolute CO_2 concentration has increased considerably, but the growth rate has been increasing as well from 1% PPM/yr. in 1960 to around 2% PPM/yr. in the past decade [1].

Underlying facts of ongoing atmospheric changes inevitably led to the creation of the International Panel on Climate Change (IPCC) in 1988. The IPPC was set up as an intergovernmental body of the United Nations to provide scientific understanding of the potential impacts of climate change on environmental, social and economic aspects [2].

General Assembly Resolution 43/53 from 1988 named *Protection of global climate for present and future generations of mankind* was first to recognize climate change as common concern that affects humanity as a whole [3]. It further urges governmental and organizational bodies to assist the IPCC tasked to prepare a *comprehensive review* of the current state of research, knowledge and practices to combat adverse effects of climate change.

The first IPCC scientific assessment highlighted key factors adversely influencing climate change. It has defined Greenhouse Gases (GHG) and their effect on global climate. The same report revealed industrialized countries to be the major emitters of GHGs and therefore classifying them as responsible for GHG pollution [4]. Data provided by the same report concluded that international cooperation would be required if any progress is to be made, this led to the formation of the United Nations Framework Convention on Climate Change (UNFCCC) [2].

After several months of delays, the United Nations Conference of Environment and Development (UNCED) better known as the *Earth Summit* was held in 1992 in Rio de Janeiro. A crucial part of the summit revolved around cooperation of individual member states after the end of the Cold War on sustainability issues. The UNFCCC represented a significant progress in worldwide efforts to mitigate climate change and to curb GHG emissions. It was ratified and adopted at the summit in June 1992 and came into force in March 1994 [5].

Article 2 of the UNFCCC sets a definitive goal to stabilize the concentration of GHG emissions in the atmosphere necessary to prevent negative anthropogenic effects on the environment [6]. Positive action should be achieved through the employment of five principles denoted in Article 3. These principles include the protection and preservation of the environment for present and future generations. Article 3 also specifies the special needs of developing countries, and the disproportionality between climate change burden between industrialized and developing countries.

This disproportionality is further addressed in two annexes (Annex I and Annex II). The UN member states were divided into three main parties according to their level of development based on previous articles.

Annex I parties consist of industrialized developed countries and countries in transition to market economy. Several new entrant countries were added by an amendment following 4/CP.3 resolution from 1998, this included post-soviet republics (the Czech Republic, Slovakia etc.).

Annex II parties comprise developed countries but not economies in transition. The developed countries are required to support developing countries. Lastly, developing countries and countries considered least developed were included in Non-Annex I group [7].

The UNFCCC treaty lacked tangible and measurable steps to mitigate adverse effects of climate change. Instead, it laid a fundamental and grounding framework for future conferences by providing global goals, principles, and rules. Even though Annex I countries were subject to a reduction of GHG emissions production and development of carbon sinks, this resolution did not lead to concrete commitment goals.

2.2. KYOTO PROTOCOL

The highest statutory authority of the UNFCCC is the Conference of Parties (COP), which is held annually, and supports representatives from all involved parties. COP is tasked with reviewing progress made by Annex I parties and reflect on the results. First COP negotiations began in 1995 in Berlin with a decision that measurable goals for emissions reduction would be set at COP3.

The Kyoto Protocol (Protocol) is the first international agreement connected to mitigating adverse climate change effects, it was adopted in Kyoto, Japan in December 1997. It extends the original UNFCCC treaty and requires signatory parties to commit to GHG emissions reduction. Two main important aspects were agreed upon. First, based on scientific evidence global warming is happening and has a negative impact on the environment and second, that human activity is the predominant cause of global warming [8].

The Protocol came into force in 2005 during COP7 in Marrakesh, Morocco, after both conditions set by Article 25 were met [9]. A total of 55 parties had to ratify the Protocol and these had to include an overall 55% of carbon dioxide emissions within Annex I countries.

Unlike all previous treaties the Kyoto Protocol set forth measurable and specific targets for GHG emissions reduction within Annex I parties, this regulation applies to a total of six gases, which are listed in Annex A: Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur Hexafluoride (SF_6) [8].

Article 3 states that during the first commitment period (from 2008 to 2012) each party must achieve at least a 5% reduction in GHG emissions compared to 1990 levels. However, Annex B assigned reduction factors varying on an individual basis for each committed member party. EU Member States (including the Czech Republic) agreed to an 8% reduction, while the USA to 7%, Russia to 0% and countries like Australia and Iceland were allowed an increase of 8% and 10% respectively compared to 1990 levels. Reduction in total emissions must be achieved separately from land-use, land-use change, and forestry (LULUCF). The Protocol defines a unit, which corresponds to an allowance to emit one metric ton of CO_2 or equivalent. Each country had been allocated assigned amount units (AAU) in accordance with their specific reduction factor times five for the first commitment period [8].

LULUCF activities must be accounted for separately from other emissions reduction projects, while each LULUCF project is subject to specific rules [8][9]. These activities generate saleable carbon credit called removal units (RMU), which countries can add to their pool of assigned units based on Article 3 of the Protocol [10].

All Annex I countries are required to establish and operate national emissions registry, which will account for all emissions transactions, including activities established through flexible mechanisms [8].

2.2.1. FLEXIBLE MECHANISMS

Flexible mechanisms were introduced in the Protocol to allow Annex I countries to fulfill a part of their emissions reduction commitment through three additional mechanisms. Generally, these mechanisms allow Annex I countries to reduce their emissions in a different Protocol member country or purchase AAUs from other Annex I countries.

In order to promote sustainable growth without an unnecessary increase in GHG emissions the Clean Development Mechanism (CDM), entitles Annex I countries to pursue emission reducing or emission limiting projects in developing countries, and by such earning certified emission reduction (CER) credits. CERs are tradable credits similar to AAUs and are equal to a metric ton of CO_2, which Annex I countries can use towards meeting their commitment goals as required by the Protocol [11].

CDM projects can range from construction of energy efficient power sources to carbon sinks. These projects allow for Non-Annex I countries to gain access to clean technology or capital investments through associated programs. CDM projects increase the pool of tradable carbon credits and therefore are not considered an emissions reduction scheme.

The next type of flexible mechanism is the Joint Implementation (JI), defined in Article 6 of the Protocol. Unlike the CDM only Annex I countries can participate in the JI mechanism, where an investor country can fund an emission reducing or emission limiting project in another Annex I country to obtain emission reduction units (ERU), which are again tradable carbon credits like the AAUs. Through this mechanism, a host country gains cleaner technology and capital investment, while the investor country receives ERUs [12].

The core concept of additionality is fully expressed in the JI mechanism, where an investor country must prove that the project would not happen without the JI mechanism. This concept alleviates potential misuse of the JI mechanism, in projects that would have otherwise happened without the JI. The overall effect of the JI project is beneficial since it achieves the set reduction target within the Protocol scope [12].

The JI mechanism is based on an economic premise that Annex I countries have dissimilar marginal abatement costs (MAC) of carbon emissions, therefore reducing a set amount of emissions in one country with a high emissions reduction potential yields lower MAC of reduction than in a country with a low emissions reduction potential. When the JI project is implemented, the investor country gets a set amount of ERUs from the host's national pool of AAUs. This mechanism prevents extra carbon credits to be created and therefore does not raise the total emission allowance set by the Protocol.

The third mechanism allows countries with a surplus in carbon credits, which are all marketable credits such as AAUs, RMUs, CERs, and ERUs, to sell them through a mechanism defined in Article 17 of the Protocol, called the Emissions Trading (ET). This mechanism creates a new commodity openly marketed and sold via carbon markets [13].

The ET is a market-based approach to emissions reduction, that allows Annex I countries to choose in which way to achieve their commitment targets to the Article 3 of the Protocol, without sacrificing the overall emission reduction effect. Carbon trading leads to a transfer of carbon credits from a seller to the buyer and thus does not increase the total cap.

3 ANALYSIS OF THE EU ETS

The EU was strongly influenced by the outcomes of the COP1 in Rio de Janeiro, Brazil held in 1992. Since the summit did not lead to any tangible emissions reduction targets, the EU tried to propose an EU-wide carbon tax. This proposal was met with a great deal of opposition by the Member States, while most felt that taxes should be handled on a national level and that an EU-wide carbon tax would compromise their sovereignty. The carbon tax proposal finally failed in 1997, the same year the COP3 in Kyoto was held [14].

The first commitment period defined by Article 3 of the Protocol subjects Member States to an 8% reduction in GHG emissions compared to 1990 levels in 2012, and also requires members to take active measures to achieve verifiable progress in developing and implementing mechanism into the national legislature by the year 2005 [8].

The approval of the Protocol showed to be very challenging since the two major superpowers USA and Russia refused to ratify the Protocol. This led to an increased responsibility of the EU, which at the time had the largest economy among the Protocol signatories [14]. The 1997 summit ended, but with no legal force backing up the Protocol commitments. The EU took this opportunity of nonbinding commitments set by the Protocol and in 2000 the European Commission (Commission) adopted a new platform called the European Climate Change Program (ECCP). This platform included a creation of several working groups consisting of local government officials, experts, industry leaders, and NGO representatives. The working groups published a final report in 2001, which recommends that the EU should develop a carbon market as soon as practicable and should not wait for the Protocol ratification. The same report also concludes that the emissions trading system must be transparent and both environmentally and economically efficient. Phase I of the emissions trading is described as “learning-by-doing” process and gives an incentive to start a pre-Kyoto emissions trading scheme [15].

In March 2003, the Commission published a Green Paper on GHG emissions trading within EU, which outlines a basic framework for a limited emission trading starting in 2005 and covering only CO_2. The most important approaches within the framework can be summarized as the following: burden sharing, emission trading, “learn-by-doing”, carbon credits allocation, and sectors covered by trading. Furthermore, Phase I of emission trading should be a pilot phase and last only three years, with the Commission having the ability to change the rules within the ongoing emissions trading framework [14][16].

Consequently, the European Parliament (EP) put forth an EU Directive 2003/87/EC (Directive), which established an emission allowance trading system within the EU. Combining information and data gathered by the ECCP working groups and the Green Paper [17]. The Directive omitted Kyoto saleable credits generated by flexible mechanisms. In late 2004, a new amending directive was put forth. The EU directive 2004/101/EC links credits produced by the CDM and the JI mechanisms to European emission allowance (EUA) as this would lead to an increase in diversity and liquidity within the unified carbon market. The 2004 EU Directive further specifies the use of Kyoto credits within the EU ETS framework [18].

3.1. PHASE I

Several key aspects of the EU ETS had to be figured out before the pilot phase could be implemented. These included the type of carbon market, the total allowance, the allocation method, and the sectors affected by carbon trading.

The EU ETS was established as a *cap-and-trade* system, where the cap represents a maximum amount of emissions released into the atmosphere within a set timeframe, and the trade embodies the ability of all involved parties to sell their surplus of allowances through a market mechanism. This Directive also allows subjects not included in mandatory carbon trading, to operate within the market on a voluntary basis and use EUAs as any other financial derivate for speculations.

Each Member State is required to design a National Allocation Plan (NAP). Criteria for drafting NAPs are specified in Annex III of the Directive. Member States must set a total quantity of allowances for the set timeframe in compliance with the individual Protocol commitment targets. The NAPs must then be submitted to the Commission for independent evaluation based on criteria defined in Annex III. If a Member State fails to comply with the Directive, the Commission has the right to refuse the submitted NAP and the Member State is forced to make changes and go through the submission process again [17].

The *grandfathering* concept was used as a method of calculating the quantity of allowances needed during Phase I for each Member State individually. This statistical method combines historical emissions production and projects future requirements. Article 10 of the Directive demands at least 95% of total allowances to be allocated to subjected emitters free of charge, while not stating what is to be done with the remaining 5% of all allowances. Member States can auction, allocate or otherwise dispose of the remainder independently [17].

The pilot phase of the EU ETS was officially launched in 2005, featuring 11 500 participating installations and covering nearly 45% of the total CO_2 production in the EU [14][19]. Annex I of the Directive recognized four categories of activities to be subjected to the mandatory carbon trading. Included were parts of the energy sector (fuel combustion plants, mineral oil refineries, coke ovens), production and processing of ferrous metals (metal ore roasting or sintering, production of pig iron and steel), mineral industry (production of cement, glass, and ceramic), other activities (timber based production, pulp, paper, cardboard) [17]. A minimum production amount was set to include only major producers, manufactures and therefore emitters. Even though both the Protocol and the Directive operated with a total of six GHGs only CO_2 was implemented throughout the Phase I, as it was the major contributor to atmospheric pollution within the selected sectors.

Founded on information provided in Annex IV of the Directive participating installations must monitor CO_2 emissions, either by calculation or measurement. Based on monitoring, each installation must provide an annual report to the national regulation authority, which must be verified by an independent agency [17].

3.1.1. ANALYSIS OF PHASE I

The EU carbon market was officially launched in January 2005, with EUA prices starting at around €8 per allowance, however, during mid-2005 the price escalated quickly to a range of €20-30 per allowance and remained high until April 2006. The high price provided a positive feedback to the market and encouraged producers and manufacturers to adopt new cleaner technologies. The 2013 OECD report called *Taxing Energy Use* suggests that pricing allowances to release one metric ton of CO_2 at €30 is a good estimate for costs associated with adverse climate change effects [20].

During April 2006 the EUA prices plummeted to a price of €15 per allowance within three days, and remained somewhat similar for about four months, as shown in Figure 1. The primary reason for the fall arose from the first publication of verified emissions, which showed a 4% surplus of allowances compared to the emissions produced in 2005.[21]

With the market already in excess and a steady annual supply of fresh allowances the price further fell and by the time the second year verified emissions were published the allowance price dropped to a few cents.

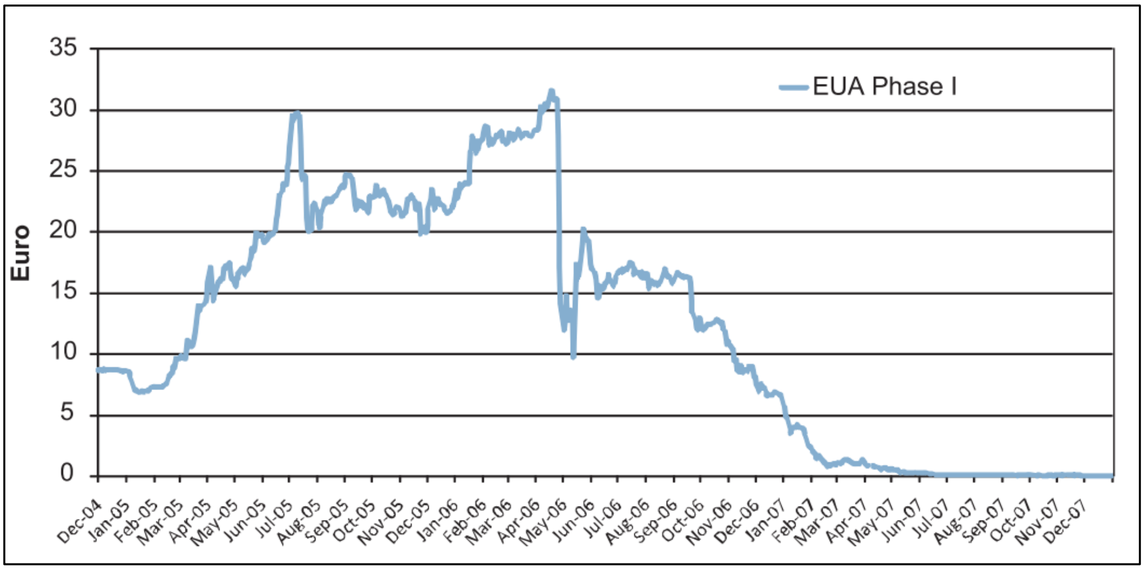

Figure 1. EUA futures price during Phase I. (Source: [21])

The second report on verified emission proved the market to be long again, and this led to the already crashed prices never being able to recover during the last year of the pilot phase. Banking of unused allowances was not allowed and therefore the remaining allowances became worthless. Trading officially concluded in December 2007.

3.1.2. PHASE I DISCUSSION

The three-year pilot phase was born out of a lack of global initiative to ratify the Protocol and the Commission’s commitment to abate carbon emissions. At first, EUA prices as depicted in Figure 1 showed a positive market feedback since higher allowance price serves as a driver for cleaner technology, however this did not last long. Through the middle of the trading period prices crashed, ending up losing almost half its pre-crash value. In the following few months, allowance prices remained stable. During a very mild winter of 2006/2007, EUA prices declined further to virtually zero during the last trading year.

As for almost any system in the world, the EU ETS in its pilot phase had its positives, drawbacks, flaws, and important lessons learned. In this subsection, I will discuss key aspects that played a crucial role during Phase I and served as primary change drivers for Phase II.

The Commission managed to deploy a universal trading scheme in a vastly diverse environment, combining 25 countries with differing sizes, economies, industries, policies, and national interests, which on its own was a huge success because many others had failed in establishing a working carbon market or even a carbon tax in the past [14].

The carbon market was established, however that did not lead to an efficiency within the market since almost all allowances were given to emitters free of charge and auction-based carbon markets can only be effective if all regulated bodies are involved in trading, which proved not to be the case of Phase I [22]. If a correct allowance cap is set, and most allowances are auctioned off, then a real market value of carbon can be estimated. As shown in Figure 1, real carbon price during Phase I could be assessed at around €25 per allowance, which is similar value correlating with OECD estimates.

The EU ETS pilot phase had been operating rather smoothly through its first half while giving a positive feedback to both policymakers and the industry. This all changed when verified emissions were reported for the first time and an allowance over-allocation was shown by the data [21]. Most Member States designed their NAPs in a way that would protect the countries' major emitters [23]. Verified emissions exposed the extensive issues with the use of the NAPs. Inconsistencies arising from different methodologies used in calculating the number of allowances, transparency problems of the process, and the overall accuracy provided through the NAPs, were found to be the major flaws of the allocation process.

Grandfathering method yielded far greater allocations numbers than necessary, which led to negligible or sometimes no emissions abatement at all. A 2010 journal article from the Environmental and Resource Economics [24] looks at verified emissions and compares them to emissions that would arise from a business-as-usual (BAU) approach. This article questions the integrity of data provided by the individual NAPs and finds the overall EU-wide net abatement to be just one-fifth of the reported net emission reduction as presented by the Member States.

As mentioned above the pilot phase served mainly to establish a functioning carbon market, gather necessary data for future phases, and figure out the potential flaws of the system. These flaws included the design of the NAPs, over-allocation, the unfairness of free allowance distribution, the lack of central control mechanisms, and the absence of allowance banking.

3.2. PHASE II

With the previous phase resulting in a failure, mainly due to factors like allowance over-allocation and many other miscellaneous problems, the Commission shifted its focus on the allocation process. The main target prior launching Phase II (also known as the Kyoto Phase), was the mechanisms, through which the individual Member States assigned their overall allowance for the entire duration of the trading phase. Several important changes were made to the structure of NAPs in order to reduce complexity and promote transparency, and consequently leading to prevention of over-allocation within the process. Member States were required to submit NAPs 18 months prior to the start of the next trading period [25].

Phase II began in 2008 and ended in 2012, which was announced in accordance to the first commitment period under the Protocol while introducing several new important changes associated with the past phase. Overall emission caps were lowered to around 6.5% EU-wide compared to 2005 levels. Member States could voluntarily start reporting on additional GHG emission including N_2O (which is 298 times better GHG than CO_2, according to the global warming potential presented in the Protocol) from nitric acid production and PFCs from aluminum production. Furthermore, the penalty for not submitting the required amount of allowances increased from €40 to €100. Paying the penalty does not free the perpetrator from allowance submission [26].

Moreover, three new non-EU countries joined the EU ETS (Iceland, Lichtenstein, and Norway). Additionally, there were two new entrants to the EU in 2007 (Bulgaria and Romania), which were also legally required to join the trading scheme. At the beginning of Phase II the EU ETS covered 30 individual countries and remained the largest carbon market in the world [26].

The Commission reached a compromise within the free allocation process for the second phase. Ending up with 90% of total allowances given free of charge. Meanwhile, economists argued for a wider adaptation of auctioning (because only four out of 25 Member States auctioned the 5% allowance budget set during Phase I) [27]. In contrasts businesses remained generally reluctant to give up free allowances. In the end, national governments could auction up to 10% of allowances issued during the second phase instead of giving them away free of charge.

The emission allowance caps for Member States were not only lowered based on actual verified emissions submitted during the pilot phase but also through the burden sharing agreement (BSA), which redistributed EU commitment targets of the Protocol to the individual Member States based on their MAC [16][28]. In compliance with the Kyoto trading period international carbon credits generated through Flexible Mechanisms like the CDM or the JI mechanism, were allowed to be used during Phase II.

International carbon credits could be purchased and transferred into national registries and would be treated as extra allowances, increasing the total EU emissions pool [18]. This process permitted businesses with high MACs to not only purchase additional EUA but also CERs and ERUs to cover its actual emission production.

The EU ETS became an integral mechanism of the EU climate change mitigation policy in the 2007 when leaders of Member States set goals for the long debated *2020 climate & energy package* as part of the Europe 2020 strategy. The Directive 2009/29/EC legally binds the EU to cut GHG emissions by 20% (from 1990 levels), produce at least 20% of energy from renewable sources, and improve the overall energy efficient by 20%. All these targets must be met before 2020, while the individual Member States had been assigned varying targets based on their level of economic development [29]. Under the Directive Member States should fund projects that help to mitigate problems arising from climate change; these include GHG emissions abatement, adaptation to impacts of the climate change, research and development, and renewable energy sources. Such efforts should be at least partially (50%) funded by proceeds acquired through the auctioning of emission allowances [30].

3.2.1. ANALYSIS OF PHASE II

An increased number of emissions allowances were auctioned in the second phase. The following Member States led in having the most notable average annual quantities of allowances auctioned; Germany (9%), United Kingdom (7%), The Netherlands (3.7%), Hungary (2%), Czech Republic (2%), Austria (1.3%), and Ireland (0.5%) [31].

As mentioned in the previous chapter, allowances issued during Phase I could not be banked for future use. This was not the case for Phase II issue allowances, which could be banked and used in the future phases.

Phase II issue allowances began auctioning in January 2007 for an average price of €20, which seemed a good starting position for the trading period. The high starting price was primarily accredited to the significant change in the allocation process within the NAPs and higher reduction goals based on the commitment targets set by the Protocol.

In early 2007, Phase I and Phase II issue allowances were being auctioned at the same time. As discussed in the previous subchapter, the over-allocation of Phase I allowances led to a crashing fall in price. The allowances were virtually worthless for the remainder of the trading period.

The Phase II allowances suffered from the same trend and lost 25% of its initial value during the first six months. Situation slightly improved in the last few months of 2007 as prices jumped to an average of €25. Prices remained relatively steady throughout 2008. In July 2008 the €30 threshold was broken for the first time since the beginning of the trading period. At the end of the same month price almost tackled the €35 mark, as shown in Figure 2.

Figure 2. EUA futures price during Phase I and II. (Source: [32])

With the coming winter of 2008/2009 EUA prices began falling. At first, the EUA price dropped to €25 and by January 2009 prices hit a new low of just around €10. Figure 3 shows that the major crash did not lead to a subsequent crash like in the case of Phase I; instead prices recovered to around €15 and remained mostly stable at €15 per allowance for the next two years. Unfortunately, in the second part of 2011 prices again began to decline and settled at around €7 per allowance for the remainder of the trading period.

Figure 3. EUA futures price during Phase II. (Source: [32])

Two main reasons were attributed to the crash of the EUA price in 2009. First, the economic recession as reported by the UNFCCC showed a substantial role, which led to a decreased output in energy-heavy sectors. Second, prices of futures contracts for natural gas and coal were revised downward [33].

3.2.2. PHASE II DISCUSSION

The second phase started out with tighter cap and stricter rules compared to the pilot phase, however, this did not lead to anything we could call a big success. At first, EUA price showed a positive feedback for policymakers, while reaching the €30 mark. Soon on the verge of economic recession, the price had collapsed to just mere €10 per allowance, while being able to recover at least part of its original value, it was never able to surpass the €20 threshold. It remained somewhat steady for the next two years but ended up concluding at only €7, which could be construed as a failure.

In this subsection, I will discuss the key aspects that led to the price depression over the duration of the second trading phase. Some of these aspects are well out of the scope of this thesis and will only be mentioned, others especially the most relatable to the topic of this thesis will be discussed in more detail.

Undeniably many factors in combination had a major impact on the turbulent price differences of EUA. The steep rise in price during 2008 was caused primarily by two aspects. The EP announced that trading would continue after the second phase until 2020, which was in accordance with Europe 2020 strategy. This resulted in an increase in carbon futures trading, where around 80% of all allowances were traded. Furthermore, during the same timeframe, a worldwide gas shortage occurred, which caused the gas prices to spike to about $147 per barrel. The record high price pushed carbon prices up as well [34].

NAPs posed another hot topic of discussion. Verified emissions published by the Member States showed that there was a deficit in EUA issued only in 2008. Consequent years showed an increasing surplus of allowances issued namely 2009 (8%), 2010 (7%), 2011 (9%), 2012 (14%) [35]. A total of 10.5 billion allowances were issued during the second phase and only 8.6 billion were used, resulting in a net bank of 1.8 billion or 17% in relative terms. In sharp contrast to over-allocation in the first phase, which was only 1.3% [36].

There were two principal reasons for such a large net bank. Emitters were able to use offset credits generated by Flexible Mechanism under the Protocol, resulting in an overall submission of 1.1 billion offsets [36][37]. In October 2008, the European Economic Area witnessed the first glimpses of the economic crisis, with a lack of market demand followed closely by a drastic decrease in industrial output. Several studies investigated this problem and tried to unravel, which elements played the key role in the overall emission abatement achieved during the trading period. Data evaluation revealed that the largest share of explanatory variables was caused by the economic recession, while about 10% could be explained by Europe's move to renewable energy [37][38].

The amount of auctioned allowances increased slightly to around 500 million, while a majority was sold as a futures contract since the EU ETS relies primarily on regulated energy sectors, which tend to be risk-averse and thus rely on long-term contracts [36].

As discussed above, Phase II suffered from many similar problems already present in the pilot phase, while trying to improve upon them, it was also faced with a fair share of new issues flawing the system. These included VAT frauds, hacker attacks aimed to cripple emissions registries, stealing of allowances directly from the depositories, and others. With all these negative aspects, EUA price managed to retain at least a portion of its initial price, which could be mostly accredited to the effects of banking [39].

A few key inferences could be drawn from the second phase. First, a central registry system would provide a greater security and transparency. Second, a replacement of problematic and over-complex NAPs and move to a centralized cap would allow central authorities to combat problems with over-allocation. Third, a standardized and controlled transfer of international credits into the registry would lead to fraud prevention. Fourth, more sectors should be required to submit allowances for emitting GHGs, since current setting causes unfair advantages for other sectors. Fifth, emission trading should be expanded to cover all GHG as declared by the Protocol. Sixth, to increase market efficiency and truly reduce emissions all emission allowances should be auctioned off. Last, central banking authority that would control the supply of fresh allowances should be established if the EU ETS is to succeed.

3.3. PHASE III

The Kyoto phase led to significant improvements compared to the Pilot phase. Nevertheless, it still suffered from many flawed aspects, which the Commission had set out to fix during the third phase of carbon trading. Directive 2009/29/EC established new rules for the 2013 to 2020 trading period in accordance with EU commitments to the Protocol. Mainly, the allocation process was moved from assigning allowances free of charge to auctioning as the key mechanism of the framework. The Directive put the electric utility companies at the forefront of no free allowances given, starting effectively in 2013. However, the Directive allowed for exceptions for free allocations in weaker economies, that were below 90% of the EU average GDP. Electric utility companies in these Member States would be given allowances free of charge based on national plans, which described retrofitting and upgrading electric utility infrastructure or new investments in clean energy sources. These optional transitional free allocations were designed to decline each year and inevitably end in 2020. Furthermore, district heating and high-efficiency cogeneration would get free allowances as well, with respect to the individual production of each installation. The amount assigned annually was set to decline by a linear factor each year [30].

Other sectors under the EU ETS, would get free allowances based on an EU-wide *benchmarking* process, which had been developed prior and was based on best available technology (BAT). With free allocations starting at 80% in 2013, gradually declining to 30% in 2020 and being completely phased out in 2027. Installations in sectors, that tend to be more prone to carbon leakage were provided with individual allocation plans even at full benchmark [36].

Problematic NAPs, which were based on historical emissions and calculated by *grandfathering* concept, were completely removed and replaced by a single EU-wide cap. This cap is based on the mid-point of the number of allowances issued between 2008 and 2012 and is set to decrease by a linear factor of 1.74% annually. The linear factor was set in accordance to satisfy the 2020 EU projections of the overall emission abatement by at least 20%.

The single EU-wide cap was established to fix both fundamental flaws of the individual NAPs, which led windfall profits and the lack of harmonization in the allocation process. Windfall profits gained via pass-through CO_2 costs and free allocation, this goes hand in hand with the individual Member State allocation process. Complete transition to auctioning as the main mechanism of acquiring new allowances would alleviate most of these problems [36].

The scope of the EU ETS was further extended by including new GHGs, Member States, and sectors. Installations must start reporting on N_2O and PFCs, based on their global warming potential, as defined by the Protocol. In 2013 Croatia joined the EU and as a Member State it was also required to join the EU ETS. Now accounting for a total of 31 countries. A decision from the EP in 2008 led to Directive 2008/101/EC about the inclusion of the aviation sector and its activities into the allowance emission scheme. Only flights to, from and within the European Economic Area would be affected by the legislature [40].

The primary reason for the inclusion of the EU aviation sector was that the sector is among the fastest growing across all polluting industries. In 2012, it contributed to the overall emission production of EU by nearly 3%. This number increased to 5% in 2016 and is set to keep increasing further up to 15% in the coming years [41]. Furthermore, kerosene as jet fuel is usually tax-exempt, unlike gasoline, which is used in private or commercial transportation [42].

European Union Aviation Allowances (EUAA) were specifically designed only for the aviation sector. This led to a second carbon market within the EU ETS, while trading between the two can only happen unidirectionally. Airline operators can use EUAs as well as EUAAs in compliance with their abatement caps. However, other sectors cannot use EUAAs as substitutes to EUAs. Allowances will be distributed to airline operators based on individual historical ton-kilometers flown at 97% of the benchmark. The allocation process is harmonized across the EU and at least 15% of allowances must be auctioned off [36][43].

The third trading phase allowed the use of international credits generated through CDM. However, the Commission restricted the use of international credits generated after 2012 only to projects in the least developed countries, as defined by the Protocol. This led to an exclusion of China, India, Brazil, and similar rapidly growing countries. Furthermore, projects with a high global warming potential would not be accepted by the Commission either. The Commission set an overall limit of 1.6 billion international carbon credits to be accepted into the EU ETS during 2008 to 2020 trading periods. The limit set by the Commission allowed banking of international credits and EUAs issued during Phase II, as both units could be transferred to Phase III [36][44].

3.3.1. BACKLOADING AND MARKET STABILITY RESERVE

The Commission introduced two new mechanisms to combat a substantial surplus of allowances that had built up in the system since the second phase. Backloading was introduced as a mechanism designed to alleviate short-term problems, whereas the more robust mechanism called the Market Stability Reserve (MSR) was intended to serve as a long-term solution.

As discussed in the previous subchapter, the substantial surplus of allowances was mainly accredited to two factors. The economic crisis followed closely by the economic recession, which led to a significant decrease in power consumption and thus the output of emissions. Mostly unrestricted access to the pool of international credits, at much lower prices, resulted in an abundance of offsets used within the framework. Both these factors certainly helped to achieve a total surplus of 2.1 billion allowances in 2013 [45].

The process of backloading postpones issuance of allowances to a further timepoint during the same phase. The number of auctioned allowances was decreased by 400 million in 2014, followed by 300 million in 2015, and ending with 200 million in 2016. These allowances were to be issued during 2019-2020 [46].

Even though the MSR was scheduled to start operating in the upcoming fourth phase, it was put forward to start operating in January 1, 2019 by the Commission. All backloaded allowances were placed into the reserve instead of being issued. Furthermore, allowances that were not allocated to installations were also moved to the reserve [47].

Several important changes were made to the functioning of the MSR by the Communication from the Commission published in May 2018. The MSR would be active from 2019 to 2023 at a temporarily doubled threshold (24%) and return to the planned regular threshold (12%) in 2024 and forth [48].

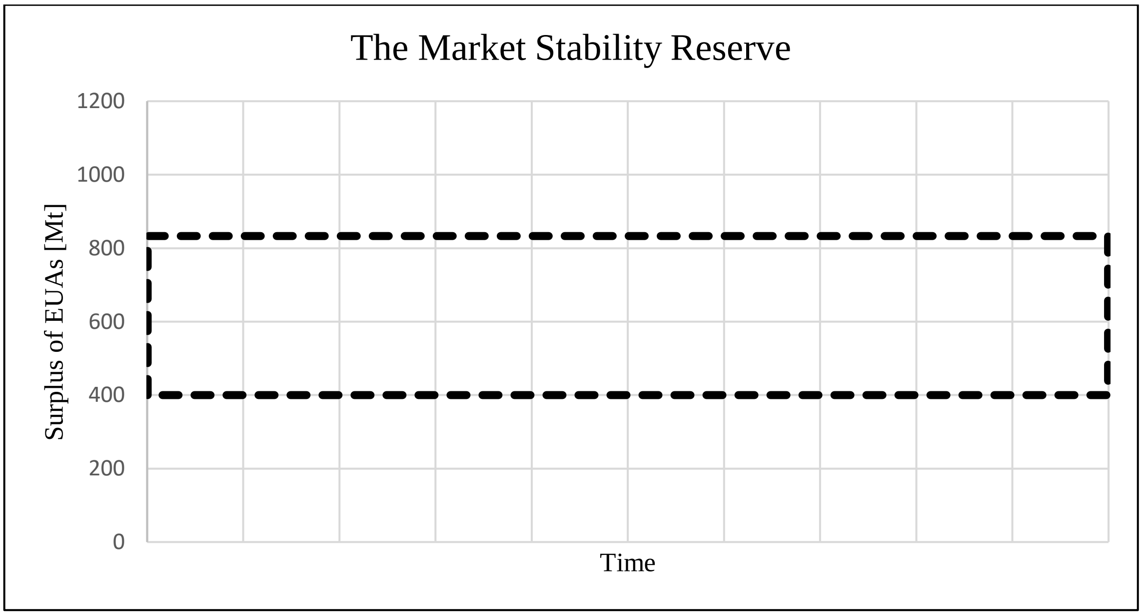

Figure 4. The Market Stability Reserve. (Source: [48])

The 2018 Communication defines the MSR as an automated function, which puts allowances in or out of the market based on a predefined range and a set threshold value. If the total surplus of allowances for a given year exceeds 833 million, the amount of auctioned allowances is decreased by 24% and the remainder is put in reserve. When the surplus of allowances drops below 400 million in circulation, 100 million allowances will be put on the market from the reserve in the future. If the surplus is within the optimal range of 400 to 833 million, the MSR is inactive, as shown in Figure 4 [48].

3.3.2. ANALYSIS OF PHASE III

Market speculations about emission trading in the third phase began already in late 2012, when first EUAs were auctioned off. However, this did not lead to an increase in price or volume traded. In the mid of 2013 the EUA price hit its rock bottom with prices as low as €2.95 per emission allowance. The rest of 2013 saw a very similar trend with prices oscillating around the €5 mark, while trading volumes remained mostly constant at 4 million per trading week.

Based on the data shown in Figure 5, the EUA price began slowly creeping up in the first quarter of 2014 and managed to almost graze the €7 mark. But again, during the spring and summer, which are known to be weaker months for emission allowance trading, since there is a less demand for power and especially commercial and district heating. Overall, the 2014 was not a very successful year for the EU ETS. Only 2.5 million allowances were traded per week and the price came back to roughly €7 per allowance.

The position for 2015 trading was looking better, with an increase in average trading volumes to around 3.2 million per week and the EUA price slowly but steadily increasing to around €8.5. This price did not last long either. An agreement within the UNFCCC in the name of the *Paris Agreement* (PA) was sealed on December 12, 2015. The EUA prices began falling and lost 40% of their value in just a few weeks and remained somewhat constant at around €5 per allowance.

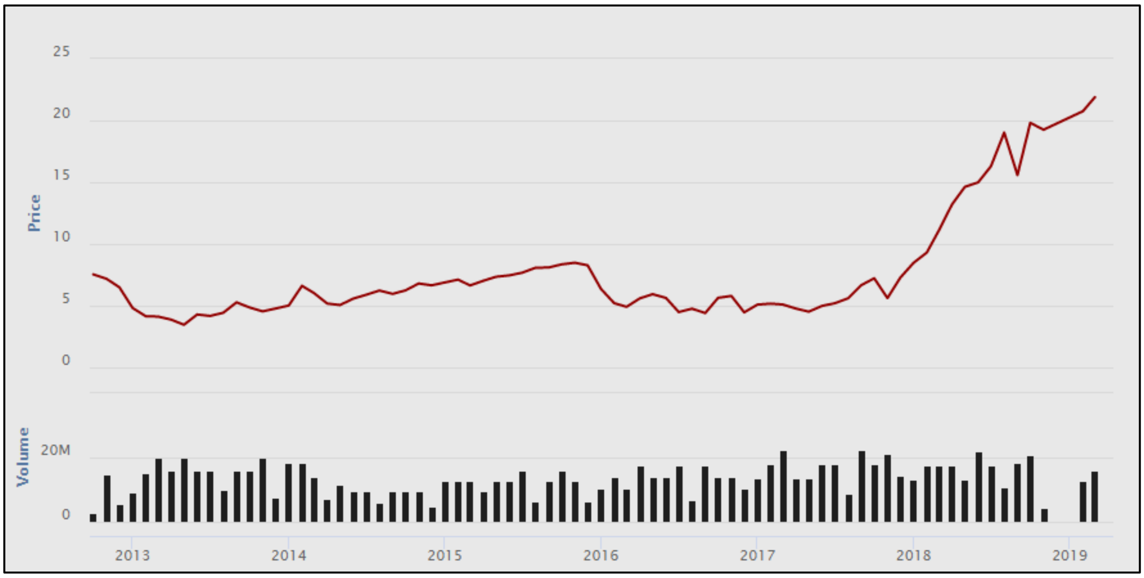

Figure 5. EUA spot price and market volume during Phase III. (Source: EEX)

The following year saw an increase in trading volumes to about 4.5 million per week and a steady increase to €7 per allowance. However, this growth in prices at €2/year could not be construed as a satisfactory result. In fact, the EUA price doubled back to its original price at the end of Phase II.

The 2018 saw the largest surge in emission prices since the third phase began. In just five months the EUA price doubled and in nine months tripled. When looking back at the historical high EUA prices, we can clearly see that most high prices in the past were caused by a sudden spike in price, which usually came after an important event such as the economic recession or the allowance surplus public disclosure.

But neither was the case in 2018, where price grew very steadily and quickly. The 2018 market closed at €19.3 and opened again in 2019 at €21.4, while at the time of writing this paragraph prices remained at around €22 per EUA.

3.3.3. PHASE III DISCUSSION

The EU ETS had been named by the Commission as a pivotal part of the EU emission abatement scheme and would get the necessary support to allow for an effective, harmonized, liquid, safe, and stable carbon market. This should further extend to the 2050 low carbon economy defined by the Commission [49].

The most important aspects, changes and novelties that led to the betterment of the EU ETS will be discussed here. In 2012, the first commitment phase of the Protocol had ended and thus the Commission could introduce a harmonized EU-wide allocation, which did not feature individual Member State goals, but instead it proposed only a single abatement goal. In order to alleviate issues that came from free allocation unfairness, Member State over-allocation caused by protectionism, carbon leakage and more, benchmarking was used as the process of allocation. Unlike in the previous phases, verified historical emission were very well known and thus the Commission applied BAT to calculate the benchmark. Free allocation was then given based on historical emission multiplied by the benchmark coefficient dependent on the type of installation in question [50].

In its current form benchmarking serves as one of the best methods of allocation, clearly offering better results than grandfathering, however it still has a few drawbacks that are mainly cause by its *ex ante* origin. Making implications about the future could potentially cause unexpected issues. Such in a case of output decrease, where free allowances will not reflect the correct amount. This can happen due to a recession or structural changes in the economy [51].

The PA replaced the Protocol and should serve as one of the drivers for low carbon economy in the near future. It is argued that long-term effects of the PA should be positive and should lead to new approaches to combat climate change. The PA itself does not explicitly mention carbon markets directly, however several implications can be made for its signatories. One such is global voluntary cooperation in GHG reductions. The key word here is voluntary, which is the exact opposite of the Protocol, which was mandatory to the signatories. The PA could potentially lessen carbon leakage in industries such as in manufacture of steel, pig iron and similar heave industries, because it had been signed and ratified by China, the world's major steel and iron manufacturer, which introduced its own emission trading scheme in 2018 [52].

The effects of backloading are somewhat speculative, when we look at the data presented in Figure 5 we cannot observe any dramatic changes in market volumes or prices, this however does not mean that the EUA price could not have dropped lower if backloading hadn't taken place.

A few inferences can be made about the MSR based on historical EUA prices. The price remained somewhat constant and low when the MSR was planned to be introduced in early 2021. Nonetheless, the Commission reacted to the low price by changing the MSR adoption scheme. The operation began in early 2019. When the proposal was accepted EUA prices climbed sharply and hit the Phase III all-time high just before the introduction of the MSR.

Several papers tried to model and predict EUA prices based on coal, natural gas and Brent prices. The regression analysis used in modeling found a correlation between the dependent and independent variables. Nevertheless, this is had only been the case in 2013-2017 time period. While the 2018 surge in EUA price cannot be explained by the models at all [53]. And thus, one could argue whether it was the MSR that caused it or not.

3.4. FUTURE OF THE EU ETS

Many very solid changes were made to the trading system during the current trading period, especially with the inclusion of the MSR. However, the EU ETS is picking up the pace and the fourth phase is set to start in 2021 and is scheduled to last until 2030. Phase IV itself will see drastic changes compared to the previous years, mainly due to the fact that the staple of the EU ETS, which is the cap-and-trade scheme will shift towards a far more dynamic scheme as opposed to a static capped environment as it had been used in the previous phases. Directive 2018/410/EC amending previous directives to enhance cost-effective emission reductions and low-carbon investments entered into force in April 2018. This Directive contains several important and many incremental changes to the current system and operational programs under the EU ETS [54].

The most important changes were designed for the MSR. Since its inception, the MSR proved to be a cost-effective and quick solution to some of the short-term but also medium-term complications that crippled Phase I and Phase II, but it could not fully compensate for the damage caused by the over-allocation and the economic recession. The Directive allots several new functions to the MSR and banking of allowances and binds them together. The dynamic nature of the new scheme is shown largely in two ways.

The first dynamic factor comes from the new functioning of the MSR, while the linear reduction factor is increased from 1.74% to 2.2%, the dynamics are achieved through a different functioning of the MSR. Opening in 2023, the MSR will exclusively hold only a limited number of allowances, which will be based on the number of allowances auctioned in the previous year and the amount of already banked allowances. All allowances that will be above this sliding limit will be inevitably canceled.

Moving forwards the MSR will only be able to hold about 57% of the annual cap. This fact fundamentally changes how the MSR will affect long-term targets, because current approximations suggest, that as a result, up to 1.7 billion banked and unused allowances could get potentially canceled in 2023 [55]. The following scenarios illustrate the effects of the new functioning of the MSR and can be observed in Figure 6.

In scenario **a**, the bank holds more allowances than the upper threshold, while the MSR is functioning within the normal operational range. This situation will lead to 24% (12% starting in 2024) of all allowances in circulation to be placed into the reserve [56].

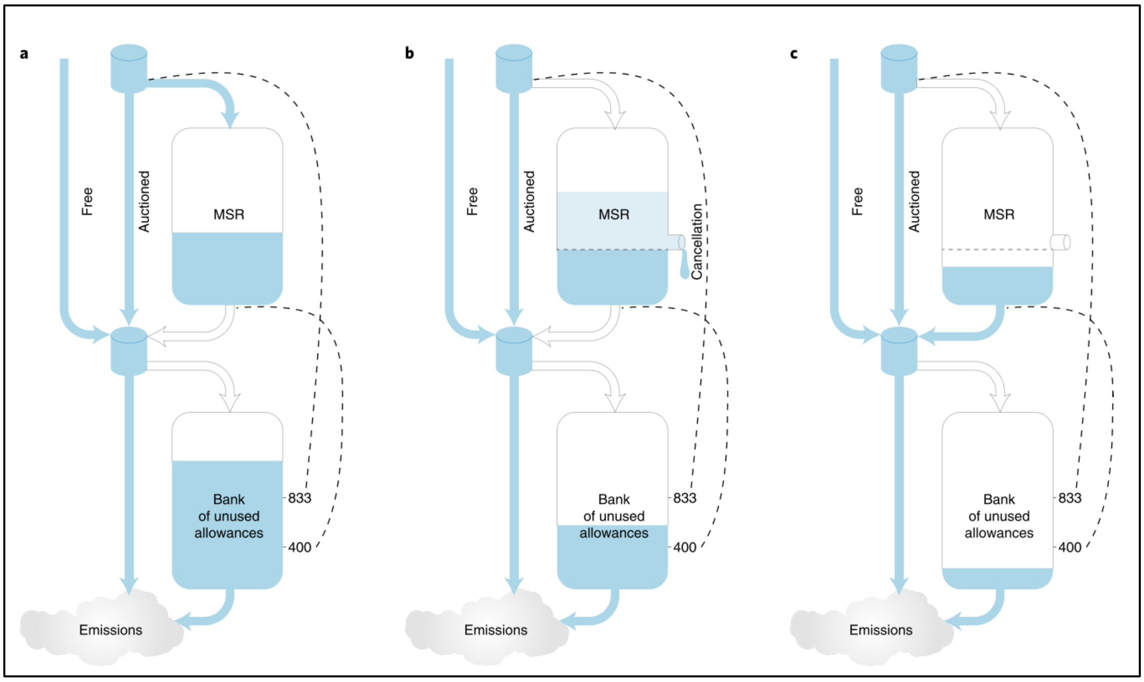

Figure 6. New functioning of the MSR. (Source: [55])

In scenario **b**, the bank holds an optimal amount of allowances but the MSR is operating above the upper limit. This case will lead to a certain cancelation of the surplus number of allowances, depicted by a lightly shaded area in Figure 6.

In scenario **c**, the bank holds less than the lower threshold, while the MSR has allowances put on reserves. This instance will trigger the MSR to release 100 million allowances into the market for auction.

The second dynamic factor is aimed primarily at carbon leakage and free allocation. Flexible rules were put into place that will adjust the number of free allowances given based on the actual production and not on the adjusted historical emissions. Benchmarks values will also see an adjustment, which will happen twice in the fourth phase based on the current BAT [56].

If any installation covered by the EU ETS will limit its production or completely cease its operations, it will be only given a proportion of allowance based on the actual output. This step should reduce the amount of windfall profits companies and businesses could gain from lowering their output.

The fourth phase will continue to feature free allowance allocation at up to 100% in sectors with a high risk of carbon leakage. The Directive states that the free allocation for medium risk sectors should be ultimately phased out in 2026, followed by high risk sectors in 2030. The reserve fund also holds free allowances geared towards new entrants and growing installations. The amount comprises all free allowances that will not get allocated by the end of 2020 plus a lump sum of 200 million from the MSR [56].

Lastly, to support the shift to a low-carbon economy, the *Innovation Fund* was founded. It will support cutting-edge and breaking technology in climate change prevention, carbon emission reduction and other projects that benefit the environment. The total funding should correspond to the market price of at least 450 million emission allowances. The *Modernization Fund* will continue to support retrofitting and upgrading installations in order to achieve lower carbon emissions or higher efficiency in 10 lower-income Member States. Along with Article 10c, which will continue to provide optional transitional free allowances in the lower-income Member States [56].

3.5. SUMMARY OF THE EU ETS

To this date, the EU ETS has been continuously operating for 14 years and much has changed since its inception in 2005. The first phase ran for three years as a pilot phase. It succeeded in proving that a functioning and cost-efficient carbon market can be established in such a diverse environment, which features differing economies, policies, public views, and approaches to climate change, alas it did not have any tangible impact on carbon emission abatement at all.

The second phase ran in allegiance to the Protocol for five years straight. Based on the ex-post evaluation, the second phase was a remarkable failure that managed to only survive thanks to the Commission's commitment to the environment. Studies showed, that no significant reduction in carbon emissions could be attributed to the EU ETS, rather almost all emission reductions were mostly achieved by the economic recession. Furthermore, the allocation processed based on individual NAPs was completely flawed and led to the over-allocation we are dealing with to this date.

Not only that, but many installations were given such vast amounts of emission allowances free of charge, which inherently led to significant windfall profits and no deliberate carbon emission abatement as a result.

Finally, Phase III came along with a major overhaul of the trading scheme. It changed the Member State based free emission allowance allocation to EU-wide instead. This total cap was set to decline by a linear factor and a much larger proportion of total allowances were auctioned off.

Additionally, free allocations were given based on benchmarking rather than grandfathering concept, which resembled the real-world emissions far more accurately. This could be attributed as a success to Phase II after all, which managed to gather the necessary verified emissions data for benchmarks to be created.

The third phase was designed to run for eight years in total, but the last quarter saw an introduction of a new game-changing mechanism called the MSR, which is described in much more detail in the previous subchapters. Nonetheless, the MSR accomplished to cut into the over-allocation and slowly started fixing the issues that are currently crippling the proper functioning of the EU ETS. Overall, the current phase saw a few much-needed changes that could potentially strengthen the system and prove its worth in the long-term emission reduction.

The Commission has very high hopes for the upcoming fourth phase. For the first time ever, all stakeholders including the public were able to provide feedback on the revision to the EU ETS, which is now set to operate for ten years [57]. While trying to solve the long-term problems bugging the scheme, the MSR will be given new functionalities to alleviate most of the problems with over-allocation. Other flexible functions were introduced so that the scheme can dynamically react to new BAT and changes in the economy.

In conclusion, the EU ETS struggled since its beginnings but also during each past and also the present phase; however, it managed to survive and succeed in establishing itself as the largest cap-and-trade and also carbon market in the whole world. Many mistakes were made along the way, but the new reforms made in Phase III bolstered the crippled system and made it into a fairly working market. The changes put forth by the new Directive are even more drastic than what was done in Phase III but judging from the current market price and looking at the problem from an ex-ante perspective, the changes should lead to a properly functioning carbon market but again only time will tell.

3.6. EU ETS IN THE CZECH REPUBLIC

Prior to gaining independence in 1989, the Czech Republic had virtually no environmental legislation covering air and water protection. It was also a highly industrialized country with a very high carbon intensity per capita, which was supported by a lack of high-quality fuels such as oil or natural gas. The Czech Republic was and still is highly dependent on domestic sources of lignite, which is used in most combustion plants producing power, heat or other secondary products. Higher-quality hard coal is mined in smaller quantities and is mostly used for coke or steel production.

After the fall of the USSR, the Czech Republic was highly influenced by its western neighbor countries and had to transition to a market-based economy in a very short amount of time. This led to increased demand in the tertiary sector compared to a significant output reduction in primary and secondary sectors of the national economy.

Furthermore, the Czech Republic signed the UNFCCC in 1998 and the Protocol in 2001. Another crucial step in improving upon the environmental policies was entering the EU in May 2004 and the further development and harmonization of the environmental legislature with respect to a single market strategy [58].

The Czech Republic is not part of the original EU15 and as such, it was not a part of the BSA; therefore, the only apparent emission abatement targets arose from the Protocol. However, these targets were already met by most new entrants to the EU because of their transition to a market-based economy. The Protocol goal for the Czech Republic was an 8% reduction in CO_2 emissions by 2012 compared to 1990 levels. While the actual emission abatement was about 17% in 2007 given by economic recession and market transition alone. The absence of effective measures to ensure further emission reduction goals within the EU forced the Commission to implement a system of NAPs.

Implementing the EU ETS in the Czech Republic proved to be a serious challenge for the Ministry of the Environment (MZP) since guidelines for NAPs were not very specific and allowed for different approaches to be taken. The MZP had a very limited amount of historical data to work with, therefore it chose a baseline period of 1999-2001 for which all selected major emission producers were required to submit an independent report of CO_2 emission in the set time period [59].

The emission data collected by the MZP was then adjusted for expected sectoral growths, which proved to be the main variable of the NAP. A total net adjustment of 4.5% of allowances was made for CHP installations. The NAP draft was further adjusted for country-specific issues such as district heating, individual corrections, and new entrants reserve. The NAP draft was officially proposed in October 2004 and it requested an annual allocation of 107.9 million emission allowances. The Commission evaluated the proposed NAP draft and allowed a much lower amount of 90.2 million. In April 2005 a revised NAP was fully adopted by the Commission as it featured arguments for the increased allocation requested. Mainly an increase in electricity export, an increase in industrial production along with GDP growth rate projections [59].

The Phase I NAP yielded a total amount of 323.0 million emission allowances (107.7 million annually) and covered 65% of total GHG emissions in the Czech Republic [60]. The Phase II NAP granted a total amount of 509.5 million emission allowances (101.9 million annually) and covered roughly 69% of all GHG. In contrasts to the first NAP, banking was allowed and producers could use international credits up to 10% of the total trading period allowance [61].

The changes made to the EU ETS by Phase III were significant and so was the impact on the Czech Republic. As discussed in the subchapter 3.3. NAPs were abandoned for a single EU-wide cap. Benchmarking replaced grandfathering concept as the only method of allocation. The Commission’s decision was to move to a full auctioning system with zero emission allowances given away free of charge. However, Article 10c of the Directive entitles countries that are below 90% of the average EU GDP i.e. the Czech Republic to exceptions.

In the case of the Czech Republic, electrical utility companies could request free emission allowances based on the Directive and §12 of 383/2012 Sb law. Each case would be treated individually on a case by case basis and must be approved by the national government and the Commission. The monetary amount of emission allowances received free of charge must be used for retrofitting and upgrading electric utility infrastructure or new investments in clean energy sources. Starting in 2013 only 70% of eligible and requested allowances would be given out. This amount is set to decline annually by 10% and finally ending in 2020 [30][62].

According to *Trends and projections in the EU ETS in 2018*, the free emission allowances were mostly distributed to lignite and hard coal installations and thus not contributing the diversification of the overall energy mix [63].

Moreover, district heating and high-efficiency cogeneration companies are eligible for free emission allowances through individual requests. This incentive is also available for installations and sectors prone to carbon leakage. According to the Directive, all incentives and free emission allowances will be discontinued by 2027 [30].

4 METHODS USED IN MACROECONOMIC IMPACT ANALYSIS

The primary focus of this chapter is the right selection of an econometric method used in predicting and evaluating shock impacts based on sudden price change. The most commonly used econometric methods will be further explored and assessed based on several important criteria, which include clarity, complexity, data requirements, and valuation scope.

Even though all econometric methods explored by this thesis are being used for energy impact analysis, not all of them are created equal, and therefore cannot be used in the same manner. Methods differ mostly on the set criteria mentioned above, but they also tend to support a different approach when it comes to the valuation scope. For the purpose of this thesis, methods will be described by two additional aspects. First is the resolution of the process, which measures whether the method can only assess national economy as a whole or if it can also further evaluate sectoral impacts within the national economy. With the second aspect being the duration of the process, which depicts whether the method can be used for short-term or long-term assessment.

4.1. AGGREGATE DEMAND AND SUPPLY METHOD

The first models used in exogenous energy impact evaluation on the national economy used the Keynesian functions of aggregate demand and aggregate supply. Where the aggregate demand curve acts as the demand of the entire national economy and comprises household, corporate and governmental expenditures. While the aggregate supply curve portrays the supply side of the economy.

Each aggregate curve is defined by its slope, which is determined by the relationship to price. An increase in price leads to a decrease in aggregate demand because the market entities are willing to purchase lesser quantities at a higher price, therefore making the relationship negative. While the opposite is true for the aggregate supply, therefore price increase leads to more supply entering the market, which translates to an increase in the overall supply, making the relationship positive [64][65].

An impact on the national economy caused by an exogenous shock would lead to a change in the price equilibrium, which is where aggregate curves intersect, while the impact itself affects movement along the curves, it also results in a shift of the curves. This effect is most noticeable in small economies that are price-takers and therefore have a very limited or no power to influence the price.

The method itself is based on an evaluation of long series of historical data, which are then evaluated by using regression methods, which must account for changes induced to aggregate demand by the aggregate supply and vice versa. These induced changes reflect the simultaneous behavior observed in both curves. Furthermore, these methods cannot be used to assess sectoral changes within the economy, because of the inherit aggregate character. Lastly, these methods use a static approach to historical data evaluation, which could lead to inaccurate or inconsistent data, because the national economy reacts to changes in a dynamic fashion [66].

4.2. VECTOR AUTOREGRESSION METHOD

Vector autoregression method was developed as an extension to the univariate autoregressive model since it allows for two or more evolving variables. The method is primarily used to test causalities between variables, which are often in a form of non-stationary time series data. Furthermore, in vector autoregression method each variable is considered random and also simultaneously dependent. Each endogenous variable is then explained by a linear function, which consists of level constant, error term and all lagged values of every endogenous variable while leaving all exogenous variables out of the equation [66][67].

Vector autoregression is regularly used in estimating impacts of fiscal or monetary policies on national economies, and combined effects on macroeconomic indicators. This method features several improvements compared to the aggregate demand and supply method because it does not require simultaneous equations, which are based on hard to verify empirical assumptions. However, it has its drawbacks, mainly due to the lack of economic theory and its models, which could lead to misinterpretation of results or an inability to verify results based on the selected economical model. Vector autoregression demands a large number of historical data, which could lead to inconsistencies within developing economies [66][68].

4.3. INPUT-OUTPUT METHOD

Symmetrical Input-Output (I-O) method provides a different approach to quantitative economic modeling, focusing primarily on interdependencies between national economies or industrial sectors. In the I-O method, an output of one industrial sector may serve as an input of another sector and vice versa. This approach allows for assessing shock impacts on the national economy while allowing for a deeper understanding through intra-industry analysis since all industries affect each other because they react to changes in input and output of all other industries. The static nature of the results provided by the I-O method reveals both positives and negatives of the method, while it can be used for a detailed national and intra-industry analysis within a given year, it cannot be used to provide a long-term assessment, like the previously mentioned methods [66][69].

Varying types of I-O analysis are used in present studies. The most commonly used is a single-region I-O analysis because it requires a very low amount of historical data compared to other methods and is generally more flexible than a multi-region I-O analysis [70]. Due to its simplicity and data availability, the I-O method finds its use in many recent economic studies. Several varying studies used the I-O method to assess national and sectoral economic effects of auctioning emission allowance, carbon emissions embodied in trade, and carbon footprint [71][72].

4.4. DSGE METHODS

Dynamic Stochastic General Equilibrium (DSGE) refers to a whole host of modern econometric quantitative methods used in assessing economic growth, relationship changes in macroeconomic indicators, and real business cycles. The DSGE model provides rarely a straight answer. Instead, it relies on a combination of novel algorithms and powerful simulation techniques, which had only become available in the recent years since the modeling requires vast amounts of computational power [73].

As the name suggests the method is applied to a general economy while finding an equilibrium point in each cycle with respect to processes within the cycle, which are not static or predetermined. The DSGE are commonly used by central banks to estimate changes in macroeconomic indicators such as GDP, unemployment rate, inflation or deflation rate, output and income of the economy.

The main advantage of the DSGE models is that they allow for far more complex analysis of shock impacts on the economy since multiple scenarios of economic development can be used to assess the problem. Secondly, they can distinguish between competing forces in the economy through countless simulations, which cannot be done with models that are based solely on historical data [74]. However, the DSGE model needs to be calibrated by an array of historical data in order to work correctly, this factor could inherently be problematic in developing economies, where such data is not available. The second issue lies with the use of equilibrium point itself, where the models work with the assumption that equilibrium point is achieved in each modeled economic cycle. The DSGE models were therefore designed to provide a long-term assessment, rather than a short-term, like in a case of a price shock [66].

4.5. METHOD EVALUATION AND SELECTION

Selecting the right method for an econometric impact analysis is crucial, therefore I have defined several criteria mentioned and discussed above to choose the right method for assessing issues proposed by this thesis. As there are many variations of advanced dynamic modeling methods, I was only able to cover the general Real Business Cycle method, which is often used in energy-related impact modeling on national economies.

Table 1. Comparison between econometric methods and their use for assessing shock impact on national economies and sectoral effects. (Source: Author)

Method	Clarity	Complexity	Data Req.	Resolution	Duration
AD/AS	High	Moderate	High	National	Long-term
VAR	Moderate	High	High	Sectoral	Both
I-O	High	Moderate	Moderate	Sectoral	Short-term
DSGE	Moderate	High	High	Sectoral	Long-term

In order to clearly distinguish between the strengths and weaknesses of each discussed econometric impact assessment method, I have rated each method on the foundation of five criteria set at the beginning of this chapter. Each rated econometric method and its score is displayed in Table 1.

The first criterion is clarity, which describes how transparent the method. The general rule of thumb implies that the more complex the method gets, the less clear it becomes and vice versa. Clarity criterion goes hand in hand with complexity, where each method balances between higher clarity or higher complexity, while inevitably sacrificing part of the other.

Data requirements criterion explains how much historical data is necessary for each method to work correctly. In general, lower data requirements are better. The last two criteria describe the valuation scope of each method, with more detailed resolution and more versatile duration being the better options.

For the purpose of this thesis, I will assume that in the case of the Czech Republic, which is a relatively new and transitioning economy, there is a lack of comprehensive historical data, which narrows down the method selection quite significantly. Furthermore, since I want to assess the impact of a shock change in emission allowance prices, the set method must provide a short-term valuation scope and allow for sectoral analysis.

Under these conditions, the I-O method shows to be better suited for issues proposed by this thesis, with the VAR method coming in second.

4.6. INPUT-OUTPUT METHODOLOGY

The previous subchapters provided a basic overview and evaluation of the I-O method. This subchapter serves as a way to introduce the I-O methodology and terminology based on the *Methods of Interregional and Regional Analysis* [69] and *Auctioning CO_2 Permits in the Czech Republic* [71]. For a more detailed introduction please see those publications.

4.6.1. DEFINITIONS

Symmetrical I-O tables are used to describe relationships between individual industry sectors and the overall condition of a national economy. Each sector is represented twice in the I-O table, once as a supply side in a form of rows and once in columns for the demand side. It is important to note, that sectors must produce or provide a homogenous product or service, which must be unique to the given sector based on a standardized sector definition like NACE v2 classification or similar. Any given national economy can have n number of sectors.

A typical symmetrical I-O table is often defined by three separate matrices, an interindustry demand matrix **Z**, a primary input matrix **Y**, and a final demand matrix **F**. If a given economy has n number of sectors, then **Z** will have $n \times n$ dimensions. Let us define each element of **Z** as z_{ij}, which shows a monetary value of sales from sector i to sector j over a given time period. These elements express the intermediate demand for products or services in the national economy, while elements of the **F** matrix f_i explain the total value of sales from sector i to the final consumers (aggregated number for households, corporate investments, governmental purchases, and exports).

The previous two matrices explain the flow between the industry sectors and final consumers, while the last matrix **Y** shows value-added components and imports.

The primary input matrix **Y** defines value-added sectors including labor, land, and capital, and others such as taxes, profits, and imports. The following relationships can be defined for the **Y** matrix:

The total payment for labor in the entire economy L is equal to a sum of l_j, which is a payment for labor employment in sector j.

$$L = l_1 + l_2 + \ldots + l_n \tag{1}$$

The total other value-added payment in the entire economy OV is equal to a sum of ov_j, which is a payment for other value-added items in sector j to the other sectors.

$$OV = ov_1 + ov_2 + \ldots + ov_n \tag{2}$$

The total import of the national economy M is equal to a sum of m_j, which is a payment for imports in sector j.

$$M = m_1 + m_2 + \ldots + m_n \tag{3}$$

Same assumptions can be made about the final demand matrix **F**, which explains the final demand for products or services by households, corporate investments, governmental purchases, and exports. The following relationships can be defined for the **F** matrix:

The total household expenditure C is equal to a sum of c_i, which is household expenditures for product i.

$$C = c_1 + c_2 + \ldots + c_n \tag{4}$$

The total corporate investment I is equal to a sum of i_i, which is corporate investments in the sector i.

$$I = i_1 + i_2 + \ldots + i_n \tag{5}$$

The total governmental purchase G is equal to a sum of g_i, which is governmental purchases of products in sector i.

$$G = g_1 + g_2 + \ldots + g_n \tag{6}$$

The total export E is equal to a sum of e_i, which is exports of products of sector i.

$$E = e_1 + e_2 + \ldots + e_n \tag{7}$$

Let us further define a total production matrix **X**, with elements x_i being the total monetary value of products or services produced or provided by sector i in the given time period (the gross output of this sector). The total production in sector i can be described as a sum of all interindustry sales and final demand for the set product. For each sector $i = 1, \dots, n$ we get

$$x_i = z_{i1} + z_{i2} + \dots + z_{in} + c_i + i_i + g_i + e_i \tag{8}$$

Identically the total production in sector j can be assessed as a sum of all interindustry sales and primary inputs to that sector. For each sector $j = 1, \dots, n$ we get

$$x_j = z_{1j} + z_{2j} + \dots + z_{nj} + l_j + ov_j + m_j \tag{9}$$

Equations (8) and (9) show the nature of symmetrical double accounting in I-O methodology. This can be further observed in the Table 2.

Table 2. Typical Input-Output table. (Source: [71])

	Interindustry Demand (Z)	Final Demand Expenditures (f)	Total (x)
Sectors	$\begin{matrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{n1} & \cdots & z_{nn} \end{matrix}$	$\begin{matrix} c_1 & i_1 & g_1 & e_1 \\ \vdots & \vdots & \vdots & \vdots \\ c_n & i_n & g_n & e_n \end{matrix}$	$\begin{matrix} x_1 \\ \vdots \\ x_n \end{matrix}$
Value-added Components Imports (Y)	l_1 ... l_n ov_1 ... ov_n m_1 ... m_n	*Transactions between the payment sectors (inc. import) and final demand*	*L* *OV* *M*
Total (x)	x_1 ... x_n	*C I G E*	

Both summarized equation (8) and (9) describe the total volume of the economic activity and therefore both equations should be equal to each other and thus provide the same overall effect

$$\sum_{i=1}^{n} x_i + C + I + G + E = \sum_{j=1}^{n} x_j + L + OV + M \tag{10}$$

Under normal circumstances the total interindustry sales must be equal to the interindustry purchases, while imports and exports are accounted for, then we can put

$$\sum_{i=1}^{n} x_i = \sum_{j=1}^{n} x_j \tag{11}$$

At that point we can further simplify equation (10) by introducing equation (11) and subtracting the total imports M, then we get

$$C + I + G + (E - M) = L + OV \tag{12}$$

The left-hand side of the equation comprises the totals of household expenditures, corporate investments, governmental purchases, and balance between exports and imports, which in itself is the definition of GDP and this is equal to the total value-added in the entire economy as described by equation (12).

4.6.2. DIRECT COEFFICIENTS

By aggregating elements of the final demand matrix **F** into a vector **f**, we get the following relationship for the elements

$$f_i = c_i + i_i + g_i + e_i \tag{13}$$

and subsequently we simplify equation (8) to

$$x_i = z_{i1} + z_{i2} + \ldots + z_{in} + f_i \tag{14}$$

The direct coefficient matrix (also sometimes referred to as technical coefficient or direct requirement coefficient) is calculated by normalizing matrix **Z** by the total resource. The process is defined as $a_{ij} = z_{ij} / x_j$ and they indicate the input value of sector i on one unit of output of sector j. The following direct coefficients can be arranged using a matrix.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{15}$$

The sum of individual elements in each column represents the total amount the sector j has spent per one monetary unit of its production. We will assume that the technical coefficients remain constant in the given time period, and production of each sector j is known, therefore x_j is known, then we can use the direct coefficient matrix **A** to compute the required inputs of all sectors $i = 1, \ldots, n$ required to produce x_j. This can be done for every sector j. If we substitute $z_{ij} = a_{ij}x_j$ in the equation (14), then for each sector $i = 1, \ldots, n$ the total production of this sector can be calculated using the known intermediate and final demand.

$$x_i = a_{i1}x_1 + a_{i2}x_2 + \ldots + a_{in}x_n + f_i \tag{16}$$

4.6.3. MATRIX ALGEBRA

Since the I-O method operates with arrays of numbers, we can simplify our equations through the use of matrix algebra. Both the total production matrix **X** and the final demand matrix **F** can be written as n-dimensional column vectors **x** and **f** respectively. In addition, we define an identity vector **i** and an identity matrix **I** with $n \times n$ dimension.

$$x = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}, f = \begin{bmatrix} f_1 \\ \vdots \\ f_n \end{bmatrix}, i = \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix}, I = \begin{bmatrix} 1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{bmatrix}$$

Since we already have the direct consumption matrix **A**, we also need to compute the necessary total consumption matrix **B**. In matrix algebra we can write the following equations:

$$x = Ax + f \tag{17}$$

And then by rearranging equation (16) we get

$$(I - A)x = f \tag{18}$$

Equation (18) shows the relationship between production and final demand.

$$x = (I - A)^{-1} f \tag{19}$$

We can further define matrix **B** = (**I**-**A**)$^{-1}$ also known as Leontief Inverse matrix or total consumption matrix.[75]

4.6.4. IMPACT OF AN EXOGENOUS SHOCK

To assess the impact on the final demand caused by an exogenous shock we must first estimate or calculate the size of the exogenous shock but also its sectoral effects. The exogenous shock will lead to a shift in final demand f^* and we need to find the total production vector x^*, which explains the new final demand with respect to the shock. For the shock we can identically with equation (19) write the following

$$x^* = (I - A)^{-1} f^* = Bf^* \tag{20}$$

According to the standard algebraic rules if a such that $0 \leq a \leq 1$ holds that

$$(1 - a)^{-1} = 1 + a + a^2 + a^3 + \ldots + a^k \tag{21}$$

and the approximation gets more accurate with larger k. Similar results can be obtained for square matrices where all elements are non-negative and smaller than one. Finally, the sum of elements in each column must be smaller than one. In our case, matrix **A** meets these conditions and therefore

$$(I - A)^{-1} = I + A + A^2 + A^3 + \ldots + A^k \tag{22}$$

and similarly

$$x^* = f^* + Af^* + A^2 f^* + A^3 f^* + \ldots + A^k f^* \tag{23}$$

The first factor on the right-hand side of equation (23) is the new final demand. This new final demand captures the initial demand of each sector of the entire economy. Production in each sector must be at least equal to f^* because no interactions between sectors exist, therefore all elements of matrix **A** are equal to zero. The second element explains the direct effect of the change, while a sum of all the remaining factors shows the indirect effect. Equation (20) can also be written in differences:

$$\Delta x = (I - A)^{-1}\Delta f = B\Delta f \tag{24}$$

Equation (24) explains the relationship between the change in production and the change in total demand. This equation will be further used in the calculations.

4.6.5. I-O MULTIPLIERS

Multipliers are used to assess the overall impact of the I-O method on general production, employment, income, and more. Basic multipliers can be calculated as a ratio between the total change and the initial change. Sum of all changes Δx explains the total change in turnover of the entire economy. These multipliers are also known as type I multipliers, which could also be defined as a sum of direct and indirect changes divided by the total direct change. Similarly, type II multipliers can be calculated by adding induced change to type I multipliers [76].

The output multipliers for each industry sector can be calculated by adding individual column elements together. It is important to calculate not only the total output change but also change in the intermediate demand due to the change in a specific sector. This difference can be assessed as the output multiplier for a given sector multiplied by change Δf_j^*, which is induced by a change in final demand f_j^* caused by the exogenous shock.

$$MO_j = \sum_{i=1}^{n} b_{ij} \tag{25}$$

where b_{ij} are elements of the total consumption matrix **B**.

When output changes across the sectors in the economy, and the technology remains constant, we can calculate the employment multiplier, which utilizes a unit of labor instead of a monetary unit. We can define the labor intensity of a sector i as e_i. The employment multiplier explains the change in employment in sector j based on a monetary change in the same sector.

$$ME_j = \sum_{i=1}^{n} e_i b_{ij} \tag{26}$$

The employment vector is not a standard part of the I-O table, and therefore must be acquired through other means. One way of calculating the employment vector is by using gross output generated by sector *j* divided by gross average wage in that sector. Other methods utilize similar data to find the employment vector, such as average number of employees in sector *j* divided by the gross output. Basically, this multiplier shows how many new jobs will be created when the demand in that sector increases by one monetary unit [77].

4.6.6. I-O MODELING ASSUMPTIONS

The I-O methodology operates with static inputs; such as these: interindustry demand matrix **Z**, primary input matrix **Y**, and final demand matrix **F**. However, these matrices, and their respected elements are not static in time. The following assumptions must be made when the I-O modeling is correctly used.

First, I-O models are demand based and therefore supply must be always able to match the new demand. Furthermore, there are no limits to output capacities in the industries.

Second, the input structure for producing each homogenous and unique product is fixed, and the same must be true for value-added components.

Third, the structure of the national economy remains constant and no new products or sectors are created.

Lastly, as seen above all these assumptions rely heavily on the fact that the I-O modeling is linear and static within the examined time period. In reality, this is not the case as both the supply and demand side would naturally adapt to the new environment, thus lessening the impact of the induced change. However, the I-O modeling can still be used to assess shock changes or short time changes within the national economy if all three assumptions are respected. Since the method operates with a fixed structure of inputs and outputs, the results serve as the maximal impact scenario [78].

5 I-O MODEL IMPACT ANALYSIS

5.1. SECTORS OF THE NATIONAL ECONOMY

For the purpose of this thesis, I will assume the Czech Republic to be a small market-based economy and inherently a price-taker, therefore incapable of influencing the emission allowance market price.

As mentioned in the previous chapter, the I-O method is based on intra-industry sales as inputs to other industries. This methodology is often used by the Czech Statistical Office (CZSO) in impact assessment studies. The CZSO calculates and publishes symmetrical I-O tables every five years. The last available data are from 2015 [79].

Statistical categories are used to classify and distinguish between effects and processes in the national economy. The purpose of categorization is to divide statistically observed data into homogenous classes that can be further used in econometric assessments. It is pivotal for the categories to be mutually exclusive as each statistical unit can only be assigned to one category [80].

Each Member State is required to use NACE for standard classification of economic activities under the EU. A unified system provides means to compare statistical data between countries and industries. According to the methodology, each statistical unit involved in an economic activity is assigned a NACE code. Economic activity is defined as a process of product manufacturing or providing services by using labor, manufacturing processes, or intermediate products as a means of achieving this economic activity. The economic activities are defined by inputs, manufacturing processes, and outputs in terms of products or services. In NACE, activities are defined either by one or more manufacturing processes. If a statistical unit is manufactured by several linked processes, then all the processes are considered as a single economic activity. NACE does not categorize statistical units, because each unit can be involved in more than one economic activity. Furthermore, NACE does not differentiate between privately or governmentally owned statistical units [80].

The NACE methodology includes up to four levels of categories in each economic activity. The first level is denoted by an alphabetical character and can be observed in Table 2. The alphabetical characters form main groups with similar economic outputs.

Such as category A, which combines agriculture, forestry and fishing or specific groups dealing with manufacturing, electricity, gas, steam and air-conditioning or water supply and sewage treatment facilities.

Table 3. NACE v2 categories. (Source: [81])

Code, Sector	
A	Agriculture, forestry and fishing
B	Mining and quarrying
C	Manufacturing
D	Electricity, gas, steam and air conditioning supply
E	Water supply; sewerage; waste management and remediation activities
F	Construction
G	Wholesale and retail trade; repair of motor vehicles and motorcycles
H	Transporting and storage
I	Accommodation and food service activities
J	Information and communication
K	Financial and insurance activities
L	Real estate activities
M	Professional, scientific and technical activities
N	Administrative and support service activities
O	Public administration and defense; compulsory social security
P	Education
Q	Human health and social work activities
R	Arts, entertainment and recreation
S	Other services activities
T	Activities of households as employers; undifferentiated goods - and services - producing activities of households for own use
U	Activities of extraterritorial organizations and bodies

The second level, which the CZSO uses for calculating the symmetrical I-O tables, is signified by a two-digit number that further breaks categories down. While the third and fourth level is represented by a three-digit and four-digit number respectively and these categories provide the most detailed view of the individual sectors because they go as far as mining specific ores or casting specific metals. The total number of categories in a complete NACE v2 table is 995, which tends to be impractical in modeling use [81].

5.2. SECTORAL EMISSIONS

The European Environmental Agency (EEA) is charged by the Commission to gather, store, and present emissions data for each Member State. The following sectors are covered by the EU ETS in the Czech Republic: aviation, combustion of fuels, refining of mineral oil, production of coke, production of pig iron and steel, production or processing of ferrous metals, production of secondary aluminum, production of cement clinker, production of lime, or calcination of dolomite or magnesite, manufacture of glass, manufacture of ceramics, manufacture of mineral wool, production of pulp, production of paper or cardboard, production of nitric acid, production of bulk chemicals, and other activity opted-in under Article 24.

The proportion of verified emissions and free allocation during Phase III in the individual sectors can be observed in Table 4 and Table 5 respectively. The base year for each sector is 2013 as the beginning year of Phase III.

Table 4. Verified emissions in the Czech Republic. (Source: EEA, Calculations: Author)

Sector (EU ETS)	2013	2014	2015	2016	2017
10 Aviation	100	94	103	115	119
20 Combustion of fuels	100	98	98	99	98
21 Refining of mineral oil	100	111	113	87	121
22 Production of coke	100	100	96	101	108
24 Production of pig iron or steel	100	100	96	103	92
25 Production or processing of ferrous metals	100	98	81	71	73
27 Production of secondary aluminum	100	103	105	115	132
29 Production of cement clinker	100	110	115	127	130
30 Production of lime, or calcination of dolomite/magnesite	100	102	103	103	108
31 Manufacture of glass	100	106	114	115	118
32 Manufacture of ceramics	100	99	97	102	104
33 Manufacture of mineral wool	100	119	127	133	137
35 Production of pulp	100	46	37	35	33
36 Production of paper or cardboard	100	101	101	99	99
38 Production of nitric acid	100	97	94	87	77
42 Production of bulk chemicals	100	109	103	103	100
99 Other activity opted-in under Art. 24	100	95	93	88	103
Total	100	99	99	100	99

Data provided by the EEA show that the largest increase of verified emission was in these sectors: manufacture of mineral wool, production of secondary aluminum, and production of cement clinker. Whereas the largest abatement was achieved in production of pulp, production or processing of ferrous metals, and production of nitric acid.

The total of verified emissions for all sectors including aviation was one percent lower compared to the base year. When we exclude combustion installations, the total increases by two percent.

Table 5. Free allocation in the Czech Republic. (Source: EEA, Calculations: Author)

Sector (EU ETS)	2013	2014	2015	2016	2017
10 Aviation	100	100	100	100	100
20 Combustion of fuels	100	86	73	61	47
21 Refining of mineral oil	100	92	91	89	87
22 Production of coke	100	98	97	95	93
24 Production of pig iron or steel	100	98	97	94	93
25 Production or processing of ferrous metals	100	86	80	68	63
27 Production of secondary aluminum	100	98	96	110	119
29 Production of cement clinker	100	98	97	95	93
30 Production of lime, or calcination of dolomite/magnesite	100	98	96	96	90
31 Manufacture of glass	100	97	95	96	94
32 Manufacture of ceramics	100	97	96	93	90
33 Manufacture of mineral wool	100	101	100	98	96
35 Production of pulp	100	98	97	95	93
36 Production of paper or cardboard	100	102	101	98	95
38 Production of nitric acid	100	98	96	93	91
42 Production of bulk chemicals	100	100	96	94	93
99 Other activity opted-in under Art. 24	100	98	97	95	93
Total	100	91	83	84	65

The decline of free allocation can be observed in Table 5, with the largest decline in combustion of fuels, and production or processing of ferrous metals. The total free allocation for all installations including aviation was significantly lowered compared to the base year to about 65. This is mainly due to the fact, that combustion of fuels accounts for nearly 52 percent of all free allocations.

The amount of auctioned allowances can be assessed as the difference between verified emissions and free allocation within the sector. Absolute values for the year 2017 can be categorically observed in Table 6.

Table 6. The 2017 carbon emissions in the Czech Republic. (Source: EEA, Calculations: Author)

Sector (EU ETS)	Verified Emissions	Free Allocation	Auctioned Allowances
10 Aviation	495 006	374 779	120 227
20 Combustion of fuels	53 609 859	16 770 695	36 839 164
21 Refining of mineral oil	995 680	852 032	143 648
22 Production of coke	115 268	181 786	-66 518
24 Production of pig iron or steel	5 453 937	8 270 435	-2 816 498
25 Production or processing of ferrous metals	101 457	44 992	56 465
27 Production of secondary aluminum	22 935	18 089	4 846
29 Production of cement clinker	2 588 940	2 350 856	238 084
30 Production of lime, or calcination of dolomite/magnesite	1 230 127	946 691	283 436
31 Manufacture of glass	751 595	647 796	103 799
32 Manufacture of ceramics	408 300	409 115	-815
33 Manufacture of mineral wool	61 573	43 365	18 208
35 Production of pulp	16 753	10 428	6 325
36 Production of paper or cardboard	444 785	318 388	126 397
38 Production of nitric acid	735 559	490 817	244 742
42 Production of bulk chemicals	370 089	329 961	40 128
99 Other activity opted-in under Art. 24	68 901	181 249	-112 348
Total	67 470 764	32 241 474	35 229 290

The disproportionality between the combustion of fuels and other sectors is clearly visible in the last column of Table 6. The total amount of auctioned allowances is lower than expected, since several sectors get free allocation larger than their verified emissions, thus lowering the total pool of necessary allowances. These include production of pig iron and steel, production of coke, and manufacture of ceramics, which are sectors proven to be very susceptible to carbon leakage.

Since the sectoral structure provided by the EEA does not directly match NACE v2 classification, I have created a conversion chart, which matches sectors in NACE to EU ETS ones. The matched sectors along with the amount of emission allowances based on BAU and full actioning (FA) allocation approach are displayed in Table 7.

Table 7. Conversion chart between NACE and EU ETS. (Source: EEA, Calculations: Author)

NACE sector	EU ETS sector	BAU	FA
17 Manufacture of paper and paper products	35 Production of pulp 36 Production of paper or cardboard	132 722	461 538
19 Manufacture of coke and refined petroleum products	21 Refining of mineral oil 22 Production of coke	77 130	1 110 948
20 Manufacture of chemicals and chemical products	38 Production of nitric acid 42 Production of bulk chemicals	284 870	1 105 648
23 Manufacture of other non-metallic mineral products	29 Production of cement clinker 30 Production of lime, or calcination of dolomite/magnesite 31 Manufacture of glass 32 Manufacture of ceramics 33 Manufacture of mineral wool	642 712	5 040 535
24 Manufacture of basic metals	24 Production of pig iron or steel 25 Production or processing of ferrous metals 27 Production of secondary aluminum	-2 755 187	5 578 329
35 Electricity, gas, steam, and air conditioning supply	20 Combustion of fuels 99 Other activity opted-in under Art. 24	36 726 816	53 678 760
51 Air transport	10 Aviation	120 227	495 006
Total		35 229 290	67 470 764

Several important inferences can be made based on data provided in Table 7. First, it is very evident, that sector electricity, gas, steam, and air conditioning supply is by far taxed by the EU ETS the most. Second, NACE classification is greatly aggregated compared to EU ETS classification, leaving only seven sectors compared to 16 in the beginning.

Third, the gap between other industries is rather small, however, this does not apply to the manufacture of basic metals, which has the largest and only surplus of allowances based on data provided by EEA.

The values found in the last column provide the necessary inputs to the income side of the national budget, which will be further discussed in the next subchapter.

5.3. ENVIRONMENTAL POLICY EFFECTS

It is pivotal for the I-O modeling to consider both the expenditure side of the $\Delta\boldsymbol{f}$ vector and also the income side. To achieve consistency across the model, I will assess the scenarios from the sectoral perspective. The analyzed sectors are subjects of emission allowance trading, and thus they are exposed to the primary market impact (PMI). For this very reason, I will denote the expenditure side in my calculations as $\Delta\boldsymbol{f}$-, which represents the PMI and is principally a negative number. On the other hand, the funds raised through emission allowance auctioning are then redistributed back to the national economy, and thus they become capital and non-capital sectoral expenditure. The redistribution portrays the income side and is further denoted as $\Delta\boldsymbol{f}$+. This part represents the primary redistribution impact (PRI) and is always a positive number.

Furthermore, I will assume the I-O model to be fiscally neutral. It is implied that all funds generated through emission allowance auctioning will be redistributed back to the national economy in a form of capital and non-capital expenditures. The final form of vector $\Delta\boldsymbol{f}$ is shown in formula (27).

$$\Delta\boldsymbol{f} = \Delta\boldsymbol{f}_{-} + \Delta\boldsymbol{f}_{+} \tag{27}$$

For fiscally neutral scenario the following must be true:

$$\Delta\boldsymbol{f} \cdot \boldsymbol{i} = 0 \tag{28}$$

And hence the total income must be equal to the total expenditure or in other words, there is no net profit or loss, but only on the national economy level. Sectoral distribution could vary quite significantly.

Finally, in order to get accurate and real-world data I have used the 2017 *Statistical Yearbook of the Czech Environment* published by the MZP [82], which features (among many other things) an overview of capital and non-capital expenditures for climate and environment protection of the MZP and other joint governmental organizations in a detailed NACE v2 classification.

The primary capital expenditures were in the following sectors: manufacture of paper and paper products, electricity, gas, steam and air conditioning supply, water collection, treatment and supply, and public administration, defense, and social security. Just these four sectors alone accounted for 86% of all capital expenditures in 2017.

For non-capital expenditures, which were about 73% higher than capital expenditures, the main sectors were the following: manufacture of chemicals and chemical products, manufacture of basic metals, electricity, gas, steam and air conditioning supply, water collection, treatment and supply, and public administration, defense, and social security. These five sectors alone accounted for 82% of all non-capital expenditures in 2017.

I have combined both capital and non-capital expenditures and used this data during calculations of the I-O model.

5.4. MODELED SCENARIOS

To study the impact of different approaches to the governmental redistribution of funding into the national economy in accordance with the national environmental policies, I have chosen to calculate and analyze two main scenarios each featuring a different approach to auctioning. The first scenario accounts only for emission allowances truly purchased through auctioning as required by the current legislation, therefore acting like BAU scenario. The second scenario plays with the idea, that in the near future all emission allowances will have to be purchased through auction. Thus, the second scenario employs verified emissions as the number of emission allowances that would have to be purchased. This not only leads to an increased pool of emission allowances (about doubling the current non-free pool) but also changing the distribution since many sectors were favored by being given a surplus of emission allowances based on historical values.

As mentioned in the previous subchapters, the funds raised through emission allowance auctioning must be (at least 50%) used to fund climate and environment protection projects. In the subchapter about the EU ETS in the Czech Republic, I mentioned law 383/2012 Sb., which deals with terms and conditions of emission allowance trading. This law specifies that all income generated through emission allowance auctioning must go through the national budget, and then is split in half.

The first half goes to the MZP and the second is often used as an income to the national budget. Whilst this is unfavorable information, I have decided to use the MZP capital and non-capital expenditure as described previously as a 100% model rule. This basically means that the real-world scenario would be somewhat lessened because the government can use the other half to fund whatever issues it deems the most important at that time.

Furthermore, for the purpose of the I-O model, I have decided to use a set price of €30 per emission allowance. This is due to a general consensus, which equates to real expense estimates that a production of a ton of CO_2 levies on the environment.

This, however, poses no problem for the results and other pricing scenarios, because all the results obtained through the I-O model are linear.

A different pricing scenario of emission allowance can be easily obtained from the results by multiplying the desired results by a coefficient, which can be calculated as a new desired price per emission allowance divided by the set price. Such formula can be used to obtain both different turnovers as shown in equation (29) but also employment.

$$\Delta x_i^* = \Delta x_i \frac{desired\ price}{set\ price} \tag{29}$$

Additionally, all calculations were made in CZK, however, emission allowances are sold in EUR, thus I have used a fixed currency exchange rate of 25 CZK per EUR. A different exchange rate can be used to access the result data by the coefficient mentioned above.

Lastly, each modeled scenario includes not only primary impacts but also induced (total) impacts. This results in three new terms. Firstly, the induced market impact (IMI) stands for a total impact caused only by assuming the expenditure side, this vector is denoted as $\boldsymbol{\Delta x_-}$ in the calculations. Similarly, the induced redistribution impact (IRI) relates to a total impact caused only by assuming the income side, this variable is denoted as $\boldsymbol{\Delta x_+}$. Lastly, the total induced impact (TII) adds the two vectors together, which represents a total impact caused by a fiscally neutral case. The following equation (30) shows the addition of the two vectors into the final vector.

$$\Delta \boldsymbol{x} = \Delta \boldsymbol{x}_- + \Delta \boldsymbol{x}_+ \tag{30}$$

Same terms will be used also to assess impact on employment by substituting the $\mathbf{\Delta x}$ vectors in equation (30) by $\mathbf{\Delta e}$ vector.

5.5. PRIMARY MARKET IMPACT OF EUA PRICING

Illustration of the primary market impact based on both emission allowance pricing scenarios can be observed in Table 8 and Table 9 respectively for each scenario. I have chosen to start with an EUA price of €10 and opted for a total of four increments each of €10.

Table 8. Primary market impact in mil. CZK – Scenario I. (Source: EEA, Calculations: Author)

Sector / EUA price	€10	€20	€30	€40	€50
17 Manufacture of paper and paper products	-33.2	-66.4	-99.5	-132.7	-165.9
19 Manufacture of coke and refined petroleum	-19.3	-38.6	-57.8	-77.1	-96.4
20 Manufacture of chemicals	-71.2	-142.4	-213.7	-284.9	-356.1
23 Other non-metallic mineral products	-160.7	-321.4	-482.0	-642.7	-803.4
24 Manufacture of basic metals	688.8	1 377.6	2 066.4	2 755.2	3 444.0
35 Electricity, gas, steam and air conditioning	-9 181.7	-18 363.4	-27 545.1	-36 726.8	-45 908.5
51 Air transport	-30.1	-60.1	-90.2	-120.2	-150.3
Total	-8 807.3	-17 614.6	-26 422.0	-35 229.3	-44 036.6

Other than the large disproportionality between the electricity, gas, steam and air conditioning sector and all the other sectors, one other phenomenon can be observed. In the previous subchapter, I wrote that the PMI is principally negative, however for the manufacture of basic metals in Table 8 the opposite is true.

This phenomenon is caused by a surplus in the free allocation and will be further discussed in the entire next chapter along with its impacts and implications, and thus I will not address this issue here any further.

Unlike the first scenario, the second scenario is void of the negative phenomenon. And even though the total PMI has nearly doubled, the sectoral effects are very much disproportional when viewed side-by-side with the previous scenario.

Table 9. Primary market impact in mil. CZK – Scenario II. (Source: EEA, Calculations: Author)

Sector / EUA price	€10	€20	€30	€40	€50
17 Manufacture of paper and paper products	-115.4	-230.8	-346.2	-461.5	-576.9
19 Manufacture of coke and refined petroleum	-277.7	-555.5	-833.2	-1 110.9	-1 388.7
20 Manufacture of chemicals	-276.4	-552.8	-829.2	-1 105.6	-1 382.1
23 Other non-metallic mineral products	-1 260.1	2 520.3	-3 780.4	-5 040.5	-6 300.7
24 Manufacture of basic metals	-1 394.6	-2 789.2	-4 183.7	-5 578.3	-6 972.9
35 Electricity, gas, steam and air conditioning	-13 419.7	-26 839.4	-40 259.1	-53 678.8	-67 098.5
51 Air transport	123.8	-247.5	-371.3	-495.0	-618.8
Total	-16 867.7	-33 735.4	-50 603.1	-67 470.8	-84 338.5

For example, the manufacture of coke and refined petroleum sector is subject to an increase of almost 1500% in the second scenario. This is all due to the different emission allowance distribution.

5.6. SCENARIO I – BUSINESS AS ASUAL

The BAU scenario results show an overall national economic impact of a shock change in emission allowance pricing of €30 per allowance would cause a PMI of -26.4 bn CZK, resulting in an IMI of -52.0 bn CZK, however this is contested by the PRI of 26.4 bn CZK, resulting in an IRI of 48.0 bn CZK. Based on the present environmental policy, the net result of the TII comes down to about -4.0 bn CZK.

The change in net employment results in an increase of around 10 000 work jobs, however as can be observed in Table 11, the PMI causes about 7 000 jobs to be lost, while the IMI results in a loss of nearly 17 000 jobs. Again, this is opposed by the PRI of 16 000 new jobs and the IRI of 27 000 new jobs. Moreover, the net number of new jobs comes from a loss of around 10 000 productive non-governmental jobs, most notably in power and heat generation and other carbon-heavy industries.

This loss is contended by an increase of slightly over 20 000 new jobs created largely in public administration, defense, and social security. Along with jobs in sewage treatment, water treatment, and water collection.

Moreover, few sectors prone to carbon leakage were given a surplus amount of emission allowances (the difference between verified emissions and free allocation is negative) and this fact leads to increased capital in the given sectors and thus increasing both turnover and employment as is the case for manufacture of basic metals.

The most impacted sectors are displayed in Table 10 and Table 11. Both tables express an excerpt from the turnover change and change in employment tables respectively. Full versions of both Table 10 and Table 11, can be found in Appendix A under Table 16 and Table 18 respectively.

The results show that the electricity, gas, steam and air conditioning sector is the most severely impacted sector with the PMI of -27.5 bn CZK, which is larger than of a whole national economy (this is caused by the general over-allocation to protect from carbon leakage). While the IMI of this sector is even higher at -34.1 bn CZK. When the redistribution takes place, this causes PRI at 2.0 bn CZK and IRI at 3.4 bn CZK. The total turnover impact comes down to -30.7 bn CZK and net change in employment of about negative 8 000 workers.

On the other hand, the largest increases in both the total turnover and net employment come from heavily subsidized sectors in accordance with the existing environmental policy, which puts more money in public administration, water supply, and sewage treatment sectors. These incentives in forms of capital and non-capital expenditure yield expected results, which are much higher than for the other sectors regardless of their adherence to the EU ETS or not.

Several sectors, which could be considered carbon-heavy are omitted from the EU ETS, however, their strong relationships with other sectors, which are included in the emission trading scheme make for an interesting case. For example, sector extraction of crude petroleum and natural gas, which is tightly linked to combustion of fuels, chemicals, and others, is not included in the EU ETS, thus Table 10 shows no PMI in this sector.

Yet, the IMI is nearly -3.1 bn CZK, while the governmental redistribution only returns about 1.0 in a form of IRI. The resulting induced change in turnover is -2.1 bn CZK. The net loss of workers in this sector is not as predominant since the sector has a very low employment multiplier of 0.106.

This example perfectly illustrates linkages between industries and how an impact in other industries (regardless of backward or forward linkages) affect the given industry, either directly in a form of a primary impact, or indirectly in a form of a secondary or induced impact.

Table 10. Excerpt from turnover change in mil. CZK at €30 per EUA – Scenario I.
(Source: EEA, CZSO, MZP, Calculations: Author)

Sector	PMI	IMI	PRI	IRI	TII
National Economy	-26 422.0	-51 968.9	26 422.0	48 009.4	-3 959.5
05 Mining of coal and lignite	0.0	-1 858.6	247.8	511.7	-1 346.9
06 Extraction of crude petroleum and natural gas	0.0	-3 144.4	534.8	997.4	-2 147.0
17 Manufacture of paper and paper products	-99.5	-227.1	3 547.9	4 367.3	4 140.2
19 Manufacture of coke and refined petroleum	-57.8	-393.8	0.0	413.2	19.4
20 Manufacture of chemicals	-213.7	-662.5	855.8	1 510.5	848.0
23 Other non-metallic mineral products	-482.0	-689.2	241.6	465.6	-223.6
24 Manufacture of basic metals	2 066.4	1 795.4	1 140.9	2 386.4	4 181.8
35 Electricity, gas, steam and air conditioning	-27 545.1	-34 081.7	1 969.7	3 392.4	-30 689.3
36 Water collection, treatment and supply	0.0	-193.0	3 165.9	3 627.0	3 434.0
37-39 Sewerage. Waste collection, water treatment	0.0	-172.7	6 379.9	7 671.5	7 498.8
51 Air transport	-90.2	-109.6	28.0	45.1	-64.5
84 Public administration and defense	0.0	-96.4	5 369.4	5 691.5	5 595.1

(PMI – primary market impact, IMI – induced market impact, PRI – primary redistribution impact, IRI – induced redistribution impact, TII – total induced impact)

Furthermore, few sectors featured in Table 10 suffer from a primary market impact, however thanks to the environmental policy their resulting TII is positive. Such is the case of manufacture of paper and paper products, manufacture of coke and refined petroleum, manufacture of chemicals, and manufacture of basic metals.

The opposite can be said about these sectors: other non-metallic mineral products, electricity, gas, steam, and air conditioning and air transport, which do not benefit from the current legislation as much as the other sectors, however, the IMI is always lower (negative value) than the TII (also negative). In other words, it can be supposed that the overall environmental policy lessens the induced change across all industries regardless of the industry, albeit not at the same level.

Table 11. Excerpt from change in employment at €30 per EUA– Scenario I.
(Source: EEA, CZSO, MZP, Calculations: Author)

Sector	PMI	IMI	PRI	IRI	TII
National Economy	-7 070	-16 986	16 058	27 069	10 083
05 Mining of coal and lignite	0	-484	65	133	-351
06 Extraction of crude petroleum and natural gas	0	-332	56	105	-227
17 Manufacture of paper and paper products	-35	-81	1261	1 552	1 472
19 Manufacture of coke and refined petroleum	-16	-108	0	113	5
20 Manufacture of chemicals	-61	-188	242	428	240
23 Other non-metallic mineral products	-180	-257	90	174	-83
24 Manufacture of basic metals	637	553	352	735	1 289
35 Electricity, gas, steam and air conditioning	-7 348	-9 092	525	905	-8 187
36 Water collection, treatment and supply	0	-135	2 220	2544	2 409
37-39 Sewerage. Waste collection, water treatment	0	-129	4 760	5 723	5 594
51 Air transport	-68	-82	21	34	-48
84 Public administration and defense	0	-93	5 187	5 498	5 405

(PMI – primary market impact, IMI – induced market impact, PRI – primary redistribution impact, IRI – induced redistribution impact, TII – total induced impact)

Lastly, the results of obtained through I-O modeling could be used as a maximum case scenario, where the environmental policies cannot change as quickly and drastically as emission allowance prices do. In a real-world scenario, the overall effects both on total turnover and net employment would probably be lessened by changes in legislature.

The main focus would be on restructuring the current capital and non-capital project support so that fewer productive jobs are lost, and fewer jobs in public administration are opened. This proves that the existing environmental policy is not ready for a shock increase in EUA price or for a larger increase in general since the capital and non-capital incentives are based on a lump sum, which was mostly achieved by auctioning EUA at a very low price.

This issue is even more evident in the second scenario, where all emission allowances are auctioned off and that the capital and non-capital expenditures favor few sectors drastically more than all the other sectors, even those that are levied by the EU ETS.

5.7. SCENARIO II – FULL AUCTIONING

The hypothesis discussed in the subchapter about modeled scenarios puts forth an idea when legislation changes and suddenly all emission allowances in all sectors covered by the EU ETS must purchase all their emissions allowances through auction markets and no free emission allowances are further given. This is after all the ultimate goal of the EU ETS. The verified emissions in the Czech Republic have barely decreased on a year-over-year basis as depicted in Table 4 and this leads me to the calculation of the FA scenario using the same conditions as in the previous subchapter, however with both increased pool of emission allowances and a different distribution vector.

This is not simply a linear extrapolation of results obtained in the previous subchapter, because each scenario has a different proportion of emission allowances as compared to the total emission allowance. In fact, two sectors from the EU ETS had a surplus of emission allowances, which is no longer the case in this scenario.

The FA approach yields a total PMI of -50.6 bn CZK, which is roughly double the first scenario, and an IMI of -96.1 bn CZK, which again is roughly double and so is the proportion of emission allowance in the FA scenario compared to BAU scenario. Furthermore, the redistribution side of the vector shows similar doubled values, namely a PRI of 50.6 bn CZK and an IRI of 91.9 bn CZK. Nonetheless, the TTI results in -4.1 bn CZK, which is almost the same value as in the first scenario. This is primarily due to a different distribution of emission allowances, where basically doubling the pool of emission allowances, does not relate to a doubled increase in turnover, this all relays to the individual output multipliers in each analyzed sector.

The most severely impacted sectors are displayed in Table 12 and Table 13 respectively. Both tables express an excerpt from the turnover change and change in employment tables. Full versions of both Table 12 and Table 13, can be found in Appendix A under Table 17 and Table 19 respectively, while all sectoral multipliers including employment multipliers can be also found in Appendix A under Table 20.

Table 12. Excerpt from turnover change in mil. CZK at €30 per EUA – Scenario II.
(Source: EEA, CZSO, MZP, Calculations: Author)

Sector	PMI	IMI	PRI	IRI	TII
National Economy	-50 603.1	-96 088.2	50 603.1	91 947.0	-4 141.2
05 Mining of coal and lignite	0.0	-2 915.6	474.6	980.0	-1 935.7
06 Extraction of crude petroleum and natural gas	0.0	-4 970.9	1 024.2	1 910.2	-3 060.7
17 Manufacture of paper and paper products	-346.2	-625.4	6 794.9	8 364.2	7 738.8
19 Manufacture of coke and refined petroleum	-833.2	-1 497.3	0.0	791.3	-706.0
20 Manufacture of chemicals	-829.2	-1 850.5	1 639.1	2 892.9	1 042.4
23 Other non-metallic mineral products	-3 780.4	-4 654.8	462.7	891.8	-3 763.0
24 Manufacture of basic metals	-4 183.7	-5 638.0	2 185.1	4 570.4	-1 067.7
35 Electricity, gas, steam and air conditioning	-40 259.1	-50 304.0	3 772.4	6 497.1	-43 806.9
36 Water collection, treatment and supply	0.0	-305.9	6 063.3	6 946.4	6 640.5
37-39 Sewerage. Waste collection, water treatment	0.0	-603.1	12 218.8	14 692.5	14 089.4
51 Air transport	-371.3	-418.5	53.6	86.4	-332.1
84 Public administration and defense	0.0	-200.8	10 283.5	10 900.3	10 699.5

(PMI – primary market impact, IMI – induced market impact, PRI – primary redistribution impact, IRI – induced redistribution impact, TII – total induced impact)

The net employment change for this scenario leads to an opening of 19 500 new jobs, which comes from a loss of 14 000 and 32 000 jobs from PMI and IMI respectively.

The loss is offset by an increased opening of new jobs of almost 31 000 and 52 000 from PRI and IRI respectively. The final change in employment is composed mainly by an increase of nearly 25 000 jobs in public administration, sewerage treatment and water collection, along with a loss of around 12 000 jobs primarily in power and heat generation sector.

Similarly, to the first scenario the electricity, gas, steam and air conditioning sector is the most severely impacted sector with a PMI of -40.3 bn CZK, resulting in an IMI of -50.3. On the opposite side of the equation, we get a PRI of only 3.8 bn CZK, leading to an IRI of 6.5 bn CZK. This totals to a TTI of -43.8 bn CZK. As for a change in employment, the net number concludes in a loss of nearly 12 000 jobs, which is only moderately lessened by the redistribution.

Table 13. Excerpt from change in employment at €30 per EUA – Scenario II.
(Source: EEA, CZSO, MZP, Calculations: Author)

Sector	PMI	IMI	PRI	IRI	TII
National Economy	-14 303	-32 379	30 754	51 842	19 462
05 Mining of coal and lignite	0	-760	124	255	-504
06 Extraction of crude petroleum and natural gas	0	-525	108	202	-323
17 Manufacture of paper and paper products	-123	-222	2 415	2 973	2 751
19 Manufacture of coke and refined petroleum	-229	-411	0	217	-194
20 Manufacture of chemicals	-235	-524	464	820	295
23 Other non-metallic mineral products	-1 410	-1 736	173	333	-1 403
24 Manufacture of basic metals	-1 289	-1 738	673	1 409	-329
35 Electricity, gas, steam and air conditioning	-10 739	-13 419	1 006	1 733	-11 686
36 Water collection, treatment and supply	0	-215	4 253	4 872	4 657
37-39 Sewerage. Waste collection, water treatment	0	-450	9 115	10 961	10 511
51 Air transport	-278	-314	40	65	-249
84 Public administration and defense	0	-194	9 934	10 530	10 336

(PMI – primary market impact, IMI – induced market impact, PRI – primary redistribution impact, IRI – induced redistribution impact, TII – total induced impact)

Only two sectors under the EU ETS achieve an increase in final turnover. These include the heavily subsidized manufacture of paper and paper products with an IMI of -0.6 bn CZK and an IRI of 8.4 bn CZK. And the manufacture of chemicals, which also gets its fair share of governmental subsidy at an IMI of -0.8 and an IRI of 2.9 bn CZK.

Besides, the two sectors others have also increased their turnover, however these are not subject to emission trading, and thus the increase comes only from the redistribution factor. Such as sewerage treatment, public administration and water collection sector.

Lastly, the mining of coal and lignite and the extraction of crude petroleum and natural gas sectors do not have any initial PMI, however their IMI is identically large at -2.9 bn CZK and -5.0 bn CZK respectively. Again, displaying the important role of the interindustry linkages. The governmental redistribution lessens the market impacts by 1.0 bn CZK and 1.9 bn CZK respectively in a form of IRI. The resulting values along with all other sectors feature in the excerpt can be found in Table 12.

6 I-O MODEL IN STEEL PRODUCTION

6.1. SECTOR SELECTION

In this final chapter of my thesis, I will be covering a more detailed impact analysis of a shock change in the price of emission allowances on a selected sector. It is imperative that the chosen sector must be covered by the EU ETS, therefore it has a PMI and is subject to emission allowance submission and trading. It also must be an important sector within the national economy, otherwise the primary impact and induced change will be insignificant. The relative importance will be based on the number of verified emissions or free allocation and their relation to the overall amount. Last but not least, the chosen sector must be a producer or a provider of a very homogenous product or service. The last criterion is very relative in its definition, however in order to relate general sectoral results to a more detailed sector definition or to individual installations, the accessed sector must show a certain amount of homogeneity. Either in the product or service itself or the processes that lead to the creation of the set product or service.

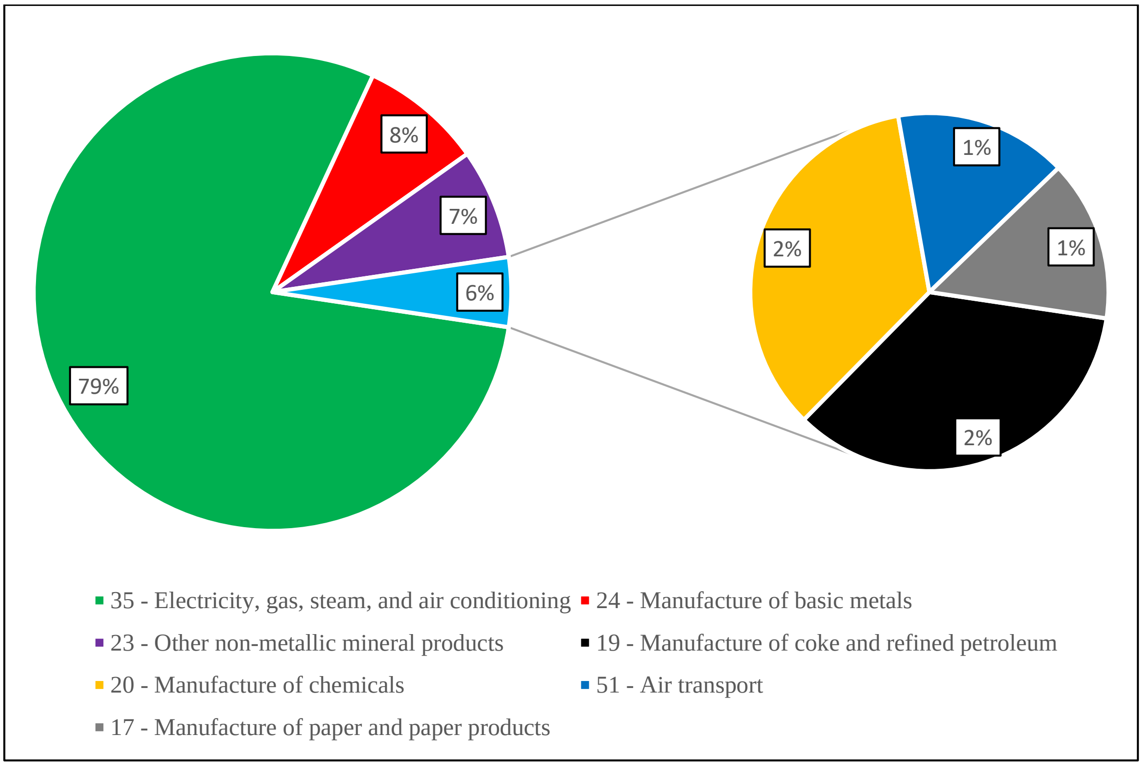

Figure 7. Proportion of verified emissions in the Czech Republic in 2017. (Source: EEA)

The first criterion rules out sectors not covered by the emission trading scheme. Only the following industrial sector remain: electricity, gas, steam, and air conditioning, manufacture of basic metals, other non-metallic mineral products, manufacture of coke and refined petroleum, manufacture of chemicals, air transport, and manufacture of paper and paper products. A comparison of these sectors based on a proportion of total verified emission in the Czech Republic is displayed in Figure 7. Similarly, a comparison founded on free allocation approach can be observed in Figure 8. The latter figure shows a proportion of total free allocation within the Czech Republic.

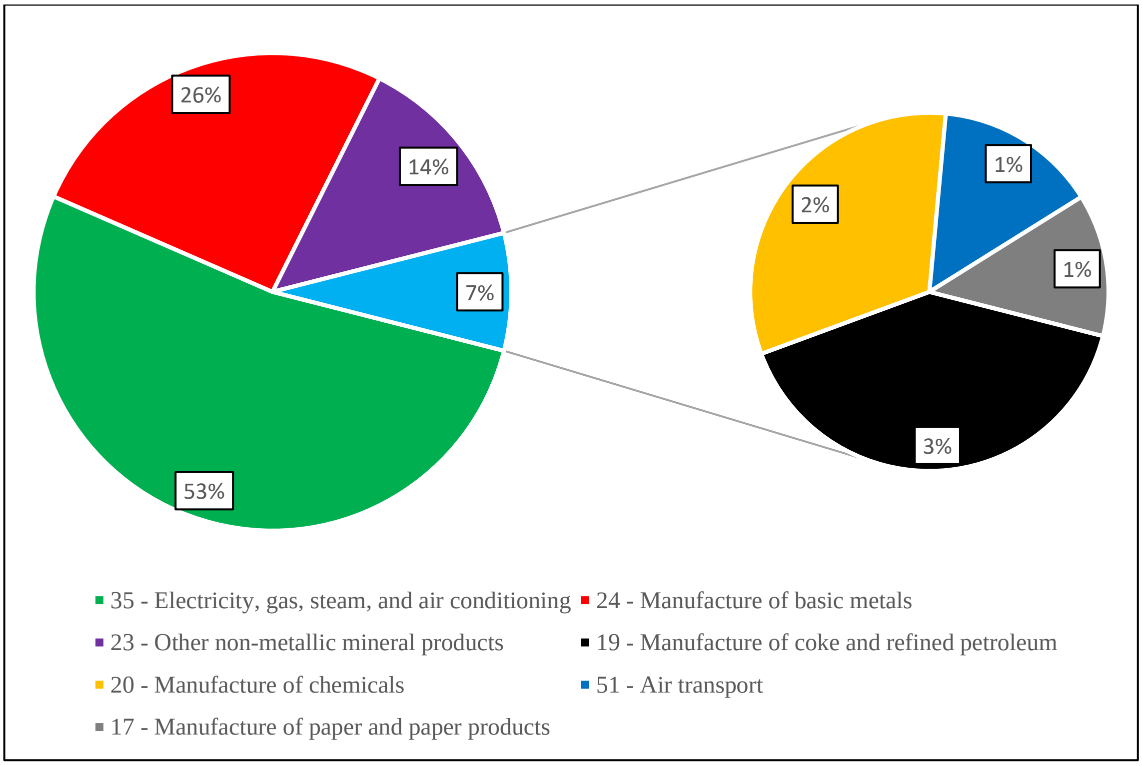

Figure 8. Proportion of free allocation in the Czech Republic in 2017. (Source: EEA)

Both figures show the clear dominance of electricity, gas, steam, and air conditioning sector, with the former showing a whopping 79% of all verified emissions and the latter totaling nearly 53% of the total amount of free allocation. Manufacture of basic metals comes in second with 8% of the total verified emissions and 26% of the total free allocation. The last industrial sector that is among the very important ones is other non-metallic mineral products, which accounts for nearly 7% of the total verified emissions and about 14% of the overall free allocation.

The last criterion dictates, that the selected sector must be a producer of a very homogenous product or service. Unfortunately, this is not the case of the NACE power sector, which acts primarily as an aggregated sector for electricity and heat production, plus a handful of other small installations. The classification used by NACE makes this sector rather heterogeneous and thus not enabling the use of results obtained through I-O modeling to be used to access a more detailed impact analysis in the sector itself. This does not mean that the results are incorrect, but for this specific sector, they can only be used at the national economy level or sectoral level. Going into further detail would require a different approach that would allow for such vastly diverse environment, which is due to the use of varying technologies to generate electricity such as lignite, hard coal, natural gas, gasoline, biomass, etc. The heat generation is achieved through very similar measures i.e. combustion of fossil fuels.

The next feasible industrial sector is basic metals, which embodies a much smaller portion of verified emissions, but based on free allocation it is still very important in the national economy. Also, the processes used in manufacturing basic metals are much more homogenous than in the power industry. For the aforementioned reasons, I will assess a more detailed impact analysis in this sector.

6.2. CRUDE STEEL PRODUCTION

The data provided by the EEA allow for a breakdown of the basic metals sector into three subsectors. Namely: production of pig iron or steel, production or processing of ferrous metals, and production of secondary aluminum.

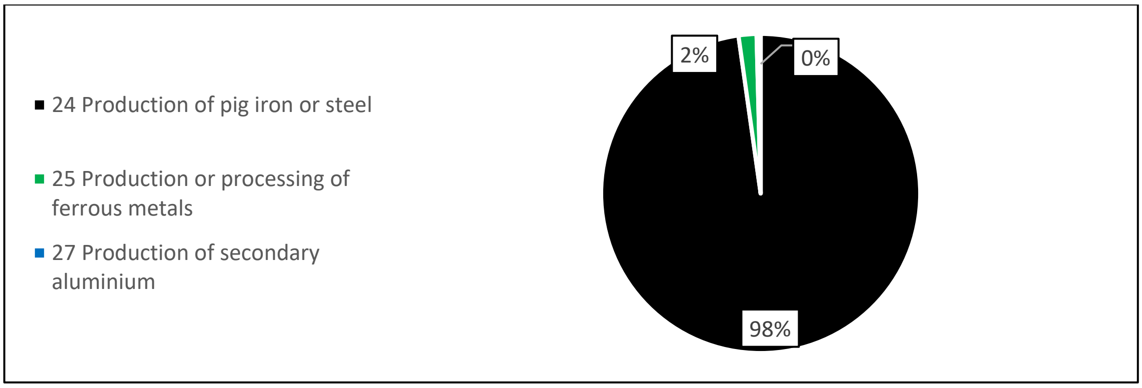

Figure 9. Proportion of verified emissions in Manufacture of basic metals sector. (Source: EEA)

In order to satisfy the homogeneity criterion, I will further narrow the selected sector down to the production of crude steel, which makes up almost all verified emissions of basic metals sector as shown in Figure 9.

In short, there are two main ways of producing crude steel. Either from iron ore or from scrap metal. The former is melted in a blast furnace producing pig iron, which in turn is processed in blast oxygen furnaces, where crude steel is formed. The latter undergoes a similar process in electric arc furnaces. Generally, both methods could use either iron ore or scrap metal as their main resource for crude steel production, however individual installations are designed with a specific input in mind. Furthermore, the blast oxygen furnaces are generally much higher producers of carbon emissions. And since the Czech Republic is not a coastal nation, it relies heavily on primary crude steel production with over 90% of production coming from the blast oxygen furnaces, while the EU average is around 60%. The proportion between blast oxygen furnaces and electric arc furnaces greatly differs based on maritime availability. Countries such as Portugal and Greece have only electric arc furnaces, whereas landlocked countries operate mostly blast oxygen furnaces [83][84].

The crude steel production sector is among the major industrial polluters and accounts for up to 7% of total anthropogenic carbon emission worldwide [85]. In the EU ETS, the production of crude steel is included in the sectors with a high risk of carbon leakage. Several past studies showed an expected carbon leakage i.e. net import of crude steel at 5% to 20% level [84][86]. This fact had been partially addressed in all phases of emission trading and had often resulted in gross over-allocation. Assuming full elasticity of substitution and no new import tariffs then, the current models show that at €12 per allowance the blast oxygen furnaces stop being profitable and the same can be assumed about the electric arc furnaces at around €20 per emission allowance if the full auctioning scenario is in place [84].

6.3. I-O MODEL SECTORAL RESULTS

In the first modeled scenario the primary impact caused by a sudden shock change in emission allowance price causes a significant increase in capital in the crude steel industry. This due to major over-allocation of emission allowances given to this sector. The data suggest that in 2017 the manufacturing of crude steel industry was given 152% of free allowances compared to the amount of verified emission; thus anything above 100% is basically a form of incentive for the industry and aims to improve operational efficiency and mitigate carbon leakage to countries like China. The PMI ranges from 0.7 bn CZK at €10 per EUA to 3.4 bn CZK at €50 per EUA. The positive number implies that the sector capital is boosted and as the capital grows so does the ability of this sector to increase its turnover. This is the only case where the PMI along with IMI is positive, and thus each increase in EUA price drives the sectoral turnover up.

Looking at the induced factors, we can see a slight dip in turnover caused by the secondary relationships between industries. The IMI is still positive at 0.6 bn CZK to 3.0 bn CZK, while the governmental redistribution adds even more capital with PRI ranging from 0.4 bn CZK up to 1.9 bn CZK and the consequent IRI of 0.8 bn CZK to almost 4.0 bn CZK.

The sum of both inducing factors leads to an increase in turnover ranging from 1.4 bn CZK to nearly 7 bn CZK. Similarly, the number of new jobs opened varies between 430 up to 2 148 based on the EUA price, while the largest increase could be attributed to the IRI. The number of new jobs is not as predominant as in some other heavily subsidized industries because of the rather lesser employment multiplier of only 0.3082, while the national economy gross average is around 0.5907 with some industries having greater than 1.000.

The following Table 14 depicts the aforementioned EUA pricing scenarios and its impact on turnover and employment in the crude steel manufacturing sector with BAU allocation process.

Table 14. Impact in crude steel production at varying EUA prices - Scenario I.
(Source: EEA, CZSO, MZP, Calculations: Author)

EUA price	€10	€20	€30	€40	€50
Turnover – PMI	688.8	1 377.6	2 066.4	2 755.2	3 444.0
Turnover – IMI	598.5	1 196.9	1 795.4	2 393.9	2 992.3
Turnover – PRI	380.3	760.6	1 140.9	1 521.2	1 901.6
Turnover – IRI	795.5	1 590.9	2 386.4	3 181.8	3 977.3
Turnover – TII	1 393.9	2 787.9	4 181.8	5 575.7	6 969.6
Employment – PMI	212	425	637	849	1 061
Employment – IMI	184	369	553	738	922
Employment – PRI	117	234	352	469	586
Employment – IRI	245	490	735	981	1 226
Employment – TII	430	859	1 289	1 718	2 148

(PMI – primary market impact, IMI – induced market impact, PRI – primary redistribution impact, IRI – induced redistribution impact, TII – total induced impact)

The BAU scenario clearly demonstrates how much capital is allocated to this sector in the form of subsidies and incentives. This is shown both in the amount of free allocation, which plays a key role as an ecological incentive and as a measure to prevent carbon leakage, but also in the increased governmental expenditure within this sector, which demonstrates capital and non-capital subsidies. The model results show that the existing environmental policy largely favors this sector, more than doubling its market effects.

The modeled results based on the FA scenario suggest very different outcomes. Mainly, the amount of free allocation is switched from 152% to 0%, which drastically reduces the capital increase in fact, it leads to an immense decrease in capital.

Table 15. Impact in crude steel production at varying EUA prices - Scenario II.
(Source: EEA, CZSO, MZP, Calculations: Author)

EUA price	€10	€20	€30	€40	€50
Turnover – PMI	-1 394.6	-2 789.2	-4 183.7	-5 578.3	-6 972.9
Turnover – IMI	-1 879.3	-3 758.7	-5 638.0	-7 517.4	-9 396.7
Turnover – PRI	728.4	1 456.7	2 185.1	2 913.5	3 641.8
Turnover – IRI	1 523.5	3 046.9	4 570.4	6 093.8	7 617.3
Turnover – TII	-355.9	-711.8	-1067.7	-1 423.6	-1 779.5
Employment – PMI	-430	-860	-1 289	-1 719	-2 149
Employment – IMI	-579	-1 158	-1 738	-2 317	-2 896
Employment – PRI	224	449	673	898	1 122
Employment – IRI	470	939	1 409	1 878	2 348
Employment – TII	-110	-219	-329	-439	-548

(PMI – primary market impact, IMI – induced market impact, PRI – primary redistribution impact, IRI – induced redistribution impact, TII – total induced impact)

The PMI now ranges from -1.4bn CZK to -7.0 bn CZK, while the IMI is further decreased to about -1.9 bn CZK to -9.4 bn CZK. The induced change in turnover is noticeably higher than the primary impact, suggesting that the secondary impact also plays a significant role in this sector. The direct output multiplier is 1.1377, while the indirect and the total is 0.4631 and 1.6009 respectively. The governmental redistribution leads to a PRI of 0.7 bn CZK all the way to 3.6 bn CZK, whereas its induced effects displayed in a form of an IRI range from 1.5 bn CZK to 7.6 bn CZK. With governmental expenditure accounted for, the TII on turnover change begins at -0.4 bn CZK and tops at -1.8 bn CZK. Since this scenario results in a decrease in turnover it inevitably leads to a loss of jobs. Without the governmental expenditure, the loss of jobs would be drastic topping at almost 3 000 jobs, however with the governmental expenditure included the amount of jobs lost is lessened to only about 19% of its initial impact value.

6.4. IMPACT ANALYSIS DISCUSSION

The two modeled scenarios with one based on BAU allocation approach and the other on FA, show a stark contrast in both output and employment results. However, they still share similarities in form governmental capital and non-capital expenditure, which lessens the induced impact quite significantly.

There is a staggering difference of 8.8 bn CZK between the final induced change in turnover with governmental expenditure included between the two scenarios at €50, however it is highly unlikely that the EUA price will tackle this price point anytime soon. In a more realistic case, I would assume the EUA price between €20 to €30, which corresponds better with the current EUA price as shown in Chapter Three. Under these conditions, the difference between the final induced change in turnover ranges from 3.5 bn to 5.3bn CZK.

As the I-O model results show the maximum case scenario these differences cannot be necessarily viewed as the total of direct and indirect subsidies and incentives, because when a shock change in emission allowance price occurs, the national economy reacts. The industries that are directly struck by this shock change would try to react promptly, while industries affected by the secondary impacts and the government would react less promptly. All in all, the governmental environmental policy would change and thus a new equilibrium would be achieved.

Finally, the FA scenario outlines the necessary changes that will have to be addressed in the near future if the manufacturing of crude steel as an industry is to remain in the Czech Republic and retain the amount of production as of today. If no policies are changed and free allocation is phased out, this sector will suffer major problems, potentially crippling the whole sector and thus inducing a decrease in turnover in other neighboring industries.

7 CONCLUSION

This thesis aimed to fill the knowledge gap between the past studies and the newly formed settings for the functioning of the EU ETS. The past studies often used regression analysis and tried to predict EUA price based on other commodities used in power management. However, their results were never able to explain the dramatic increase in EUA price in the last year. This fact acted as a great premise in order to the evaluate impacts of the set price change on the national economy of the Czech Republic and its sectoral effects on both turnover and employment.

Firstly, I have evaluated significant changes made in EU ETS functioning throughout Chapter Two analysis and discussion parts, while touching on the most important aspects such as the economic recession in 2008/2009, which caused about 90% of all carbon emission reduction achieved in the EU. The third phase introduced several new features, where the MSR stood out the most. In less than a year since its introduction, the EUA price rose from €8 to €22, with a notable contribution caused by the MSR, but the origins of this increase were not a topic of this thesis, so the proportion of the MSR contribution remains unclear.

Secondly, based on criteria such as clarity, complexity and others, I have selected the symmetrical I-O table methodology in order to access the impacts of a shock price change emission allowances. The I-O modeling proved to be a very elegant and simple, yet powerful tool, which allowed for the interindustry contribution analysis to the total induced change.

Thirdly, I proposed two model scenarios each based on a different approach of free allocation of emission allowances. Scenario I was founded on BAU approach, which is closely related to the current practices within the EU ETS, while Scenario II introduced a full auctioning approach, which should be in compliance with the final vision of the 2050 EU carbon neutrality.

The total induced change in turnover for both scenarios is fairly similar at around -4.0 bn CZK, albeit the doubled pool of emission allowances traded, which shows the importance of not only the primary market effects at -26.4 bn CZK and -50.6 bn CZK respectively with the same totals for primary redistribution effects as need for fiscally neutral scenarios, but also the secondary interindustry effects. These induced impacts accrued a total of -52.0 bn CZK by market induction and 48.0 bn CZK by redistribution induction. Similarly, in the second scenario, the market induction is at -96.0 bn CZK and the redistribution induction is at 91.9 bn CZK. All these values were calculated at €30 per EUA.

The same cannot be said about the total induced change in employment, which follows the emission pool doubling far more significantly. The first scenario shows an increase in total jobs of around 10 000, while the second scenario depicts an even larger increase at almost 20 000 new jobs. As employment changes in both scenarios follow the same pattern these conclusions can be drawn, albeit with an almost doubled impact in the second scenario. First, jobs are primarily lost in sectors levied by the EU ETS, followed closely by sectors that purchase inputs or sell their outputs to the primary sectors. Second, jobs are created in few sectors that the national environmental policy favors, these include water and sewage treatment and supply and public administration, which account nearly for all new jobs created.

Lastly, grounded on information provided throughout Chapter Six, I have decided to evaluate the manufacturing of crude steel industry as it is an important sector within the national economy, while also being among significant atmospheric polluters. Additionally, the crude steel production sector shows a high risk of carbon leakage and thus was given up to 152% of free allowances. This last aspect plays a key role in showing the difference between the two modeled scenarios, while the former having a very positive impact on this sector at 4.2 bn CZK and the latter at -1.1 bn CZK. The difference between the two values shows at least partially the number of subsidies and incentives given to this sector, because if full auctioning at €30 per EUA was in place and no incentives were given, the total induced change in turnover would result in a whopping -5.6 bn CZK and would also lead to a significant loss in jobs.

In conclusion, the EU ETS has structured itself as a working mechanism in the EU climate policy, while based on market data the inclusion of the MSR showed the largest contribution to the overall functioning of the carbon market. The primary market effects on the national turnover are significant, however they are combated by the primary redistribution effects. The same cannot be said for the induced market and redistribution impacts, which in both modeled scenarios showed a moderated impact when summed up. Moreover, the induced effects show a stronger impact on employment redistribution, where many industrial jobs are lost, and new less productive jobs are created (i.e. in public administration), because of the inherit differences between sectoral employment multipliers.

The results for the crude steel sector demonstrate the stark difference between the free allowance allocation approach, with the BAU approach leading to a large increase in both turnover and employment, while the FA approach resulting in a moderate decrease.

The results obtained show that the national environmental policy must be changed accordingly with the increased price in EUA and must be flexible enough to facilitate future changes if the amount of surplus of EUA suddenly drops because the MSR voids them.

Furthermore, the present environmental policy was designed during a period of stagnation, where the price of EUA hovered at around €6 and thus a lump sum was calculated each year based on the set price and the amount of traded allowances. This lump sum could increase up to five times in the next year and could potentially keep increasing in the consequent years because more and more EUAs will be auctioned off. The governmental redistribution should shift more funds to the most heavily impacted sectors such as electricity and heat production to combat employment loss and reduce its spending in less productive sectors.

To end, there are several research areas that I wish I could have tackled in this thesis, but the format and size did not allow me for it. First, the future implications caused by the new functioning of the MSR, especially voiding of surplus allowance, which could happen as soon as 2023. Second, the amounts of free allocation given on a year-over-year basis to weaker economies and its impact based on Article 10c and what would happen if a Member State would suddenly become illegible under the set article. Third, what are the implications of including more if not all commercial subjects and possibly even non-commercial sectors in carbon trading.

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REFERENCES

[1] NOAA. ESRL Global Monitoring Division - Global Greenhouse Gas Reference Network. [online]. [Accessed 31 October 2018]. Available from: https://www.esrl.noaa.gov/gmd/ccgg/trends/full.html

[2] IPCC. History of the IPCC. [online]. [Accessed 31 October 2018]. Available from: https://www.ipcc.ch/about/history/

[3] UN. A/RES/43/53. Protection of global climate for present and future generations of mankind. [online]. [Accessed 31 October 2018]. Available from: http://www.un.org/documents/ga/res/43/a43r053.htm

[4] HOUGHTON, J.T., JENKINS, G.J. and EPHRAUMS, J.J. *Climate Change: The IPPC Scientic Assessment*. Cambridge : Cambridge University Press, 1990. ISBN 052140360X.

[5] UNFCCC. 20 Years of Effort and Achievement. [online]. [Accessed 31 October 2018]. Available from: http://unfccc.int/timeline/

[6] UNFCCC. Completion of a Framework Convention on Climate Change. Draft proposed by the Chairman. [online]. [Accessed 31 October 2018]. Available from: https://unfccc.int/documents/2856

[7] UN. United Nations Framework Convention on Climate Change | United Nations System Chief Executives Board for Coordination. [online]. [Accessed 31 October 2018]. Available from: https://www.unsystem.org/content/united-nations-framework-convention-climate-change

[8] UN. Kyoto Protocol: To the UNFCCC. [online]. 1998. [Accessed 31 October 2018]. Available from: http://unfccc.int/resource/docs/convkp/kpeng.pdf

[9] UN. The Marrakesh Accords. [online]. 2001. [Accessed 31 October 2018]. Available from: http://unfccc.int/cop7/documents/accords_draft.pdf

[10] UNFCCC. Reporting and accounting of LULUCF activities under the Kyoto Protocol. [online]. [Accessed 4 November 2018]. Available from: https://unfccc.int/topics/land-use/workstreams/land-use--land-use-change-and-forestry-lulucf/reporting-and-accounting-of-lulucf-activities-under-the-kyoto-protocol

[11] UNFCCC. The Clean Development Mechanism. [online]. [Accessed 31 October 2018]. Available from: https://unfccc.int/process-and-meetings/the-kyoto-protocol/mechanisms-under-the-kyoto-protocol/the-clean-development-mechanism

[12] UNFCCC. Joint implementation. [online]. [Accessed 31 October 2018]. Available from: https://unfccc.int/process/the-kyoto-protocol/mechanisms/joint-implementation

[13] UNFCCC. Emissions Trading. [online]. [Accessed 31 October 2018]. Available from: https://unfccc.int/process/the-kyoto-protocol/mechanisms/emissions-trading

[14] CONVERY, Frank J. Origins and development of the EU ETS. *Environmental and Resource Economics*. 2009. Vol. 43, no. 3, p. 391–412. DOI 10.1007/s10640-009-9275-7.

[15] EUROPEAN COMMISSION. Final Report: ECCP Working Group 1 "Flexible Mechanism." [online]. 2001. [Accessed 4 November 2018]. Available from: https://ec.europa.eu/clima/sites/clima/files/eccp/first/docs/final_report_en.pdf

[16] EUROPEAN COMMISSION. Green Paper: on greenhouse gas emissions trading within the European Union. [online]. 2000. [Accessed 4 November 2018]. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52000DC0087

[17] EUROPEAN PARLIAMENT. Directive 2003/87/EC. *Official Journal of the European Union* [online]. 2003. P. 32–46. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32003L0087

[18] EUROPEAN PARLIAMENT. Directive 2004/101/EC. *Official Journal of the European Union* [online]. 2008. No. 5, p. 18–23. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32004L0101

[19] BORGHESI, Simone and FLORI, Andrea. EU ETS facets in the net: Structure and evolution of the EU ETS network. *Energy Economics* [online]. 2018. Vol. 75, p. 602–635. DOI 10.1016/j.eneco.2018.08.026. Available from: https://doi.org/10.1016/j.eneco.2018.08.026

[20] OECD. *Taxing Energy Use* [online]. Paris : OECD Publishing, 2013. [Accessed 8 November 2018]. ISBN 9789264181250. Available from: http://www.oecd-ilibrary.org/taxation/taxing-energy-use_9789264183933-en

[21] HINTERMANN, Beat. Allowance price drivers in the first phase of the EU ETS. *Journal of Environmental Economics and Management* [online]. 2010. Vol. 59, no. 1, p. 43–56. DOI 10.1016/j.jeem.2009.07.002. Available from: http://dx.doi.org/10.1016/j.jeem.2009.07.002

[22] BALIETTI, Anca Claudia. Trader types and volatility of emission allowance prices. Evidence from EU ETS Phase I. *Energy Policy* [online]. 2016. Vol. 98, p. 607–620. DOI 10.1016/j.enpol.2016.09.006. Available from: http://dx.doi.org/10.1016/j.enpol.2016.09.006

[23] ZAPFEL, Peter. A brief but lively chapter in EU climate policy: The commission's perspective. *Allocation in the European Emissions Trading Scheme: Rights, Rents and Fairness*. 2007. P. 13–38. DOI 10.1017/CBO9780511493478.004.

[24] ANDERSON, Barry and DI MARIA, Corrado. Abatement and Allocation in the Pilot Phase of the EU ETS. *Environmental and Resource Economics*. 2011. Vol. 48, no. 1, p. 83–103. DOI 10.1007/s10640-010-9399-9.

[25] EUROPEAN COMMISSION. Communication from the Commission "Further guidance on allocation plans for the 2008 to 2012 trading period of the EU Emission Trading Scheme." *Communication from the Commission*. 2005. Vol. COM(2005), no. 703 final, p. 1–39. DOI http://dx.doi.org/10.17507/tpls.0605.12.

[26] EUROPEAN COMMISSION. Phases 1 and 2 (2005-2012) | Climate Action. [online]. [Accessed 17 November 2018]. Available from: https://ec.europa.eu/clima/policies/ets/pre2013_en

[27] HEPBURN, Cameron, GRUBB, Michael, NEUHOFF, Karsten, MATTHES, Felix and TSE, Maximilien. Auctioning of EU ETS phase II allowances: How and why? *Climate Policy*. 2006. Vol. 6, no. 1, p. 137–160. DOI 10.1080/14693062.2006.9685592.

[28] MARKLUND, Per-Olov and SAMAKOVLIS, Eva. What is driving the EU burden-sharing agreement: Efficiency or equity? *Journal of Environmental Management* [online]. 1 October 2007. Vol. 85, no. 2, p. 317–329. [Accessed 17 November 2018]. DOI 10.1016/J.JENVMAN.2006.09.017. Available from: https://www-sciencedirect-com.ezproxy.techlib.cz/science/article/pii/S0301479706003094

[29] EUROPEAN COMMISSION. 2020 climate and energy package. [online]. [Accessed 17 November 2018]. Available from: https://ec.europa.eu/clima/policies/strategies/2020_en

[30] EUROPEAN COMMISSION. Directive 2009/29/EC. *Official Journal of the European Union* [online]. 2011. P. 28. Available from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:149:0001:0003:EN:PDF

[31] EUROPEAN COMMISSION. Phase 2 auctions (2008-2012). [online]. [Accessed 17 November 2018]. Available from: https://ec.europa.eu/clima/policies/ets/pre2013/second_en

[32] EEA. Maps and graphs: European Union Emission Allowance. [online]. [Accessed 17 November 2018]. Available from: https://www.eea.europa.eu/data-and-maps/figures#c0=15&c5=&c15=all&b_start=0&c8=eua

[33] CASTAGNETO-GISSEY, Giorgio. How competitive are EU electricity markets? An assessment of ETS Phase II. *Energy Policy* [online]. 1 October 2014. Vol. 73, p. 278–297. [Accessed 17 November 2018]. DOI 10.1016/J.ENPOL.2014.06.015. Available from: https://www-sciencedirect-com.ezproxy.techlib.cz/science/article/pii/S0301421514003875#bib30

[34] ZHU, Bangzhu and CHEVALLIER, Julien. *Pricing and Forecasting Carbon Markets: Models and Empirical Analysis*. Cham : Springer, 2017. ISBN 9783319576176.

[35] EEA. EU Emissions Trading System (ETS) data viewer. [online]. 2018. [Accessed 18 November 2018]. Available from: https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

[36] ELLERMAN, A. Denny, MARCANTONINI, Claudio and ZAKLAN, Aleksandar. The EU ETS: Eight Years and Counting. *Ssrn*. 2014. DOI 10.2139/ssrn.2383870.

[37] KOCH, Nicolas, FUSS, Sabine, GROSJEAN, Godefroy and EDENHOFER, Ottmar. Causes of the EU ETS price drop: Recession, CDM, renewable policies or a bit of everything?-New evidence. *Energy Policy* [online]. 2014. Vol. 73, p. 676–685. DOI 10.1016/j.enpol.2014.06.024. Available from: http://dx.doi.org/10.1016/j.enpol.2014.06.024

[38] BEL, Germà and JOSEPH, Stephan. Emission abatement: Untangling the impacts of the EU ETS and the economic crisis. *Energy Economics* [online]. 2015. Vol. 49, p. 531–539. DOI 10.1016/j.eneco.2015.03.014. Available from: http://dx.doi.org/10.1016/j.eneco.2015.03.014

[39] AATOLA, Piia, OLLIKAINEN, Markku and TOPPINEN, Anne. Price determination in the EU ETS market: Theory and econometric analysis with market fundamentals. *Energy Economics* [online]. 2013. Vol. 36, no. October 2007, p. 380–395. DOI 10.1016/j.eneco.2012.09.009. Available from: http://dx.doi.org/10.1016/j.eneco.2012.09.009

[40] EUROPEAN PARLIAMENT. Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003 87 EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community. *Official Journal of the European Union* [online]. 2008. Vol. L, no. 8/3, p. 3–21. DOI ISSN 1725-2555. Available from: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32008L0101

[41] NAVA, Consuelo R., MELEO, Linda, CASSETTA, Ernesto and MORELLI, Giovanna. The impact of the EU-ETS on the aviation sector: Competitive effects of abatement efforts by airlines. *Transportation Research Part A: Policy and Practice*. 2018. Vol. 113, no. December 2016, p. 20–34. DOI 10.1016/j.tra.2018.03.032.

[42] EUROPEAN COMMISSION. Reducing emissions from aviation. [online]. [Accessed 17 November 2018]. Available from: https://ec.europa.eu/clima/policies/transport/aviation_en

[43] ANGER, Annela. Including aviation in the European emissions trading scheme: Impacts on the industry, CO2 emissions and macroeconomic activity in the EU. *Journal of Air Transport Management* [online]. 2010. Vol. 16, no. 2, p. 100–105. DOI 10.1016/j.jairtraman.2009.10.009. Available from: http://dx.doi.org/10.1016/j.jairtraman.2009.10.009

[44] BRINK, Corjan, VOLLEBERGH, Herman R.J. and VAN DER WERF, Edwin. Carbon pricing in the EU: Evaluation of different EU ETS reform options. *Energy Policy* [online]. 2016. Vol. 97, p. 603–617. DOI 10.1016/j.enpol.2016.07.023. Available from: http://dx.doi.org/10.1016/j.enpol.2016.07.023

[45] EUROPEAN COMMISSION. The Market Stability Reserve. [online]. [Accessed 1 December 2018]. Available from: https://ec.europa.eu/clima/policies/ets/reform_en#tab-0-0

[46] HEPBURN, Cameron, NEUHOFF, Karsten, ACWORTH, William, BURTRAW, Dallas and JOTZO, Frank. The economics of the EU ETS market stability reserve. *Journal of Environmental Economics and Management*. 2016. Vol. 80, no. November 2012, p. 1–5. DOI 10.1016/j.jeem.2016.09.010.

[47] EUROPEAN UNION. Decision (EU) 2015/1814 of the European Parliment and of the Council of 6 October 2015 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and amending Directive 2003/87/EC. *Official Journal of the European Union*. 2015. Vol. L264, no. 9.10.2015, p. 1–5. DOI 10.1007/s13398-014-0173-7.2.

[48] EUROPEAN UNION. Communication from the Commission: Total number of allowances in 2017 for the purposes of the MSR. *Official Journal of the European Union*. 2018.

[49] EUROPEAN COMMISSION. *Report from the Comission to the European Parliament and the Council: The state of the European carbon market in 2012*. 2012. Brussels.

[50] EICHHAMMER, Wolfgang, FRIEDRICHSEN, Nele, HEALY, Sean and SCHUMACHER, Katja. Impacts of the allocation mechanism under the third phase of the European emission trading scheme. *Energies*. 2018. Vol. 11, no. 6, p. 1–24. DOI 10.3390/en11061443.

[51] SARTOR, Oliver, PALLIÈRE, Clement and LECOURT, Stephen. Benchmark-based allocations in EU ETS Phase 3: An early assessment. *Climate Policy* [online]. 2014. Vol. 14, no. 4, p. 507–524. DOI 10.1080/14693062.2014.872888. Available from: http://dx.doi.org/10.1080/14693062.2014.872888

[52] ANDRESEN, Steinar, SKJÆRSETH, Jon Birger, JEVNAKER, Torbjørg and WETTESTAD, Jørgen. The Paris Agreement: Consequences for the EU and Carbon Markets? *Politics and Governance* [online]. 2016. Vol. 4, no. 3, p. 188. DOI 10.17645/pag.v4i3.652. Available from: http://www.cogitatiopress.com/ojs/index.php/politicsandgovernance/article/view/652

[53] CARNERO, M., OLMO, Jose and PASCUAL, Lorenzo. Modelling the Dynamics of Fuel and EU Allowance Prices during Phase 3 of the EU ETS. *Energies* [online]. 2018. Vol. 11, no. 11, p. 3148. DOI 10.3390/en11113148. Available from: http://www.mdpi.com/1996-1073/11/11/3148

[54] THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION. Directive (EU) 2018/410. *Official Journal of the European Union* [online]. 2018. Vol. 1933, no. 76. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0410&from=DE

[55] PERINO, Grischa. New EU ETS Phase 4 rules temporarily puncture waterbed. *Nature Climate Change*. 2018. Vol. 8, no. 4, p. 262–264. DOI 10.1038/s41558-018-0120-2.

[56] EUROPEAN COMMISSION. Revision for phase 4 (2021-2030). *EU Policies* [online]. 2018. [Accessed 5 April 2019]. Available from: https://ec.europa.eu/clima/policies/ets/revision_en

[57] EUROPEAN COMMISSION. The EU ETS Directive Revision. [online]. 2016. [Accessed 26 March 2019]. Available from: https://ec.europa.eu/clima/sites/clima/files/ets/revision/docs/swd_2015_297_en.pdf

[58] ELLERMAN, A. D., BUCHNER, B. K. and CARRARO, C. *Allocation in the European Emissions Trading Scheme: Rights, Rents and Fairness* [online]. 1. Cambridge : Cambridge University Press, 2007. ISBN 9780521875684. Available from: https://www.cambridge.org/core/product/identifier/9780511493478/type/book

[59] CHMELIK, Tomas. *Allocation in the European Emissions Trading Scheme: Rights, Rents and Fairness*. Cambridge : Cambridge University Press, 2007. ISBN 9780511493478.

[60] MŽP and MPO. Národní Alokační Plán 2005-2007. [online]. 2004. [Accessed 24 February 2019]. Available from: https://www.vlada.cz/assets/urad-vlady/poskytovani-informaci/poskytnute-informace-na-zadost/Priloha_1_Narodni_alokacni_plan_2005-2007.pdf

[61] MŽP and MPO. Národní Alokační Plán ČR 2008-2012. [online]. 2012. [Accessed 24 February 2019]. Available from: https://ec.europa.eu/clima/sites/clima/files/ets/pre2013/nap/docs/nap_czech_final_en.pdf

[62] MŽP. 383/2012 Sb. Zákon o podmínkách obchodování s povolenkami na emise skleníkových plynů. [online]. [Accessed 25 January 2019]. Available from: https://www.zakonyprolidi.cz/cs/2012-383

[63] EEA. Trends and projections in the EU ETS in 2018. *EEA Technical report* [online]. 2017. [Accessed 11 January 2019]. Available from: http://www.eea.europa.eu/publications/trends-and-projections-eu-ets-2015

[64] SMITHIN, John. Aggregate demand and supply. *Post-Keynesian Macroeconomics: Essays in Honour of Ingrid Rima*. 2007. Vol. 4, p. 108–128. DOI 10.4324/9780203964125.

[65] JONES, Charles I. *Macroeconomics*. 4. New York : W.W. Norton & Company, 2017. ISBN 978-0393603767.

[66] KLEIN, Alexander and LÍZAL, Lubomír. Přehledová studie: Analýza dopadů energetických šoků na ekonomiku. . 2019.

[67] HANSEN, Bruce E. Econometrics. [online]. 2018. No. January, p. 556. DOI 10.1016/0161-8938(92)90019-9. Available from: https://www.ssc.wisc.edu/~bhansen/econometrics/Econometrics.pdf

[68] SALMANOV, Oleg Nikolayevich, ZAERNJUK, Victor Makarovich, LOPATINA, Olga Alekseevna, DRACHENA, Irina Petrovna and VIKULINA, Evgeniya Viktorovna. Investigating the impact of monetary policy using the vector autoregression method. *International Journal of Economics and Fiancial Issues*. 2016. Vol. 6, no. S2, p. 273–282. DOI 10.1016/0022-3468(91)90518-X.

[69] ISARD, W., AZIS, I., DRENNAN, M., MILLER, R., E., SALTZMAN, S. and THORBECKE, E. *Methods of Interregional and Regional Analysis*. 1. London : Routledge, 1998. ISBN 9781351917902.

[70] SU, Bin, HUANG, H. C., ANG, B. W. and ZHOU, P. Input-output analysis of CO2emissions embodied in trade: The effects of sector aggregation. *Energy Economics* [online]. 2010. Vol. 32, no. 1, p. 166–175. DOI 10.1016/j.eneco.2009.07.010. Available from: http://dx.doi.org/10.1016/j.eneco.2009.07.010

[71] LIZAL, Lubomir. Auctioning CO2 Permits in the Czech Republic: Expected Sectoral and Overall Economic Effects. . 2008.

[72] WIEDMANN, Thomas, WOOD, Richard, MINX, Jan C., LENZEN, Manfred, GUAN, Dabo and HARRIS, Rocky. Carbon footprint time series of the UK - results from a multi-region input-output model. *Economic Systems Research*. 2010. Vol. 22, no. 1, p. 19–42. DOI 10.1080/09535311003612591.

[73] FERNÁNDEZ-VILLAVERDE, Jesús. The econometrics of DSGE models. *SERIEs*. 2010. Vol. 1, no. 1–2, p. 3–49. DOI 10.1007/s13209-009-0014-7.

[74] CHRISTIANO, Lawrence J., EICHENBAUM, Martin S. and TRABANDT, Mathias. On DSGE Models. *Journal of Economic Perspectives* [online]. 2018. Vol. 32, no. 3, p. 113–140. DOI 10.1257/jep.32.3.113. Available from: https://pubs.aeaweb.org/doi/10.1257/jep.32.3.113

[75] ZENG, Lisheng. A Property of the Leontief Inverse and its Applications to Comparative Static Analysis. *Economic Systems Research* [online]. 2001. Vol. 13, no. 3, p. 299–315. DOI 10.1080/09537320120070185. Available from: http://www.tandfonline.com/doi/full/10.1080/09537320120070185

[76] BEDNAŘÍKOVÁ, Zuzana. Ekonomický přínos zemědělství pro venkovskou ekonomiku: Aplikace input-output analýzy. *Politická ekonomie*. 2012. P. 265–285.

[77] NOSKOVÁ, Marta. Regional Economic Effects of the European Capital of Culture Project: The Use of Input-Output Analysis. *Ekonomie*. 2016. Vol. 3, no. XIX, p. 57–74. DOI 10.15240/tul/001/2016-3-005.

[78] VARVLA, Lukáš and ROJÍČEK, Marek. Sestavování symetrických input-output tabulek a jejich aplikace. *Centrum ekonomických studií VŠEM*. 2006. P. 28–43. využít zvýrazněných věcí

[79] CZSO. Symmetrical Input-Output Tables. [online]. 2019. [Accessed 26 January 2019]. Available from: http://apl.czso.cz/pll/rocenka/rocenkaout.dod_uziti?

[80] EUROSTAT and CZSO. NACE Rev. 2. *NACE ref. 2 - Statistical classification of economic activities in the European Community* [online]. 2008. Vol. ISSN 1977-, p. 1–35. DOI 10.22034/APJCP.2018.19.2.401. Available from: http://ec.europa.eu/eurostat

[81] EUROPEAN COMMISSION. List of NACE codes. [online]. [Accessed 26 January 2019]. Available from: http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

[82] MZP. Statistical Yearbook of the Czech Environment. [online]. 2017. [Accessed 1 March 2019]. Available from: https://www.mzp.cz/cz/statisticka_rocenka_zivotniho_prostredi_publikace

[83] BRANGER, Frederic, QUIRION, Philippe and CHEVALLIER, Julien. Carbon leakage and competitiveness of cement and steel industries under the EU ETS: Much ado about nothing. *Energy Journal*. 2016. Vol. 37, no. 3, p. 109–135. DOI 10.5547/01956574.37.3.fbra.

[84] SANTAMARÍA, Alberto, LINARES, Pedro and PINTOS, Pablo. The effects of carbon prices and anti-leakage policies on selected industrial sectors in spain - Cement, steel and oil refining. *Energy Policy* [online]. 2014. Vol. 65, no. 2014, p. 708–717. DOI 10.1016/j.enpol.2013.10.031. Available from: http://dx.doi.org/10.1016/j.enpol.2013.10.031

[85] BOUTABBA, Mohamed Amine and LARDIC, Sandrine. EU Emissions Trading Scheme, competitiveness and carbon leakage: new evidence from cement and steel industries. *Annals of Operations Research*. 2017. Vol. 255, no. 1–2, p. 47–61. DOI 10.1007/s10479-016-2246-9.

[86] MONJON, Stéphanie and QUIRION, Philippe. Addressing leakage in the EU ETS: Border adjustment or output-based allocation? *Ecological Economics* [online]. 2011. Vol. 70, no. 11, p. 1957–1971. DOI 10.1016/j.ecolecon.2011.04.020. Available from: http://dx.doi.org/10.1016/j.ecolecon.2011.04.020

[87] CZSO. Wages, labor costs - time series data. [online]. [Accessed 1 March 2019]. Available from: https://www.czso.cz/csu/czso/pmz_cr

[88] EEX. European Emission Allowance Auction (EUA) Primary Market. [online]. [Accessed 26 March 2019]. Available from: https://www.eex.com/en/market-data/environmental-markets/auction-market/european-emission-allowances-auction#!/

APPENDIX A: FULL I-O MODEL RESULTS

The following tables are present in this appendix:

Table No.	Description	Sources
16	Turnover change in mil. CZK at €30 per EUA – Scenario I.	EEA, CZSO, MZP, Author
17	Turnover change in mil. CZK at €30 per EUA – Scenario II.	EEA, CZSO, MZP, Author
18	Change in employment at €30 per EUA – Scenario I.	EEA, CZSO, MZP, Author
19	Change in employment at €30 per EUA – Scenario II.	EEA, CZSO, MZP, Author
20	Sectoral direct, indirect, and total output and employment multipliers.	CZSO, Author

Table 16. Turnover change in mil. CZK at €30 per EUA – Scenario I.
(Source: EEA, CZSO, MZP; Calculations: Author)

Sector	PMI	IMI	PRI	IRI	TII
National Economy	-26 422.0	-51 968.9	26 422.0	48 009.4	-3 959.5
01 Agriculture	0.0	-344.6	105.7	350.1	5.5
02 Forestry and logging	0.0	-61.2	27.0	233.4	172.1
03 Fishing and aquaculture	0.0	-0.6	1.4	2.1	1.5
05 Mining of coal and lignite	0.0	-1 858.6	247.8	511.7	-1 346.9
06 Extraction of crude petroleum and natural gas	0.0	-3 144.4	534.8	997.4	-2 147.0
07 Mining of metal ores	0.0	56.7	64.5	160.0	216.8
08 Other mining and quarrying	0.0	-30.4	88.1	165.3	134.9
09 Mining support service activities	0.0	-88.4	18.2	40.9	-47.5
10 Manufacture of food products	0.0	-145.4	300.7	513.8	368.4
11 Manufacture of beverages	0.0	-12.5	113.6	145.3	132.8
12 Manufacture of tobacco products	0.0	-6.6	0.0	9.0	2.4
13 Manufacture of textiles	0.0	-28.1	105.7	171.6	143.5
14 Manufacture of wearing apparel	0.0	-169.7	4.2	128.5	-41.3
15 Manufacture of leather and related products	0.0	-15.8	1.8	28.9	13.1
16 Manufacture of wood	0.0	-132.8	38.8	336.4	203.6
17 Manufacture of paper and paper products	-99.5	-227.1	3 547.9	4 367.3	4 140.2
18 Printing and reproduction of recorded media	0.0	-56.1	39.4	209.8	153.8
19 Manufacture of coke and refined petroleum	-57.8	-393.8	0.0	413.2	19.4
20 Manufacture of chemicals	-213.7	-662.5	855.8	1 510.5	848.0

21 Manufacture of basic pharmaceutical products	0.0	-16.3	39.1	79.0	62.7
22 Manufacture of rubber and plastic products	0.0	-198.8	174.5	561.8	362.9
23 Other non-metallic mineral products	-482.0	-689.2	241.6	465.6	-223.6
24 Manufacture of basic metals	2 066.4	1 795.4	1 140.9	2 386.4	4 181.8
25 Manufacture of fabricated metal products	0.0	-266.1	253.9	815.4	549.4
26 Manufacture of computer, electronics	0.0	-643.1	59.2	484.2	-158.9
27 Manufacture of electrical equipment	0.0	-907.7	124.9	553.6	-354.1
28 Manufacture of machinery and equipment	0.0	-738.7	188.2	674.0	-64.7
29 Manufacture of motor vehicles, trailers	0.0	-361.3	537.0	1 327.7	966.4
30 Manufacture of other transport equipment	0.0	-85.5	81.3	152.6	67.0
31 Manufacture of furniture	0.0	-20.9	19.1	46.8	25.9
32 Other manufacturing	0.0	-28.7	28.4	65.8	37.1
33 Repair and installation of machinery	0.0	-570.8	25.1	258.4	-312.4
35 Electricity, gas, steam and air conditioning	-27 545.1	-34 081.7	1 969.7	3 392.4	-30 689.3
36 Water collection, treatment and supply	0.0	-193.0	3 165.9	3 627.0	3 434.0
37-39 Sewerage. Waste collection, water treatment	0.0	-172.7	6 379.9	7 671.5	7 498.8
41 Construction of buildings	0.0	-79.0	0.0	104.4	25.4
42 Civil engineering	0.0	-307.6	0.0	278.1	-29.6
43 Specialized construction activities	0.0	-752.0	0.0	803.4	51.4
45 Wholesale and retail trade motor vehicles	0.0	-265.1	0.0	378.1	113.0
46+47 Wholesale trade	0.0	-1 211.7	0.0	1 569.2	357.6

49 Land transport and transport via pipelines	0.0	-586.2	259.6	784.5	198.2
50 Water transport	0.0	-3.0	2.1	7.0	4.0
51 Air transport	-90.2	-109.6	28.0	45.1	-64.5
52 Warehousing for transportation	0.0	-425.1	208.1	668.9	243.7
53 Postal and courier activities	0.0	-157.7	29.3	209.9	52.2
55 Accommodation	0.0	-28.1	0.0	55.0	26.9
56 Food and beverage service activities	0.0	-79.1	0.0	79.3	0.2
58 Publishing activities	0.0	-19.5	0.1	22.5	3.0
59 Film, TV, music and sound production	0.0	-4.1	0.1	6.6	2.5
60 Programming and broadcasting activities	0.0	-4.1	0.1	6.1	2.0
61 Telecommunications	0.0	-206.1	0.3	270.1	64.0
62 Computer programming, consultancy	0.0	-167.5	0.4	163.2	-4.3
63 Information service activities	0.0	-56.9	0.1	69.4	12.6
64 Financial service activities	0.0	-670.8	0.0	562.1	-108.7
65 Insurance, reinsurance and pension funding	0.0	-101.7	0.0	97.3	-4.4
66 Auxiliary financial and insurance services	0.0	-54.2	0.0	53.7	-0.5
68 Real estate activities	0.0	-473.1	0.0	869.7	396.5
69 Legal and accounting activities	0.0	-205.9	0.0	212.4	6.4
70 Activities of head and management offices	0.0	-189.3	0.0	177.3	-12.0
71 Architectural and engineering activities	0.0	-236.9	0.0	369.5	132.6
72 Scientific research and development	0.0	-68.7	0.0	63.8	-4.9
73 Advertising and market research	0.0	-144.1	0.0	166.9	22.8

74 Other professional, scientific and technical	0.0	-143.5	0.0	481.5	338.0
75 Veterinary activities	0.0	-5.5	0.0	5.8	0.4
77 Rental and leasing activities	0.0	-92.1	0.0	119.2	27.1
78 Employment activities	0.0	-19.0	0.0	27.7	8.7
79 Travel agency, tour operator	0.0	-46.7	0.0	36.3	-10.3
80 Security and investigation activities	0.0	-163.0	0.0	67.8	-95.2
81 Services to buildings and landscape activities	0.0	-107.5	0.0	155.3	47.7
82 Office administrative, office support	0.0	-54.6	0.0	271.5	216.9
84 Public administration and defense	0.0	-96.4	5 369.4	5 691.5	5 595.1
85 Education	0.0	-60.4	0.0	84.5	24.1
86 Human health activities	0.0	-12.7	0.0	21.0	8.3
87 Residential care activities	0.0	-1.0	0.0	7.6	6.6
88 Social work activities	0.0	-0.9	0.0	2.3	1.4
90 Creative, arts and entertainment activities	0.0	-3.5	0.0	7.3	3.8
91 Libraries, archives, museums	0.0	-0.8	0.0	1.2	0.4
92 Gambling and betting activities	0.0	-0.7	0.0	1.9	1.1
93 Sports activities, amusement and recreation	0.0	-8.9	0.0	26.1	17.2
94 Activities of membership organizations	0.0	-7.9	0.0	13.4	5.5
95 Repair personal and household goods	0.0	-30.2	0.0	27.5	-2.7
96+ Other	0.0	-5.1	0.0	9.0	3.9

(PMI – primary market impact, IMI – induced market impact, PRI – primary redistribution impact, IRI – induced redistribution impact, TII – total induced impact)

Table 17. Turnover change in mil. CZK at €30 per EUA – Scenario II.
(Source: EEA, CZSO, MZP, Calculations: Author)

Sector	PMI	IMI	PRI	IRI	TII
National Economy	-50 603.1	-96 088.2	50 603.1	91 947.0	-4 141.2
01 Agriculture	0.0	-535.8	202.4	670.5	134.7
02 Forestry and logging	0.0	-132.0	51.6	446.9	314.9
03 Fishing and aquaculture	0.0	-1.0	2.7	4.0	3.0
05 Mining of coal and lignite	0.0	-2 915.6	474.6	980.0	-1 935.7
06 Extraction of crude petroleum and natural gas	0.0	-4 970.9	1 024.2	1 910.2	-3 060.7
07 Mining of metal ores	0.0	-198.4	123.5	306.5	108.0
08 Other mining and quarrying	0.0	-146.0	168.8	316.5	170.5
09 Mining support service activities	0.0	-146.0	34.9	78.4	-67.6
10 Manufacture of food products	0.0	-261.6	576.0	984.0	722.4
11 Manufacture of beverages	0.0	-22.5	217.6	278.3	255.9
12 Manufacture of tobacco products	0.0	-12.9	0.0	17.2	4.4
13 Manufacture of textiles	0.0	-56.0	202.5	328.6	272.6
14 Manufacture of wearing apparel	0.0	-267.5	8.0	246.0	-21.4
15 Manufacture of leather and related products	0.0	-30.8	3.5	55.3	24.5
16 Manufacture of wood	0.0	-329.3	74.3	644.3	315.0
17 Manufacture of paper and paper products	-346.2	-625.4	6 794.9	8 364.2	7 738.8
18 Printing and reproduction of recorded media	0.0	-109.3	75.5	401.8	292.5
19 Manufacture of coke and refined petroleum	-833.2	-1 497.3	0.0	791.3	-706.0
20 Manufacture of chemicals	-829.2	-1 850.5	1 639.1	2 892.9	1 042.4
21 Manufacture of basic pharmaceutical products	0.0	-31.1	74.8	151.2	120.1

22 Manufacture of rubber and plastic products	0.0	-417.5	334.1	1 075.9	658.4
23 Other non-metallic mineral products	-3 780.4	-4 654.8	462.7	891.8	-3 763.0
24 Manufacture of basic metals	-4 183.7	-5 638.0	2 185.1	4 570.4	-1 067.7
25 Manufacture of fabricated metal products	0.0	-892.9	486.3	1 561.7	668.9
26 Manufacture of computer, electronics	0.0	-1 033.3	113.3	927.3	-106.0
27 Manufacture of electrical equipment	0.0	-1 425.6	239.3	1 060.3	-365.3
28 Manufacture of machinery and equipment	0.0	-1 321.5	360.5	1 290.8	-30.7
29 Manufacture of motor vehicles, trailers	0.0	-755.9	1 028.4	2 542.7	1 786.9
30 Manufacture of other transport equipment	0.0	-150.4	155.7	292.2	141.8
31 Manufacture of furniture	0.0	-38.4	36.6	89.7	51.3
32 Other manufacturing	0.0	-61.0	54.4	126.0	65.0
33 Repair and installation of machinery	0.0	-912.5	48.0	494.8	-417.6
35 Electricity, gas, steam and air conditioning	-40 259.1	-50 304.0	3 772.4	6 497.1	-43806.9
36 Water collection, treatment and supply	0.0	-305.9	6 063.3	6 946.4	6 640.5
37-39 Sewerage. Waste collection, water treatment	0.0	-603.1	12 218.8	14 692.5	14 089.4
41 Construction of buildings	0.0	-133.0	0.0	200.0	67.1
42 Civil engineering	0.0	-494.2	0.0	532.5	38.4
43 Specialized construction activities	0.0	-1 201.0	0.0	1 538.7	337.7
45 Wholesale and retail trade motor vehicles	0.0	-479.1	0.0	724.1	245.0
46+47 Wholesale trade	0.0	-2 345.7	0.0	3 005.4	659.7
49 Land transport and transport via pipelines	0.0	-1 097.3	497.1	1 502.4	405.1
50 Water transport	0.0	-7.2	4.0	13.4	6.2

51 Air transport	-371.3	-418.5	53.6	86.4	-332.1
52 Warehousing for transportation	0.0	-921.8	398.6	1 281.0	359.2
53 Postal and courier activities	0.0	-247.2	56.2	401.9	154.8
55 Accommodation	0.0	-49.3	0.0	105.4	56.1
56 Food and beverage service activities	0.0	-137.0	0.0	151.9	14.8
58 Publishing activities	0.0	-35.1	0.3	43.1	8.0
59 Film, TV, music and sound production	0.0	-7.5	0.1	12.6	5.1
60 Programming and broadcasting activities	0.0	-7.7	0.1	11.8	4.0
61 Telecommunications	0.0	-332.9	0.6	517.2	184.3
62 Computer programming, consultancy	0.0	-280.4	0.8	312.6	32.2
63 Information service activities	0.0	-96.1	0.2	133.0	36.9
64 Financial service activities	0.0	-1 104.0	0.0	1 076.6	-27.4
65 Insurance, reinsurance and pension funding	0.0	-171.8	0.0	186.4	14.6
66 Auxiliary financial and insurance services	0.0	-93.6	0.0	102.8	9.2
68 Real estate activities	0.0	-793.5	0.0	1 665.6	872.1
69 Legal and accounting activities	0.0	-353.3	0.0	406.8	53.5
70 Activities of head and management offices	0.0	-321.6	0.0	339.6	18.0
71 Architectural and engineering activities	0.0	-396.3	0.0	707.6	311.3
72 Scientific research and development	0.0	-118.5	0.0	122.3	3.8
73 Advertising and market research	0.0	-253.5	0.0	319.6	66.0
74 Other professional, scientific and technical	0.0	-258.2	0.0	922.2	664.0
75 Veterinary activities	0.0	-8.7	0.0	11.1	2.4

77 Rental and leasing activities	0.0	-174.8	0.0	228.3	53.4
78 Employment activities	0.0	-43.6	0.0	53.1	9.5
79 Travel agency, tour operator	0.0	-80.7	0.0	69.6	-11.2
80 Security and investigation activities	0.0	-255.5	0.0	129.9	-125.6
81 Services to buildings and landscape activities	0.0	-183.6	0.0	297.3	113.7
82 Office administrative, office support	0.0	-100.5	0.0	519.9	419.4
84 Public administration and defense	0.0	-200.8	10 283.5	10 900.3	10 699.5
85 Education	0.0	-99.2	0.0	161.8	62.6
86 Human health activities	0.0	-23.3	0.0	40.2	16.9
87 Residential care activities	0.0	-2.1	0.0	14.6	12.5
88 Social work activities	0.0	-1.6	0.0	4.3	2.8
90 Creative, arts and entertainment activities	0.0	-6.1	0.0	13.9	7.9
91 Libraries, archives, museums	0.0	-1.4	0.0	2.4	0.9
92 Gambling and betting activities	0.0	-1.3	0.0	3.5	2.3
93 Sports activities, amusement and recreation	0.0	-16.1	0.0	50.0	34.0
94 Activities of membership organizations	0.0	-13.8	0.0	25.8	11.9
95 Repair personal and household goods	0.0	-54.8	0.0	52.7	-2.1
96+ Other	0.0	-10.3	0.0	17.2	7.0

(PMI – primary market impact, IMI – induced market impact, PRI – primary redistribution impact, IRI – induced redistribution impact, TII – total induced impact)

APPENDIX A

Table 18. Change in employment at €30 per EUA – Scenario I.
(Source: EEA, CZSO, MZP, Calculations: Author)

Sector	PMI	IMI	PRI	IRI	TII
National Economy	-7 070	-16 986	16 058	27 069	10 083
01 Agriculture	0	-187	57	190	3
02 Forestry and logging	0	-32	14	121	90
03 Fishing and aquaculture	0	0	1	1	1
05 Mining of coal and lignite	0	-484	65	133	-351
06 Extraction of crude petroleum and natural gas	0	-332	56	105	-227
07 Mining of metal ores	0	9	10	26	35
08 Other mining and quarrying	0	-11	31	58	48
09 Mining support service activities	0	-30	6	14	-16
10 Manufacture of food products	0	-62	128	219	157
11 Manufacture of beverages	0	-5	47	60	55
12 Manufacture of tobacco products	0	-2	0	2	1
13 Manufacture of textiles	0	-10	36	58	49
14 Manufacture of wearing apparel	0	-39	1	29	-9
15 Manufacture of leather and related products	0	-3	0	6	3
16 Manufacture of wood	0	-61	18	154	93
17 Manufacture of paper and paper products	-35	-81	1 261	1 552	1 472
18 Printing and reproduction of recorded media	0	-25	18	95	70
19 Manufacture of coke and refined petroleum	-16	-108	0	113	5
20 Manufacture of chemicals	-61	-188	242	428	240
21 Manufacture of basic pharmaceutical products	0	-4	10	20	16
22 Manufacture of rubber and plastic products	0	-67	58	188	122
23 Other non-metallic mineral products	-180	-257	90	174	-83
24 Manufacture of basic metals	637	553	352	735	1 289
25 Manufacture of fabricated metal products	0	-93	89	287	193

26 Manufacture of computer, electronics	0	-203	19	153	-50
27 Manufacture of electrical equipment	0	-297	41	181	-116
28 Manufacture of machinery and equipment	0	-239	61	218	-21
29 Manufacture of motor vehicles, trailers	0	-150	222	550	400
30 Manufacture of other transport equipment	0	-28	27	51	22
31 Manufacture of furniture	0	-8	7	18	10
32 Other manufacturing	0	-9	9	20	11
33 Repair and installation of machinery	0	-220	10	100	-120
35 Electricity, gas, steam and air conditioning	-7 348	-9 092	525	905	-8 187
36 Water collection, treatment and supply	0	-135	2 220	2 544	2 409
37-39 Sewerage. Waste collection, water treatment	0	-129	4 760	5 723	5 594
41 Construction of buildings	0	-54	0	71	17
42 Civil engineering	0	-213	0	193	-20
43 Specialized construction activities	0	-410	0	438	28
45 Wholesale and retail trade motor vehicles	0	-211	0	301	90
46+47 Wholesale trade	0	-970	0	1 256	286
49 Land transport and transport via pipelines	0	-413	183	553	140
50 Water transport	0	-2	1	4	2
51 Air transport	-68	-82	21	34	-48
52 Warehousing for transportation	0	-317	155	498	182
53 Postal and courier activities	0	-101	19	134	33
55 Accommodation	0	-21	0	42	20
56 Food and beverage service activities	0	-62	0	62	0
58 Publishing activities	0	-9	0	10	1
59 Film, TV, music and sound production	0	-2	0	3	1

60 Programming and broadcasting activities	0	-2	0	3	1
61 Telecommunications	0	-95	0	124	29
62 Computer programming, consultancy	0	-75	0	73	-2
63 Information service activities	0	-22	0	27	5
64 Financial service activities	0	-259	0	217	-42
65 Insurance, reinsurance and pension funding	0	-51	0	49	-2
66 Auxiliary financial and insurance services	0	-25	0	25	0
68 Real estate activities	0	-143	0	263	120
69 Legal and accounting activities	0	-104	0	108	3
70 Activities of head and management offices	0	-95	0	89	-6
71 Architectural and engineering activities	0	-152	0	238	85
72 Scientific research and development	0	-29	0	27	-2
73 Advertising and market research	0	-110	0	128	17
74 Other professional, scientific and technical	0	-100	0	335	235
75 Veterinary activities	0	-3	0	3	0
77 Rental and leasing activities	0	-87	0	113	26
78 Employment activities	0	-25	0	36	11
79 Travel agency, tour operator	0	-80	0	62	-18
80 Security and investigation activities	0	-197	0	82	-115
81 Services to buildings and landscape activities	0	-133	0	192	59
82 Office administrative, office support	0	-65	0	321	256
84 Public administration and defense	0	-93	5 187	5 498	5 405
85 Education	0	-84	0	117	33
86 Human health activities	0	-15	0	25	10
87 Residential care activities	0	-1	0	9	8
88 Social work activities	0	-1	0	3	2
90 Creative, arts and entertainment activities	0	-3	0	6	3

91 Libraries, archives, museums	0	-1	0	1	0
92 Gambling and betting activities	0	-1	0	2	1
93 Sports activities, amusement and recreation	0	-9	0	25	17
94 Activities of membership organizations	0	-7	0	12	5
95 Repair personal and household goods	0	-24	0	21	-2
96+ Other	0	-4	0	6	3

(PMI – primary market impact, IMI – induced market impact, PRI – primary redistribution impact, IRI – induced redistribution impact, TII – total induced impact)

Table 19. Change in employment at €30 per EUA – Scenario II.
(Source: EEA, CZSO, MZP, Calculations: Author)

Sector	PMI	IMI	PRI	IRI	TII
National Economy	-14 303	-32 379	30 754	51 842	19 462
01 Agriculture	0	-290	110	363	73
02 Forestry and logging	0	-69	27	233	164
03 Fishing and aquaculture	0	0	1	2	1
05 Mining of coal and lignite	0	-760	124	255	-504
06 Extraction of crude petroleum and natural gas	0	-525	108	202	-323
07 Mining of metal ores	0	-32	20	49	17
08 Other mining and quarrying	0	-52	60	112	60
09 Mining support service activities	0	-49	12	27	-23
10 Manufacture of food products	0	-111	245	419	307
11 Manufacture of beverages	0	-9	89	114	105
12 Manufacture of tobacco products	0	-3	0	4	1
13 Manufacture of textiles	0	-19	69	111	92
14 Manufacture of wearing apparel	0	-61	2	56	-5
15 Manufacture of leather and related products	0	-7	1	12	5
16 Manufacture of wood	0	-150	34	294	144
17 Manufacture of paper and paper products	-123	-222	2 415	2 973	2 751
18 Printing and reproduction of recorded media	0	-50	34	182	133
19 Manufacture of coke and refined petroleum	-229	-411	0	217	-194
20 Manufacture of chemicals	-235	-524	464	820	295
21 Manufacture of basic pharmaceutical products	0	-8	19	39	31
22 Manufacture of rubber and plastic products	0	-140	112	360	221
23 Other non-metallic mineral products	-1 410	-1 736	173	333	-1 403
24 Manufacture of basic metals	-1 289	-1 738	673	1 409	-329

25 Manufacture of fabricated metal products	0	-314	171	549	235
26 Manufacture of computer, electronics	0	-326	36	292	-33
27 Manufacture of electrical equipment	0	-466	78	347	-119
28 Manufacture of machinery and equipment	0	-428	117	418	-10
29 Manufacture of motor vehicles, trailers	0	-313	426	1 053	740
30 Manufacture of other transport equipment	0	-50	52	97	47
31 Manufacture of furniture	0	-15	14	35	20
32 Other manufacturing	0	-18	16	38	19
33 Repair and installation of machinery	0	-352	19	191	-161
35 Electricity, gas, steam and air conditioning	-10 739	-13 419	1 006	1 733	-11 686
36 Water collection, treatment and supply	0	-215	4 253	4 872	4 657
37-39 Sewerage. Waste collection, water treatment	0	-450	9 115	10 961	10 511
41 Construction of buildings	0	-90	0	135	45
42 Civil engineering	0	-342	0	369	27
43 Specialized construction activities	0	-655	0	840	184
45 Wholesale and retail trade motor vehicles	0	-382	0	577	195
46+47 Wholesale trade	0	-1 877	0	2 405	528
49 Land transport and transport via pipelines	0	-773	350	1 058	285
50 Water transport	0	-4	2	8	4
51 Air transport	-278	-314	40	65	-249
52 Warehousing for transportation	0	-687	297	954	268
53 Postal and courier activities	0	-158	36	257	99
55 Accommodation	0	-37	0	80	42
56 Food and beverage service activities	0	-107	0	118	12

58 Publishing activities	0	-15	0	19	4
59 Film, TV, music and sound production	0	-4	0	6	2
60 Programming and broadcasting activities	0	-4	0	6	2
61 Telecommunications	0	-153	0	238	85
62 Computer programming, consultancy	0	-126	0	140	14
63 Information service activities	0	-37	0	51	14
64 Financial service activities	0	-427	0	416	-11
65 Insurance, reinsurance and pension funding	0	-86	0	94	7
66 Auxiliary financial and insurance services	0	-43	0	47	4
68 Real estate activities	0	-240	0	504	264
69 Legal and accounting activities	0	-179	0	206	27
70 Activities of head and management offices	0	-162	0	171	9
71 Architectural and engineering activities	0	-255	0	456	200
72 Scientific research and development	0	-50	0	52	2
73 Advertising and market research	0	-194	0	244	51
74 Other professional, scientific and technical	0	-180	0	642	462
75 Veterinary activities	0	-5	0	6	1
77 Rental and leasing activities	0	-166	0	216	51
78 Employment activities	0	-57	0	70	12
79 Travel agency, tour operator	0	-139	0	120	-19
80 Security and investigation activities	0	-309	0	157	-152
81 Services to buildings and landscape activities	0	-227	0	368	141
82 Office administrative, office support	0	-119	0	615	496
84 Public administration and defense	0	-194	9 934	10 530	10 336

85 Education	0	-137	0	224	87
86 Human health activities	0	-28	0	48	20
87 Residential care activities	0	-2	0	17	15
88 Social work activities	0	-2	0	5	3
90 Creative, arts and entertainment activities	0	-5	0	11	6
91 Libraries, archives, museums	0	-1	0	2	1
92 Gambling and betting activities	0	-1	0	3	2
93 Sports activities, amusement and recreation	0	-15	0	48	33
94 Activities of membership organizations	0	-12	0	22	10
95 Repair personal and household goods	0	-43	0	41	-2
96+ Other	0	-7	0	12	5

(PMI – primary market impact, IMI – induced market impact, PRI – primary redistribution impact, IRI – induced redistribution impact, TII – total induced impact)

APPENDIX A

Table 20. Sectoral direct, indirect, and total output and employment multipliers.
(Source: CZSO, Calculations: Author)

Sector (NACE)	MO (dir.)	MO (ind.)	MO (tot.)	ME (-)
01 Agriculture	1.144	0.762	1.906	0.542
02 Forestry and logging	1.122	0.641	1.763	0.521
03 Fishing and aquaculture	1.000	0.570	1.570	0.435
05 Mining of coal and lignite	1.008	0.580	1.588	0.261
06 Extraction of crude petroleum and natural gas	1.000	0.001	1.002	0.106
07 Mining of metal ores	1.002	0.237	1.238	0.161
08 Other mining and quarrying	1.056	0.833	1.889	0.354
09 Mining support service activities	1.186	0.735	1.921	0.339
10 Manufacture of food products	1.145	0.760	1.905	0.426
11 Manufacture of beverages	1.044	0.822	1.866	0.411
12 Manufacture of tobacco products	1.003	0.249	1.252	0.245
13 Manufacture of textiles	1.145	0.552	1.697	0.339
14 Manufacture of wearing apparel	1.070	0.178	1.248	0.228
15 Manufacture of leather and related products	1.068	0.115	1.183	0.217
16 Manufacture of wood	1.191	0.909	2.099	0.457
17 Manufacture of paper and paper products	1.191	0.578	1.769	0.355
18 Printing and reproduction of recorded media	1.253	0.933	2.186	0.454
19 Manufacture of coke and refined petroleum	1.009	0.705	1.714	0.274
20 Manufacture of chemicals	1.141	0.352	1.493	0.283
21 Manufacture of basic pharmaceutical products	1.045	0.274	1.318	0.257
22 Manufacture of rubber and plastic products	1.115	0.603	1.718	0.335
23 Other non-metallic mineral products	1.169	0.681	1.850	0.373
24 Manufacture of basic metals	1.138	0.463	1.601	0.308
25 Manufacture of fabricated metal products	1.203	0.588	1.790	0.351
26 Manufacture of computer, electronics	1.219	0.407	1.627	0.315
27 Manufacture of electrical equipment	1.081	0.629	1.710	0.327
28 Manufacture of machinery and equipment	1.032	0.627	1.659	0.324
29 Manufacture of motor vehicles, trailers	1.366	0.717	2.083	0.414
30 Manufacture of other transport equipment	1.074	0.662	1.735	0.332
31 Manufacture of furniture	1.047	0.886	1.933	0.392

32 Other manufacturing	1.100	0.453	1.553	0.299
33 Repair and installation of machinery	1.047	0.843	1.890	0.385
35 Electricity, gas, steam and air conditioning	1.238	0.708	1.946	0.267
36 Water collection, treatment and supply	1.068	0.988	2.057	0.701
37-39 Sewerage. Waste collection, water treatment	1.173	0.897	2.070	0.746
41 Construction of buildings	1.119	1.465	2.584	0.677
42 Civil engineering	1.275	1.333	2.608	0.693
43 Specialized construction activities	1.297	0.817	2.114	0.546
45 Wholesale and retail trade motor vehicles	1.028	1.040	2.068	0.796
46+47 Wholesale trade	1.146	0.743	1.889	0.800
49 Land transport and transport via pipelines	1.089	0.931	2.020	0.704
50 Water transport	1.009	0.541	1.551	0.571
51 Air transport	1.058	1.028	2.086	0.749
52 Warehousing for transportation	1.275	0.822	2.097	0.745
53 Postal and courier activities	1.222	0.509	1.732	0.640
55 Accommodation	1.006	0.663	1.670	0.755
56 Food and beverage service activities	1.019	0.798	1.817	0.780
58 Publishing activities	1.034	0.654	1.688	0.440
59 Film, TV, music and sound production	1.265	0.579	1.843	0.488
60 Programming and broadcasting activities	1.207	0.686	1.894	0.493
61 Telecommunications	1.243	0.548	1.791	0.459
62 Computer programming, consultancy	1.168	0.454	1.622	0.448
63 Information service activities	1.193	0.274	1.468	0.384
64 Financial service activities	1.094	0.522	1.616	0.387
65 Insurance, reinsurance and pension funding	1.120	0.970	2.090	0.502
66 Auxiliary financial and insurance services	1.434	0.584	2.018	0.458
68 Real estate activities	1.070	0.796	1.866	0.303
69 Legal and accounting activities	1.134	0.539	1.673	0.507
70 Activities of head and management offices	1.110	0.521	1.632	0.503
71 Architectural and engineering activities	1.195	0.977	2.172	0.644
72 Scientific research and development	1.012	0.395	1.407	0.425
73 Advertising and market research	1.528	0.931	2.459	0.765
74 Other professional, scientific and technical	1.179	1.163	2.343	0.696
75 Veterinary activities	1.001	0.908	1.909	0.542

77 Rental and leasing activities	1.013	0.393	1.406	0.947
78 Employment activities	1.023	1.397	2.420	1.315
79 Travel agency, tour operator	1.501	1.304	2.805	1.719
80 Security and investigation activities	1.160	0.774	1.934	1.209
81 Services to buildings and landscape activities	1.214	0.807	2.021	1.239
82 Office administrative, office support	1.167	0.843	2.011	1.182
84 Public administration and defense	1.018	0.498	1.516	0.966
85 Education	1.027	0.338	1.365	1.385
86 Human health activities	1.024	0.562	1.585	1.186
87 Residential care activities	1.043	0.354	1.398	1.159
88 Social work activities	1.001	0.516	1.518	1.140
90 Creative, arts and entertainment activities	1.101	0.745	1.846	0.771
91 Libraries, archives, museums	1.000	0.585	1.585	0.660
92 Gambling and betting activities	1.234	0.716	1.950	0.819
93 Sports activities, amusement and recreation	1.307	0.939	2.245	0.963
94 Activities of membership organizations	1.087	0.766	1.853	0.858
95 Repair personal and household goods	1.034	0.712	1.746	0.780
96+ Other	1.036	0.457	1.493	0.707

(MO dir. – direct output multiplier, MO ind. – indirect output multiplier,
MO tot. – total output multiplier, ME – employment multiplier

APPENDIX B: EXTERNAL DATA SOURCES

The following documents are attached to this thesis:

File name	Short description	Size	File type
CZSO_Employment	Average number of employees according to NACE	34 KB	xlsx
CZSO_SIOT	Symmetrical Input-Output Tables by CZSO	126 KB	xlsx
EC_NACE_v2	Full NACE v2 revision by EC	42 KB	xlsx
EEA_EUA_CZ	Verified emissions and free allocation in the CZE	21 KB	xlsx
FB_Additional_Calculations	Spreadsheet with additional and supporting calculations	553 KB	xlsx
FB_Input-Output_Calculations	Spreadsheet containing main I-O model computations	668 KB	xlsx