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Carbon Leakage in the context of increasing the EU greenhouse gas emission reduction targets – the ways the EU and global emission behave and what influences its scale

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Abstract

The lack of equal globally binding GHG's emission reduction targets is currently leading to a set of diverging GHG's emission prices across the world (or even no price for GHG's emission in some regions). This may result in distortions with direct implications on competitiveness of the industries in regions with strict climate policies (as the European Union) and can cause the issue of carbon leakage. Carbon leakage is defined as 'the increase in emission outside a region as a direct result of the policy to cap emission in this region'.
This paper is the first part of the set of two analysis aiming at the carbon leakage assessment. In the following paper (aimed to be published this year), we will assess the impact of free allowances for emission intensive trade exposed industries (EITE) and the NDCs in the rest of the world countries – for the sake of brevity, we decided to remove these results from the current paper, but they will be presented later this year. The purpose of this paper is to assess the possible scale of the carbon leakage using different assumptions and policy scenarios and identify channels to efficiently prevent the carbon leakage phenomenon. The analysis has been carried out using the computable general equilibrium d-PLACE model developed within the Centre for Climate and Policy Analysis (CAKE).[2] Our model is a recursive dynamic multi-regional and multi-commodity tool in which emissions are modelled in great detail, for example, the process and each fossil fuel combustion related emission are modelled separately. Furthermore, the big advantage of the applied model is a very detailed modelling of EU ETS as well as non-ETS emission targets. In the paper, the simulations using two versions of model was presented – with and without endogenous technical change to elaborate on how the assumptions on technical change affect the modelling results and consequent scale of the carbon leakage. Moreover, this paper aims mainly at the assessment of different channels of carbon leakage; therefore, we do not take into account either NDCs in the rest of the world or free allowances for emission intensive trade exposed sectors. These problems will be handled in the next paper, aimed to be published later this year.
Using the above mentioned CGE (computable general equilibrium model, we captured the main factors, that determine the carbon leakage rates. We assessed the contribution of three channels – demand channel, competitiveness channel and carbon intensity channel to the risk of carbon leakage. It turned out that carbon intensity channel and competitiveness channel are the most important, while demand channel contributes to changes in GHG's emission only in the most restrictive scenario. Moreover, energy channel was further decomposed to the impact of sectoral structure and influence in emission intensity within each sector – the impact of these two channels is also similar, but dependent on the analysed scenario. Such a decomposition allowed us to determine the main channels through which the carbon leakage occur and pursue relevant policy recommendations.

1 See: http://climatecake.pl/?lang=en

LIST OF ABBREVIATIONS

BTA	Border tax adjustment
CAK	Centre for Climate Analysis
CAKE	Centre for Climate and Energy Analyses
CGE model	Computable general equilibrium model
EC	European Commission
EFTA	European Free Trade Association
EITE	Emission Intensive Trade Exposed industries
ESD	Effort Sharing Decision
ESR	Effort Sharing Regulation
ETP	Version of d-PLACE model with energy technical progress
EU	European Union
EU ETS	European Union Emissions Trading Scheme
EU28	European Union of 28 Member States
GDP	Gross Domestic Product
GHG's	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
KOBiZE	The National Centre for Emissions Management
MSR	Market Stability Reserve
NDC	Nationally Determined Contribution
Non-ETS	Sectors not covered by the European Union Emissions Trading Scheme
PLACE	Polish Laboratory for the Analysis of Climate and Energy
PLACE model	Computable General Equilibrium Model created in Polish Laboratory for the Analysis of Climate and Energy
d-PLACE model	Dynamic version of PLACE model created in the Centre for Climate and Energy Analyses
TNAC	Total number of allowances in circulation relevant for MSR

1. INTRODUCTION AND REVIEW OF EARLIER STUDIES

The European Council in October 2014 set a binding economy-wide domestic greenhouse gas emission reduction target for the European Union of at least 40% below 1990 levels by 2030. This commitment was also confirmed in the Nationally Determined Contributions (NDC's) of the European Union and its Member States, and submitted to the secretariat of the United Nations Framework Convention on Climate Change in 2015. European contribution to the emission reduction target is shared among all the member states and the sectors of the economy, and will be delivered in the most cost-effective manner. To achieve this new objective, the European Union has introduced reforms to its Emissions Trading System (EU ETS) covering the most energy intensive economic sectors, jointly responsible to achieve the reduction of the GHG's emission of 43% below 2005 levels by 2030.

Part of the reform in the EU ETS was also the introduction of the Market Stability Reserve (MSR). In 2016, the Market Stability Reserve was established to decrease the existing surplus of allowances in the EU ETS and to avoid the growth of surplus in the future. The Market Stability Reserve is a mechanism designed to automatically adjust the number of GHG's emission allowances available in the EU ETS, depending on the number of allowances in circulation (surplus).[2]

It can be expected that Market Stability Reserve will exert stronger pressure on the sectors covered by the EU ETS due to the reduction of the number of GHG's emission allowances available for installation (thus increasing the target in the EU ETS) and, as a consequence, increasing price signal to reduce emission.

Remaining economic sectors not covered by the EU ETS (non-ETS) contribute to the GHG's emission reduction with a joint reduction target[3] of 30% below 2005 by 2030.[4]

Recently, vastly emerging regional carbon markets and tax systems have led to the emergence of diversified carbon price levels around the world, creating distortions that have a direct impact on the competitiveness of industry in countries with stricter climate policies. Additionally, in the regions outside the EU implementation of reduction targets included in the NDCs submitted under the Paris Agreement, especially by developing countries (the UNFCCC non-Annex I Parties[5] and LDCs[6]), may be threatened for several important reasons:

- Lack of legal consequences for failure to meet the reduction targets submitted in the NDCs under the Paris Agreement.
- Developing countries in many cases do not have much experience and legal mechanisms in place to implement incentives dedicated to the GHG's emission reduction. They need to develop capacity, skills and instruments in this respect.

2 Detailed information about MSR can be found on the European Commission website (link: https://ec.europa.eu/clima/policies/ets/reform_en).

3 Joint reduction target has been divided in to national emission reduction targets for 2030 for all Member States and regulated by the Effort sharing regulation adopted in 2018, see: https://ec.europa.eu/clima/policies/effort/proposal_en

4 See Regulation (EU) 2018/842 - Binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.156.01.0026.01.ENG.

5 Non-Annex I Parties to the UNFCCC – Parties not listed in Annex I of the Convention, mostly low-income developing countries.

6 Least-developed countries (LDCs) – 49 Parties that are given special status under the treaty in view of their limited capacity to adapt to the effects of climate change.

– The implementation of reduction targets in many developing regions rely on external financial support provided by developed countries (Paris Agreement, point 5 of Article 4). As a consequence, it may lead to a situation in which failure to comply with achieving reduction targets will be justified by not receiving adequate financial support and/or capacity building.

Moreover, flexibility in setting reduction targets in the NDCs made them difficult to compare. As regards developing countries, their targets may, for example, cover selected sectors of the economy and selected greenhouse gases. In addition, developing country parties may still have limited reduction targets in the light of different national circumstances. In many cases, the targets set in NDCs do not directly concern GHG's emission reduction, but they refer to developing renewable energy sources or increasing in many ways the efficiency of the economy. At the same time, when it comes to the developed countries (Annex I Parties), they are encouraged to undertake economy-wide absolute emission reduction targets (Paris Agreement, point 4 of Article 4).

The lack of existence of globally binding emission reduction treaty has brought the issue of carbon leakage to the attention of policy makers.

The carbon leakage does not have one precise definition. Broadly, carbon leakage is defined as a displacement of economic activity or investment directly or indirectly causing GHG's emission out of the jurisdiction with more stringent emission abatement policies into other jurisdiction with less stringent policies, see *CEPS (2013)*. IPCC has defined[7] carbon leakage as '*the increase in CO2 emission outside the countries taking domestic mitigation action divided by the reduction in the emission of these countries*'. Their definition is limited to relocation of energy intensive production, but also pays attention to leakage induced by decline in world prices of fossil fuels and potential demand due to the improvements of some countries. In the EU, the Directive on EU ETS[8] confirmed that carbon leakage '*could put certain energy-intensive sectors and subsectors in the Community, which are subject to international competition at an economic disadvantage. This could undermine the environmental integrity and benefit of actions by the Community*' and introduced specific technical conditions under which a sector or subsector is deemed to be at risk of carbon leakage.[9] Similar reasoning also applies for the foreign direct investments.[10]

Carbon leakage is not only a serious environmental concern that effectively undermines the effectiveness of global environmental agreements, but can also cause socio-economic concerns related to the loss of competitiveness (also job losses) on the global markets due to the costs represented by the carbon price for enterprises.

The available evidence collected by the ex-post studies seems to suggest, that due to the continuous free allocation of emission allowances[11] to energy intensive and trade exposed sectors and generally low carbon prices have resulted in a very low risk of carbon leakage in the past two EU ETS periods (2005–2007 and 2008–2012).[12],[13] Concerns, however, still prevail particularly among the Central and Eastern European countries, which remain more energy and carbon emission intensive and heavily trade exposed. This is especially important due to the lack of far-reaching structural reforms in this area and considering the growing level of ambition and changes in the EU ETS. Such concerns and growing carbon costs that impact carbon leakage and competitiveness might act as to prevent or slow down adoption of structural reforms and implementation of climate and energy policies.

In this context, we believe that further analysis on how the variation of key measures will affect the carbon leakage and competitiveness of the European industry and how this impact differs among the EU Member States is needed. In line with the 2030 climate and energy policy framework, free allocation will continue beyond 2020 until other major economies undertake similar climate policies and measures. The strategic decision of the European Commission and existing and proposed carbon leakage measures[14] at present attempt to strike the right balance,

7 For IPCC see: Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. O.R.D. B. Metz, P.R. Bosch, R. Dave, L.A. Meyer. 2007, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. https://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch11s11-7-2.html.

8 See recital 24 of the Directive 2009/29/EC amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0029&from=EN

9 See Directive 2009/29/EC, paragraphs 15-17, more details are also provided here: https://ec.europa.eu/clima/policies/ets/allowances/leakage_en.

10 In case of foreign direct investments, the key parameter is the degree of international mobility of capital.

11 According to the Directive 2003/87/EC, sectors in the EU ETS that are exposed at the risk of carbon leakage get a part of the emission allowances free of charge. Carbon lists were established to identify sectors with high risk of carbon leakage. The first carbon leakage list was valid for 2013–2014. The second carbon leakage list covers the period 2015–2019. As part of the post 2020 architecture, sectors proven to being exposed to carbon leakage continued receiving emission allowances free of charge.

12 See Carbon Leakage Evidence Project: Factsheets for selected sectors, *Ecorys (2013)*, https://ec.europa.eu/clima/sites/clima/files/ets/allowances/leakage/docs/cl_evidence_factsheets_en.pdf

13 The first (2005–2007) and second (2008–2012) ETS trading periods were characterised by fully free allocation of allowances to industry sectors. This process was administered by the individual Member States.

14 See Commission Decision of 27 October 2014 determining, pursuant to Directive 2003/87/EC of the European Parliament and of the Council, a list of sectors and subsectors, which are deemed to be exposed to a significant risk of carbon leakage, for the period from 2015 to 2020.

but should be kept under review in the coming decade, in light of the Paris Agreement. Carbon leakage will however remain as one of the major concerns even beyond 2020.[15]

The objective of this paper is to review the potential for carbon leakage driven by the adoption of the most recent GHG's emission reduction targets within the EU and operationalization of the Market Stability Reserve. Our analysis also attempts to identify the main channels driving the carbon leakage. As we still observe fragmented global market, with different, or no carbon price in some regions, there still will be increased stress in regards to carbon leakage, especially on its socio-economical aspects. In this respect, it is worth emphasizing that in this analysis, we focus mainly on emission aspects. Socio-economic changes are equally important in accordance with the principles of sustainable development, and often even greater in the context of political decision-making processes. Moreover, it must be kept in mind that results presented in this paper do not take into account measures introduced in Europe to prevent carbon leakage, such as free allowances for EITE industries and they do not include mitigation measures in the rest of the world. Therefore, the results related to the carbon leakage rates should be interpreted very cautiously.

2. METHODOLOGY

2.1 Model and data

Understanding the mechanism how the carbon leakage occurs is a key to design appropriate (efficient) policy response. A majority of papers addressing carbon leakage mechanism employed a general equilibrium framework. This framework can well capture the main factors, which determined the carbon leakage rates such as market structure, market regime on emission trading, transportation costs, elasticity parameters[16] and different policy instruments.[17] Combination of these parameters also determine the ability of companies to pass through the additional carbon related costs downstream or towards customers.

The d-PLACE Computable General Equilibrium (CGE) model[18] was employed to run the scenarios described below. d-PLACE is a recursive dynamic multi-regional and multi-commodity (20 sectors) model developed in the neoclassic tradition of CGE models. For the purpose of the analysis, we aggregated the world into 26 regions. In the context of carbon leakage analysis, this model has several advantages over its competitors. First of all, the emissions are modelled in great detail. Process and fossil fuel combustion related emissions are modelled separately. Moreover, each fossil fuel is modelled explicitly. This allows to analyse where the carbon leakage occurs and what policies can be introduced to counteract carbon leakage. Second advantage is a very detailed modelling of EU ETS market. Even though, in this paper, we do not include free allowances for industries under risk of carbon leakage in the methodology, there is a possibility to do so and results of such scenarios will be discussed in the forthcoming paper. Inclusion of non-CO_2 emission in d-PLACE model allows for modelling of leakage of other GHG's as well. As the model includes the labour-leisure choice, it allows for the analysis of impact of climate policies on households' welfare including calculation of compensation mechanisms to offset the increased costs of products for consumers.

In line with the earlier analysis, we further investigate the heavy and energy intensive and trade exposed industries such as refined oil products and coke, chemical production, non-metallic minerals (e.g., cement, lime, gypsum and glass), paper–pulp, iron and steel, aluminium production, reportedly to be expected as the key candidates for carbon leakage. One of the key driving factors behind carbon leakage is the ability of the firms to pass-through the additional climate policy related costs further towards final consumer. In turn, the cost pass-through is a result of several factors, including the underlying market structure, magnitude of the carbon penalty, product substitutability and market demand patterns.

2.2 Analysed scenarios and policy options

2.2.1 Types of scenarios

Table 1 shows the different scenarios analysed together with the respective emission reduction targets assuming for the EU States.

Important assumption of the study is that in order to better reflect and analyse the channels of carbon leakage phenomenon, we have not included emission reduction targets (NDCs) for the other regions/states (outside the EU). This should be borne in mind while analysing the results.

2.2.2 GHG40 and GHG40/ETP (the baseline scenarios)

Scenarios assume implementation of the EU's climate policy targets for GHG's emission reductions by 20% in 2020 and by 40% in 2030 relative to 1990. These targets concern emission from all sectors of the economy.

Total GHG's emission reductions were split between the sectors covered by the EU ETS and non-ETS. In the EU ETS, emission will be reduced by 21% in 2020 and by 43% in 2030 respectively, relative to 2005. Sectors included in EU

15 See Article 10b Directive (EU) 2018/410 of the European Parliament and of the Council of 14 March 2018 amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments, and Decision (EU) 2015/1814 and Commission Notice on the Preliminary Carbon Leakage List for the EU Emission Trading System for Phase 4 (2021–2030).

16 See Oliveira Martins (1996) and Bollen *et al.* (1999).

17 See Paroussos *et al.* (2015).

18 d-PLACE is a recursive dynamic model developed on the basis of the static CGE model called PLACE, which was created in cooperation with IOŚ-PIB in 2013–2016 at the Climate Analysis Centre set up in the KOBiZE. More detailed description of the PLACE model is available at: https://www.mf.gov.pl/documents/764034/5005995/mf_wp_22.pdf

Table 1. Types of scenarios and models used for analysis

Scenario	GHG's emission reduction target for EU-28			Market Stability Reserve in EU ETS
	Total GHG's emission reduction in 2030 compared to 1990	EU ETS in 2030 compared to 2005	non-ETS in 2030 compared to 2005	
Type I – *'without energy technical progress'* Version of model without exogenous change in energy use *(based on conservative assumptions)*				
GHG40	40%	43%	30%	Not included
GHG40/MSR	40%	43%	30%	Included
GHG45/MSR	45%	48%	36%	Included
Type II – *'with energy technical progress (ETP)* Version of model in which exogenous change in energy use (motivated by energy-saving technical progress) is taken into account *(based on EU Reference Scenario 2016* and World Energy Outlook**)*				
GHG40/ETP	40%	43%	30%	Not included
GHG40/MSR/ETP	40%	43%	30%	Included
GHG45/MSR/ETP	45%	48%	36%	Included

Source: CAKE/KOBiZE
* European Commission, EU Reference Scenario 2016 – Energy, transport and GHG emission Trends to 2050, 20th of July 2016.
*** International Energy Agency, *World Energy Outlook 2016 – Current Policy Scenario*, 16th of November 2016.

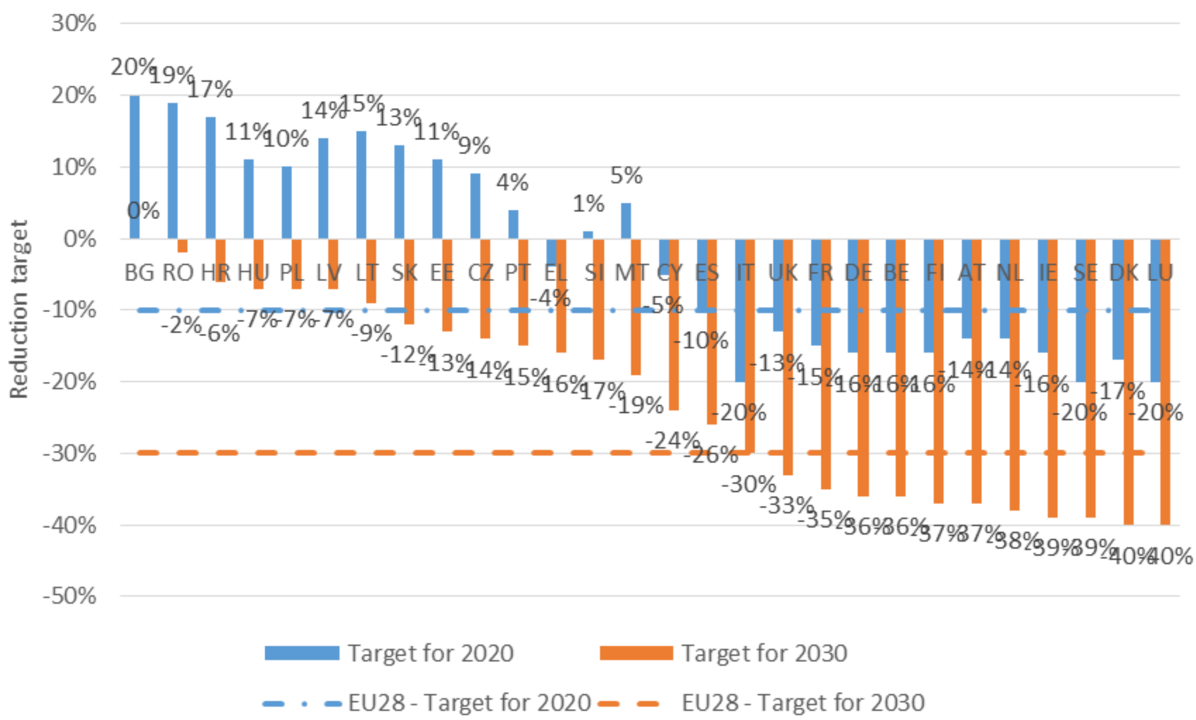

Figure 1. GHG's emission reduction targets in the non-ETS sectors for each EU Member State in 2020 and 2030 relative to 2005 (%)
Source: Based on Decision 2009/406 /EC*and Regulation (EU) 2018/842 (Effort Sharing Regulation).
* See Decision No 406/2009/EC.

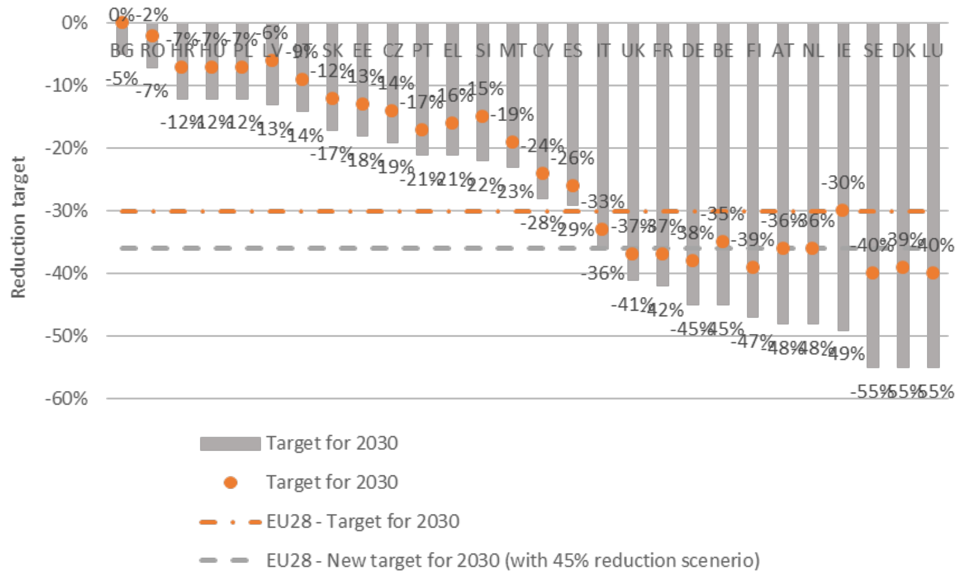

Figure 2. Emission reduction targets in the non-ETS sectors for each EU Member State for 2030 (%)
Source: CAKE/KOBiZE own study

ETS (in EU-28, and three EFTA countries) have to surrender enough emission allowances to cover all its emission. The amount of emission allowances available in the market in the EU ETS results directly from the adopted reduction target.

The non-ETS sectors would need to cut emission by 10% in 2020 and by 30% in 2030, relative to 2005. Distribution of the non-ETS reduction target between member states was set according to EC Decision 2009/406 /EC[19] and Effort Sharing Regulation[20]. The way of redistribution of the emission reduction targets in non-ETS sectors among the EU Member States is presented in the Figure 1.

2.2.3 GHG45/MSR and GHG45/MSR/ETP

The target in 2020 of 20% cut in greenhouse gas emission (from 1990 levels) stay in GHG45/MSR and GHG45/MSR/ETP scenarios unchanged. However, we assumed an increase of the GHG emission reduction target in 2030 to 45% for the EU compared to 1990. **For the EU ETS sectors, the new GHG's emission reduction target in 2030 was set at the level of 48% compared to 2005 and for the non-ETS sectors at the level of 36% compared to 2005**.[21]

To achieve the overall target in the non-ETS sectors, we determined individual binding targets for each EU Member State. The distribution of the reduction effort under non-ETS was estimated on the basis of GDP per capita for 2013 (the same methodology was used as in the Effort Sharing Regulation). It was assumed that the EU Member States will achieve reduction targets ranging from -5% to -55%. The emission reduction target for the EU Member State with GDP per capita closest to the EU average was set at the level of reduction required in the EU (equal to -36%). Countries with GDP per capita below the average (Poland can be an example) will have targets ranging from -5% to -36% and for countries with GDP per capita above average targets were set from -36% to -55%.

In Figure 2, we have presented the redistribution of emission reduction target -36% in non-ETS sectors between Member States compared to previous scenarios with -30% target.

2.2.4 The impact of MSR on the total amount of allowances in the EU ETS

We have assumed that the reduction of volume of GHG's emission allowances in the EU ETS due to the implementation of MSR will have an impact on the achievement of the emission reduction targets in 2020 and 2030 (in the scenarios with MSR). Based on the emission projections from the EU Reference Scenario 2016, we estimated that by 2020, around 760 million emission allowances (EUA's) will be transferred from auction and put into the MSR. In the next period, the MSR will have a slightly less effect on the market – during the period 2021–2030, around 690 million allowances will be transferred to the reserve.[22,23]

19 For details, see EC Decision 2009/406 /EC.

20 See Regulation (EU) 2018/842.

21 See Ingvild Sorhus (2018).

22 There is a very small difference (less than 1%) between the scenarios with different targets in EU ETS (-43% and -48% in 2030 compared to 1990) in the number of allowances transferred to the MSR.

23 From the total number of emission allowances in the period 2013–2020 was withdrawn additionally 900 million emission allowances due to the backloading (see Regulation [EU] No 176/2014) and emission allowances, which remain unallocated free of charge (on the basis of art. 10a EU ETS Directive).

The number of allowances withdrawn from the market is roughly equal to the number of allowances that will be sold in auctions during the two-year period in the EU ETS. The transfer from auctions to the MSR during the periods, such a large number of emission allowances will correspond to an annual reduction of the allowances in the EU ETS, on average 95 million in the period 2013–2020 and 69 million in the period 2021–2030 which, for example, would reflect an increase of the reduction targets in the EU ETS, only additionally in 2020 by 4% and in 2030 by 3%.

2.2.5 Differentiation of the models due to implementation of technical progress

The analysed policy options (scenarios) were done on two versions of the model:

- **Type I – '*without energy technical progress*'** – model including only GHG's emission reduction targets in 2030, without taking into account the technical progress reflecting, for example, increase of energy efficiency or decrease the use of fossil fuels.
- **Type II – '*with energy technical progress*'** – assumptions used in the model based on the projections of energy consumption adopted in the EU Reference Scenario 2016 for the EU Member States and in the World Energy Outlook 2016 '*Current Policy Scenario*' for the rest of the regions. Scenarios generated by this kind of model are marked with the ETP abbreviation in the tables and content. Implementation of these projections will decrease the use of fossil fuel (compared to the previous types of scenarios), which partly contributes to the achievement of the climate policy targets. This change corresponds to the increase of energy efficiency and decrease the demand for fossil fuels. Scenarios were generated in two steps. In the first step, assumptions concerning energy consumption were introduced to the d-PLACE model through the changes of the parameters of the production structure. In the second step, the constraint reflecting the additional emission reduction targets was added.

2.2.6 Definition and decomposition of the carbon leakage

Simplifying, in terms of climate protection, carbon leakage is defined as '*the increase in GHG's emission outside a region as a direct result of the policy to cap emission in this region*'.[24] Technically, carbon leakage is measured as the ratio of emission increase from a specific sector outside the country (as a result of a policy affecting that sector in the country) over the emission reductions in the sector (again, as a result of the environmental policy).[25]

24 See Julia Reinaud (2008)

25 There are several channels through which carbon leakage might occur. The main focus in this study is the so-called competitiveness channel working through the loss of the market shares of the affected domestic industry.

$$CL_i = -\frac{\Delta E^{\beta}{}_i}{\Delta E^{\alpha}{}_i} \times 100\%$$

Where:
CL_i – carbon leakage rate in sector i,
$\Delta E^{\alpha}{}_i$ – change (decrease) the GHG's emission in a region α and sector i, where climate policy is present,
$\Delta E^{\beta}{}_i$ – change (increase) the GHG's emission in a region β and sector i, where no climate policy is present or the activities to reduce emission are negligible.

Carbon leakage can be also decomposed into channels distinguished by a specific driving factor. Three main channels have been identified:

- The first – **energy channel** refers to the increase of the consumption of fossil fuels in the non-abating countries. This is due to the decrease of international fossil fuel prices induced by the constrained demand in the GHG's abating countries. However, this can be also achieved through technology changes, shifts in the fossil fuel mix and even the change in production structure. **Therefore, we will refer to that channel also as to carbon intensity channel**, because not only change in fuel consumption is involved.
- The second – the **competitiveness channel** refers to the induced changes in comparative advantage of the emission-intensive and trade-exposed industries vis-à-vis their competitors in the non-abating regions. Industries' comparative advantage is driven by the relative cost patterns, which are affected by the carbon mitigation policies raising production costs of the energy intensive industries. Higher production costs lead to loss of competition and international market shares. As a consequence, competitive position of the industries in countries mitigating their greenhouse gas emission might deteriorate.
- The third – **demand channel** refers to the changes in the demand for energy intensive products. Climate policies in general affect the relative prices of goods and incomes. Rising prices of energy intensive goods will induce a shift of demand from the abating into the non-abating regions.

Competitiveness channel has so far received the most attention in the literature. Through this channel, the competitiveness of the energy intensive industries would be weakened due to more stringent carbon mitigation policies. This can induce the potential relocation of the affected industries into the non-abating regions. Impact on industrial competitiveness will be visible through changes in the trade patterns[26] and capital flows. For example, *Böhringer (2012)* in his comparative analysis concluded that the competitive channel is more important than energy channel.
Carbon intensity channel refers to decline of the world fossil fuel prices induced by the fall in demand for fossil

26 Analysis by *Babiker (2001)* highlights the importance of the trade channels over capital mobility.

fuels in the abating countries. Lower fossil fuel prices might induce an increase of the fossil fuel based energy demand in the non-abating regions. Literature does not appear conclusive on the strength of this channel as also strategic interactions might play an important role such as decisions of the fossil fuel supplying countries, see, for example, *Criqui and Mima (2012)*.

Using an index number decomposition[27] of the total carbon emission, different specific channels through which the carbon leakage might occur. Literature refers to competitiveness, demand, and carbon intensity channels.[28] To show, how different channels affect the changes in emission, we will use framework that decompose the changes in emission to:

$$\Delta C_i = \frac{(\Delta EX_i - \Delta IM_i + \Delta DD_i)(CI_i^{sc} + CI_i^b)}{2} + \frac{\Delta CI_i(Q_i^{sc} + Q_i^b)}{2}$$

Where:
ΔC_i – change in carbon emission,
ΔEX_i – change in exports,
ΔIM_i – change in imports,
ΔDD_i – change in domestic demand,
CI_i^{sc} – carbon intensity in the analysed scenario,
CI_i^b – baseline carbon intensity in the analysed scenario,
Q_i^{sc} – GDP in the analysed scenario,
Q_i^b – baseline GDP.

In that framework, the three channels are calculated as follows:

$$\frac{(\Delta EX_i - \Delta IM_i)(CI_i^{sc} + CI_i^b)}{2} \text{ - competitiveness channel,}$$

$$\frac{\Delta DD_i(CI_i^{sc} + CI_i^b)}{2} \text{ - domestic demand channel,}$$

$$\frac{\Delta CI_i(Q_i^{sc} + Q_i^b)}{2} \text{ - carbon intensity channel.}$$

Moreover, carbon intensity channel may be further decomposed into changes in energy demand and changes in the structure of the economy. Therefore, changes in internal production structure (such as shifts between different domestic commodities) are also included, as well as changes in the structure of use of fossil fuels or changes in emission intensity of fuels as such.

Consequently, the carbon intensity component of change in emission can be further decomposed to changes in sectoral structure and energy intensity, using additive logarithmic mean divisia index decomposition, see *Ang et al. (2013)*:

$$\Delta CI_i = CI_i^{sc} - CI_i^b$$

$$\Delta CI_i = \sum_s \frac{L(\frac{C_{s,i}^{sc}}{C_i^{sc}}, \frac{C_{s,i}^b}{C_i^b}) L(CI_i^{sc}, CI_i^b)}{\sum_{ss} L(\frac{C_{ss,i}^{sc}}{C_i^{sc}}, \frac{C_{ss,i}^b}{C_i^b})} \ln\left(\frac{sh_{s,i}^{sc}}{sh_{s,i}^b}\right) + \sum_s \frac{L(\frac{C_{s,i}^{sc}}{C_i^{sc}}, \frac{C_{s,i}^b}{C_i^b}) L(CI_i^{sc}, CI_i^b)}{\sum_{ss} L(\frac{C_{ss,i}^{sc}}{C_i^{sc}}, \frac{C_{ss,i}^b}{C_i^b})} \ln\left(\frac{CI_{s,i}^{sc}}{CI_{s,i}^b}\right)$$

$C_{s,i}^b$ and $C_{s,i}^{sc}$ – sectoral carbon emission in baseline and scenarios,
$CI_{s,i}^b$ and $CI_{s,i}^{sc}$ – carbon intensities in baseline and scenarios,
$sh_{s,i}^b$ and $sh_{s,i}^{sc}$ – shares of sector in output (GDP) in baseline and scenarios,
$L(x,y) = \frac{x-y}{\ln x - \ln y}$ is the logarithmic average.

The first component of the sum is a part of the change in carbon intensity that is due to the changes in the share of a given sector in output and the second is the contribution of changes within sector carbon intensity. Such decomposition will allow to say whether the changes in aggregate carbon intensity are achieved due to the changes in sectoral structure of the economy or due to the efforts of enterprises either to reduce energy use or change in the internal use of fuels.

3. RESULTS

3.1. Aggregate results

3.1.1. GHG's emission

In general, under the set assumptions, we expect a fall in the EU total GHG's emission until 2030 in all scenarios. The difference between 2011 (base year) and 2030 is equal to 1054 million tonnes in the non-technical progress version of the model and 1102 million tonnes in the version where technological progress is modelled. Therefore the difference is very small, because most of the sectors emit as much as they are allowed regardless of the change in the technologies. In that context, the reduction in carbon emission is forced by regulations and the technology itself makes it easier to comply. The real difference lies in the GHG's emission in non-EU regions, where technology helps to reduce carbon emission faster and more efficiently.

Increase of the GHG's emission reduction target in the EU to 45% (modelled as more stringent constraint to emission, as described above) impacts more heavily in 2030 than the introduction of the MSR, which altered emission pathway only slightly. In scenarios without technical progress, introduction of MSR decreases emission only in the year 2030 by 2% in comparison to the baseline scenario, and additionally, further tightening of the reduction target to 45% decrease emission by another 8% in the year 2030 only (10% in total compared to baseline scenario). As long as energy-saving technical progress is included already in the baseline, the impact of policies (both MSR and tightening reduction targets) is very similar, as sectors comply to the regulations regardless of the technologies they have in place – consequently, more stringent regulations are a vital part of the emission reduction policies.

In the case of lack of binding emission reduction targets for the other than the EU regions of the world, some carbon leakage would still be observed because their total emission would not be capped in any way. Alternatively, if there will be a nationwide emission cap, carbon leakage

27 There is a broad literature considering suitability of several index number forms for decomposition, for an overview see, for example, *Agn et al. (2003)*. Our decomposition is based on *Tan et al. (2018)*.

28 Our exposition draws on *Tan et al. (2018)*.

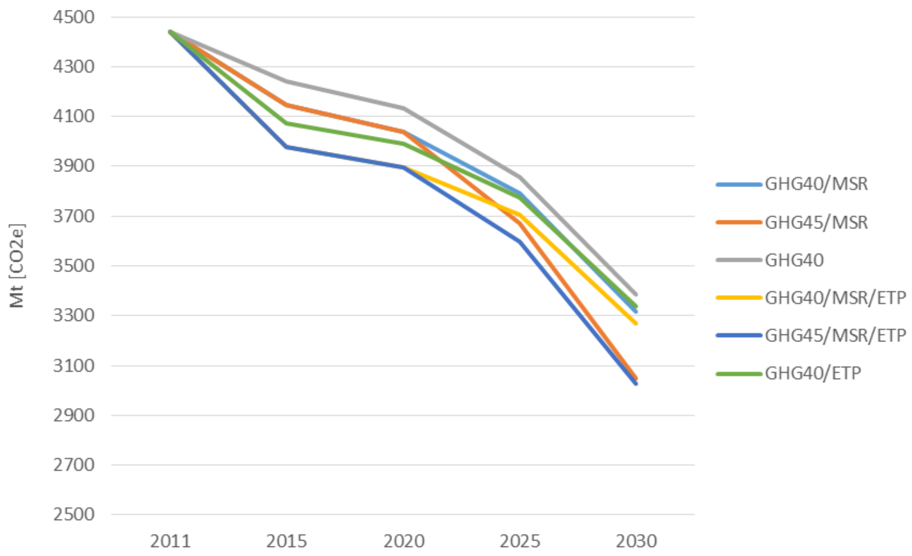

Figure 3. Total emission in the EU in different scenarios [MtCO2eq.]
Source: CAKE/KOBiZE own study based on the d-PLACE model results

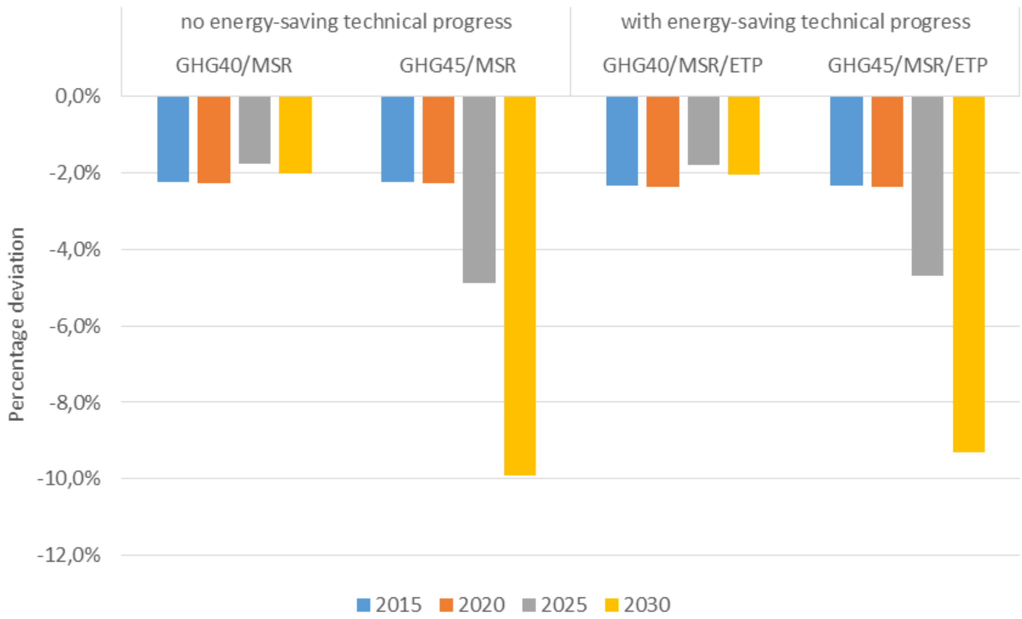

Figure 4. Deviation of total emission from the baseline in scenarios with and without ETP in the EU (%)
Source: CAKE/KOBiZE own study based on d-PLACE model results

would not exist, because their emission would equal their limits regardless of the EU actions. Therefore, the question of how binding are NDCs of the other regions of the world or in what scale they will be implemented is of crucial importance when carbon leakage is considered. Unfortunately, CGE model is not the best tool to extensively analyse how binding are emission constraints for the governments outside the EU. Consequently, in this paper, we assumed that regions other than the EU have no emission targets to show what theoretically would be carbon leakage in such a situation. We will present additional scenarios with binding reduction targets according to NDC's in the forthcoming paper. Nevertheless, this is an important caveat and must be kept in mind, while analysing the results, the purpose of which is to show the effects of the carbon leakage and factors affecting the scale of this phenomenon. Also, that (unrealistic) assumption is the reason, why these results should not be interpreted as

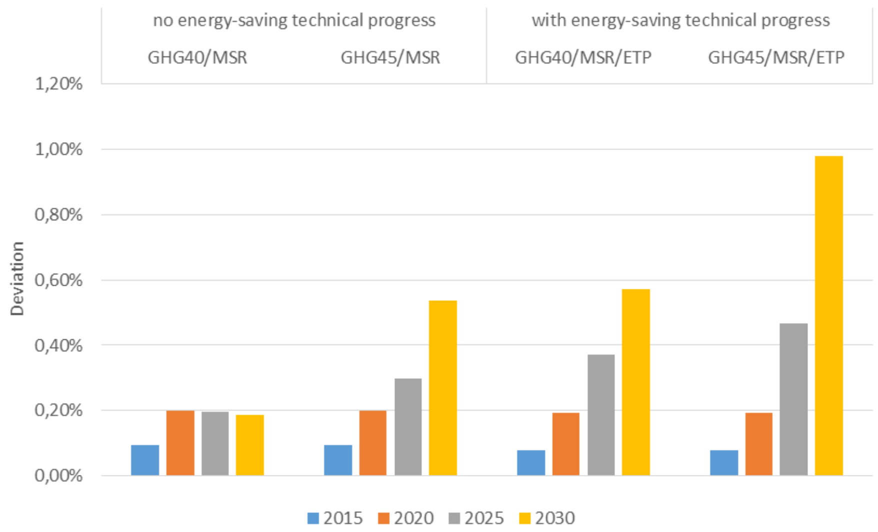

Figure 5. Deviation of total emission from the baseline in versions with and without technical progress in rest of the world regions (%)
Source: CAKE/KOBiZE own study based on d-PLACE model results

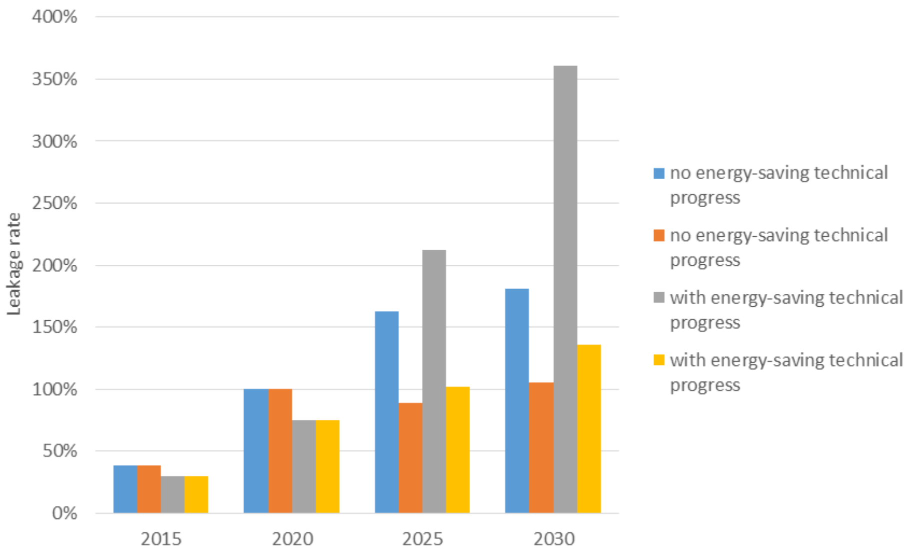

Figure 6. Leakage rate in different policy scenarios (%)
Source: CAKE/KOBiZE own study based on d-PLACE model results

a concrete answer on the question on whether the carbon leakage will occur or not (as the answer is 'it depends'), but rather as a demonstration on how important assumptions are for the results of carbon leakage.

The magnitude of increase in GHG's emission in the rest of the world is rather small and do not exceed 1%. However, due to the higher base, the amount of 'leakage' is quite substantial in absolute terms. For instance, introduction of MSR in version without taking into account energy-saving technical progress increases GHG's emission by 0.2% and 45% reduction target by another 0.1% in 2025. In the 'technical progress' version of the model, these amounts are very similar, but the base is lower. However, even such a small value of GHG's emission reduction outside the EU is enough to outweigh the emission reduction benefits of MSR/higher target for the EU in 2030 in some scenarios.

The leakage rates (measured as a ratio of increased emission in rest of the world to avoid emission in Europe) are quite high and range from 30% in the most restrictive scenario in 2015 up to 361% in 2030 in the least restrictive scenario. In general, leakage rates are higher in versions without technical progress in 2015–2025, but this changes in 2030, where leakage rates are higher in the scenarios with technological progress. When energy-saving

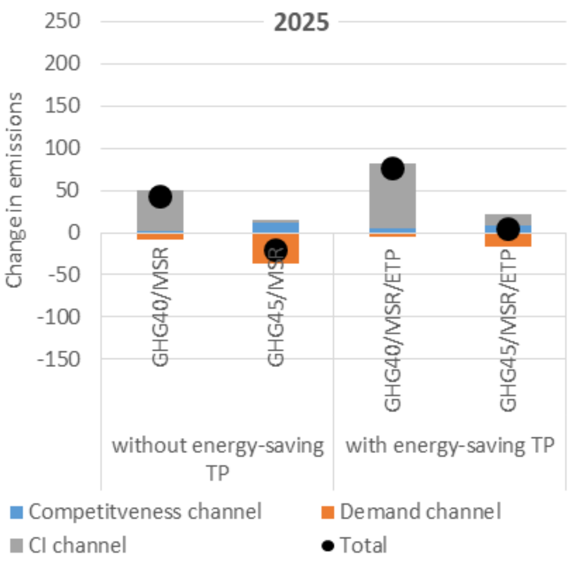

Figure 7. Decomposition of change in greenhouse gases emission in 2025 ($MtCO_2eq$)
Source: CAKE/KOBiZE own study based on d-PLACE model results

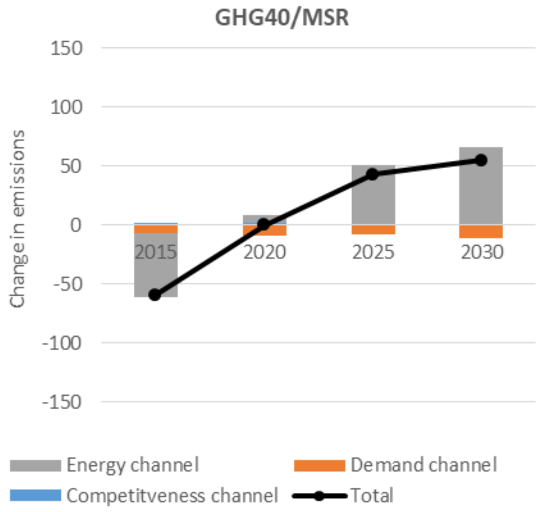

Figure 9. Decomposition of change in greenhouse gases emission in GHG40/MSR scenario ($MtCO_2eq$)
Source: CAKE/KOBiZE own study based on d-PLACE model results

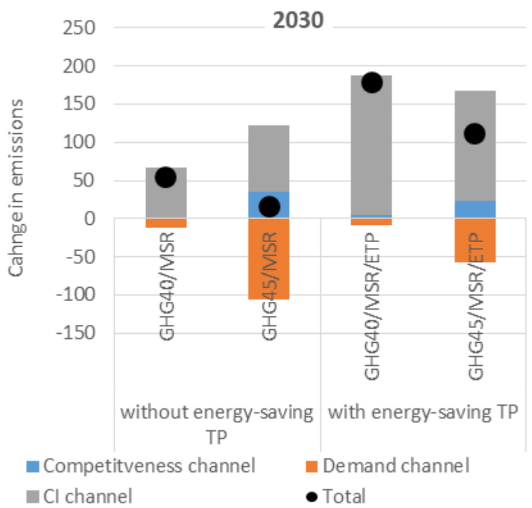

Figure 8. Decomposition of change in greenhouse gases emission in 2030 ($MtCO_2eq$)
Source: CAKE/KOBiZE own study based on d-PLACE model results

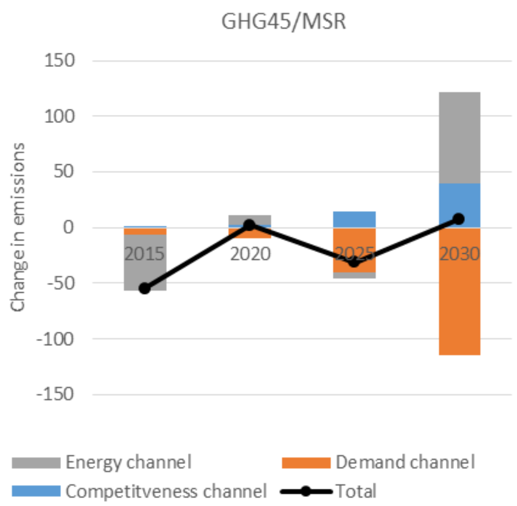

Figure 10. Decomposition of change in greenhouse gases emission in GHG45/MSR scenario ($MtCO_2eq$)
Source: CAKE/KOBiZE own study based on d-PLACE model results

technical progress is taken into account, both EU and non-EU countries are more energy efficient and therefore their production is less emission intensive. The scale of the leakage is still significant mostly due to the assumption on no reduction targets in the rest of the world.

3.1.2. Decomposition of carbon leakage

In this section, we decompose the carbon leakage into the carbon intensity, competitiveness and demand channels.

Our results indicate that carbon intensity channel is the most important channel of carbon leakage, far more important than competitiveness or demand channels. In both versions of the model, the impact of carbon intensity channel on total change in emission is positive. This phenomenon is understandable, given the use of fuels in the EU countries is significantly reduced in scenarios in comparison to the baseline and the production of energy intensive goods is outsourced to rest of the world countries. Also, as there is no convergence in energy-efficiency,

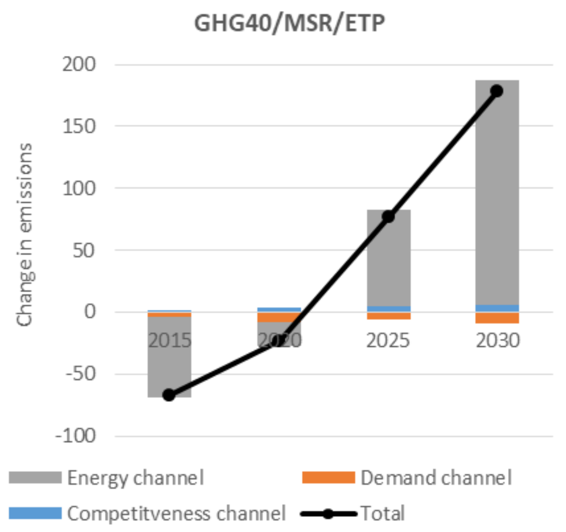

Figure 11. Decomposition of change in greenhouse gases emission in GHG40/MSR/ETP scenario ($MtCO_2eq$)
Source: CAKE/KOBiZE own study based on d-PLACE model results

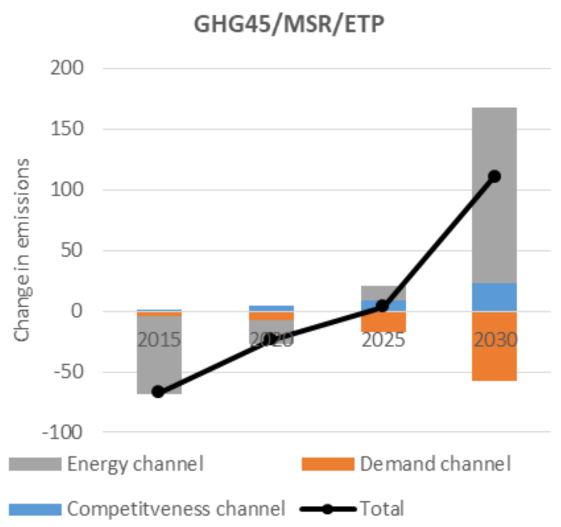

Figure 12. Decomposition of change in greenhouse gases emission in GHG45/MSR/ETP scenario ($MtCO_2eq$)
Source: CAKE/KOBiZE own study based on d-PLACE model results

these goods are produced using less effective and older technologies. Consequently, these outputs are even more energy and emission intensive if produced abroad.

Domestic demand channel is slightly more important in scenario with 45% reduction if exogenous energy-saving technical progress is taken into account. In this case, changes in production structure alone are not sufficient to reduce carbon emission in the EU countries to meet the targets. Therefore, the domestic demand must be reduced. In general, the first response of the economy to changes in emission targets is to reduce emission intensity of GDP, either through substitution between the fossil fuels or through changes in the production patterns (e.g., changing technology to less emission intensive). Outsourcing production elsewhere or reduction of the domestic demand is the next step, when reduction in emission intensity of the economy is not sufficient to meet the target.

3.2. Output by sector

Figure 13 presents the output by industry in the EU and the rest of the world countries and clearly shows, in which sectors the production is moved outside the EU. In case of GHG40/MSR scenario, there is almost perfect substitution between goods produced in the EU and the rest of the world in chemicals, oil and iron and steel sectors – this is hardly surprising given that the production in these sectors are the most carbon intensive and these goods are easily tradeable. The high decrease in output for air transport may seem surprising, but given the rising demand for air travelling in developing countries and the impact of policies on global fuel prices, this may be expected. In line with expectations is also fall of output in services, as the consumers in the EU will have less disposable income to buy imported services from abroad.

In comparison to 40% reduction, introducing more stringent GHG's reduction target will lead to stronger fall in production in the EU and higher increase in the rest of the world. The sectors in which the production will fall mostly are unchanged (coincide with those identified in the analysis of the carbon leak rate) – again these are chemicals, iron and steel and oil. The change of production in these emission-intensive tradable sectors are more or less twice as large as in the scenarios with just MSR in place. Also, with this stringent GHG's reduction target, change of output in agriculture and transport are also observed, which was not the case in 40% scenario.

Changes in output also show how differently the economy is affected if technical progress is taken into account. First of all, the required changes in output in chemicals, iron and steel, and oil are greater to satisfy the reduction targets – this is self-explanatory, as with lower emission intensity, greater is the required change in production. However, these released resources do not remain unused – there is huge spike of output in 'other manufactures' sector. It is obvious textbook result – more stringent climate policy shifts comparative advantage of the EU countries from emission intensive goods (chemicals, oil, iron and steel) towards other manufacturing. Consequently, more goods in this sector are produced in the EU and less are imported. Other manufacturing sector[29] is the only branch of the economy in which output will significantly rise because of the climate policy – and increase in production will be driven both by change in demand structure and availability of resources. Summing up, including endogenous technical progress in the model increase, the estimated changes in sectoral structure of production, even though it hardly affects the projected impact of climate policy on GDP.

29 Other manufacturing sector include: motor vehicles and parts, transport equipment, machinery and equipment, minerals, wood products, textiles, wearing apparel, leather products, metal products, manufactures.

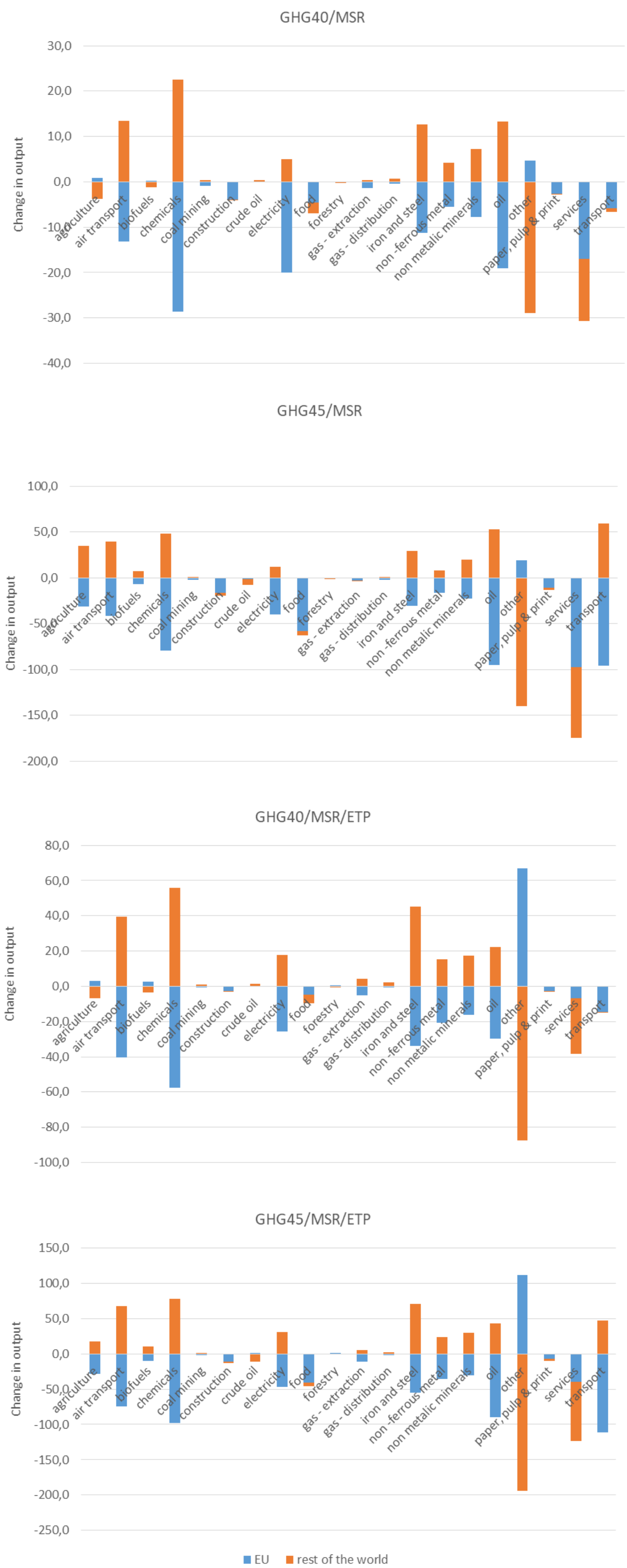

Figure 13. Change in output in the EU and rest of the world countries by industry (mln USD 2011)
Source: CAKE/KOBiZE own study based on d-PLACE model results

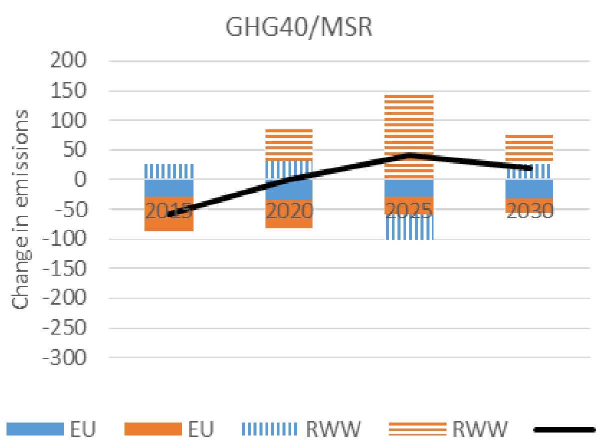

Figure 14. Decomposition of 'carbon intensity channel' impact on emission in GHG40/MSR scenario (MtCO_2eq)
Source: CAKE/KOBiZE own study based on d-PLACE model results

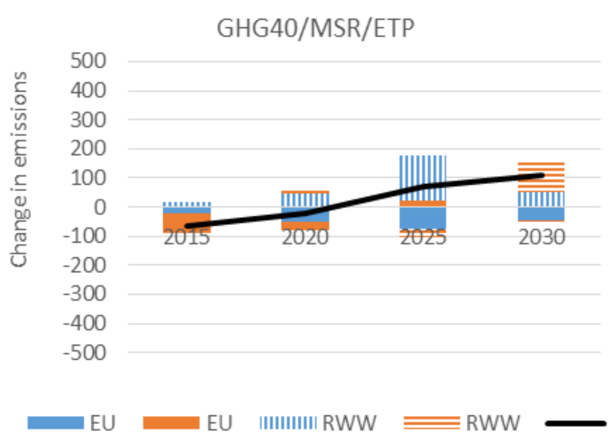

Figure 16. Decomposition of 'carbon intensity channel' impact on emission in GHG40/MSR/ETP scenario (MtCO_2eq)
Source: CAKE/KOBiZE own study based on d-PLACE model results

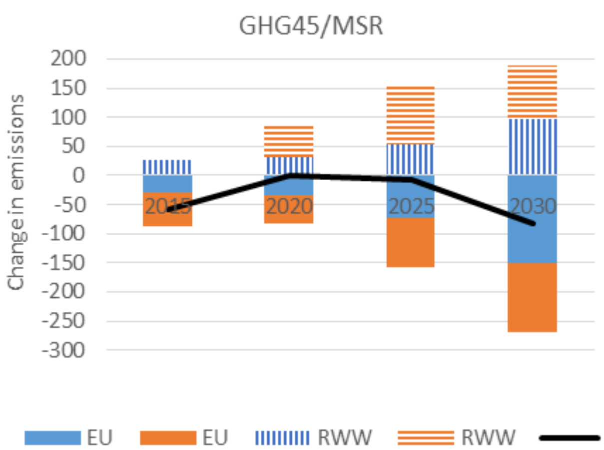

Figure 15. Decomposition of 'carbon intensity channel' impact on emission in GHG45/MSR scenario (MtCO_2eq)
Source: CAKE/KOBiZE own study based on d-PLACE model results

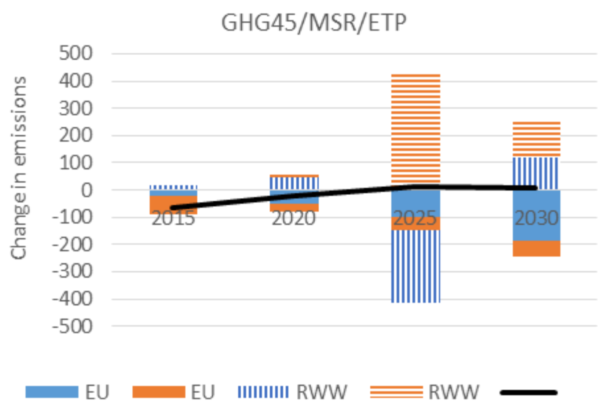

Figure 17. Decomposition of 'carbon intensity channel' impact on emission in GHG45/MSR/ETP scenario (MtCO_2eq)
Source: CAKE/KOBiZE own study based on d-PLACE model results

3.3. Emission by sector

Carbon intensity channel is the most important channel through which the emission reduction occurs. Therefore, it is a good idea to further decompose the changes in emission intensity of the GDP into sectors. Such decomposition will allow us to identify the driving factors behind the change in the emission intensity.
Results show that change in production structure and changes in sector specific carbon intensities contribute to the changes in emission to a similar degree. To illustrate this, we can use an example, if we would like to reduce GHG's emission in Poland, the production of steel and iron needs to be moved to third countries or more efficient furnaces need to be installed. The first action contributes to changes in the production structure, the second allows for improvement in sector-specific emission intensity. GHG's emission reduction targets in the EU Member States without any protective measures leads to both types of such action. However, there are some differences in the contribution of different factors between the scenarios. For instance, in the GHG40/MSR scenario, the reduction within sector carbon intensity in the EU ETS countries is relatively small, while changes in carbon intensity of production in rest of the world countries play substantial role. Such increase in rest of the world countries suggests substantial

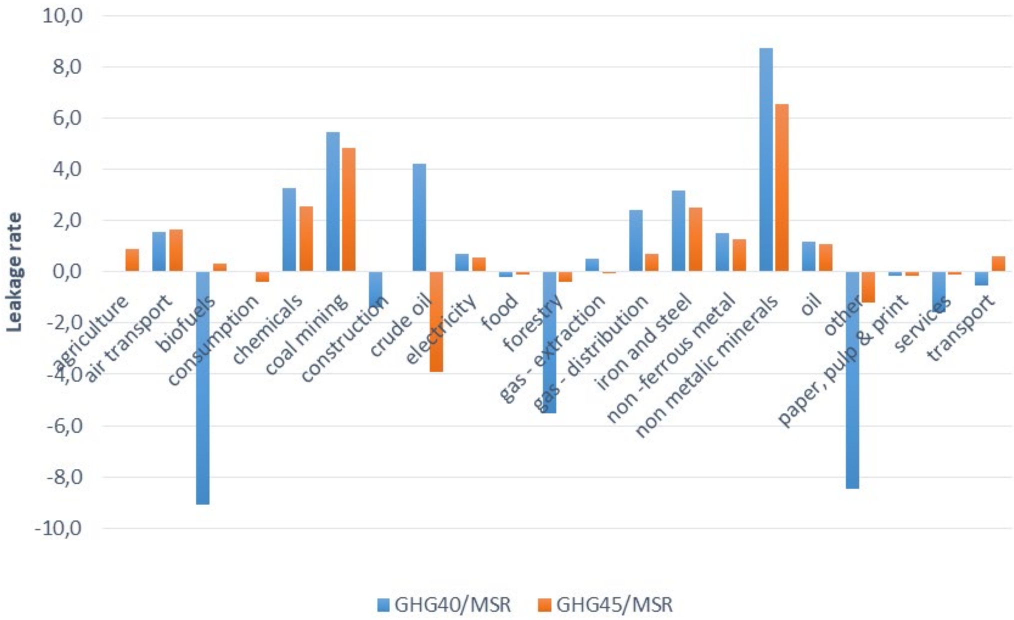

Figure 18. Leakage rate by sector, no energy-saving technical progress action scenarios in 2030 (rate)
Source: CAKE/KOBiZE own study based on d-PLACE model results

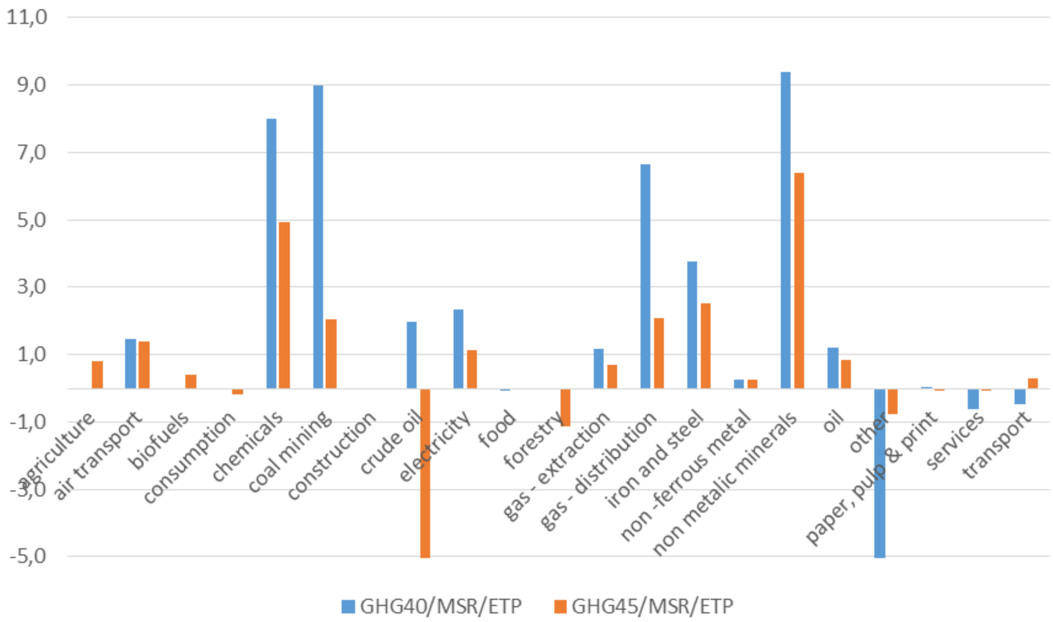

Figure 19. Carbon leakage rates by sector, scenarios with energy technical progress (rate)
Source: CAKE/KOBiZE own study based on d-PLACE model results

switch towards more carbon intensive energy sources and overall increase of energy intensity there triggered by induced change in the energy prices. On the other hand, the impact of changes in production structure in the rest of the world countries reflects the effect of policies on the structure of production in the EU. This suggests that no behavioural change is observed and carbon intensive products produced domestically are substituted by the same carbon intensive products produced abroad. This result is, however, to a large extent determined by very low elasticity of substitution between products in the consumption structure assumed in the model. This assumption was adopted on the basis of other similar GTAP-based model, such as Burniaux and Truong (2002) or Rutherford and Paltsev (2000). We plan to extend the consumption structure in the next versions of the model.

The increase in greenhouse gases' emission in the rest of the world countries (resulting from changes in the production structure within-sector) is quite significant in both versions of the model. The reason for that is that even though carbon intensity of production is reduced (due to technical progress), lower prices of energy and increased productivity (induced by energy-saving technical progress) allows foreign companies to increase production less costly. Therefore, there is an appetite to change fuel consumption towards more emission intensive sources regardless of the production technology. Therefore, the emission limits in rest of the world countries are vital factor determining the efficiency of the EU carbon mitigation policy.

Figures 18 and 19 depict the carbon leakage rates by sector in the energy-saving technical progress and without such a feature. Not surprisingly, the highest rates are observed in the energy intensive industrial sectors, such as non-metallic minerals, iron and steel or chemicals. In these sectors, and also in air transport, gas distribution, non-ferrous metals and oil, leakage rates are often higher than one. This means that an increase in emission in the rest of the world countries is higher than the reduction achieved in the EU. This is not surprising, given the very rigid consumption structure in the model and more energy efficient technologies used in these sectors by now. For instance that heavy industrial production move outside the EU countries to satisfy the constant demand for such technologies, facing the lower emission limits. However, these results strongly depend on the model assumptions on the elasticities of substitution between different consumption goods.[30]

Also, negative leakage rates for biofuels, forestry and other services in GHG40/MSR scenarios are worth commenting. As in this scenario, the reduction is achieved mostly through changes in emission intensity, carbon intensive energy fuels (such as oil, gas, etc.) are replaced with biofuels and wood. Therefore, production (and emission) from biofuels and forestry sector will increase both in the EU and in rest of the world. When bigger emission reduction is required (in GHG45/MSR scenario), substituting fossil fuels by biofuels is not sufficient and changes in production structure is required – so that there is no increase in output in biofuels and forestry. On the contrary, as oil extraction can produce emission, in GHG40/MSR scenario, the emission (and production) of crude oil sector in the EU is reduced and it is imported by imported oil; so, there is a small positive leakage. In GHG45/MSR scenario, the use of oil in EU is reduced to such an extent that the import is even smaller than in the baseline scenario. Therefore, the production and emission from crude oil are reduced both in the EU and in rest of world, and the leakage rate is negative. Moreover, when energy technical progress is accounted for, the use of energy is already reduced – so there is no need to replace fossil fuels with biofuels and wood, and there is no increase in production. In case of other services, there is a noticeable shift from industrial to services sector – therefore, the production in the EU (and emission) will increase both in the EU and rest of the world. When more stringent carbon reduction targets are considered, these actions are not sufficient, so the 'negative' leakage is much smaller.

30 Sensitivity analysis are planned for the near future.

If energy technical progress is taken into account, the carbon leakage rates are very similar – the important difference is visible only in tradable, emission-intensive goods, where there are significant differences in technologies between the EU and the rest of the world, such as chemicals, iron and steel and non-metallic minerals. These sectors are the most vulnerable to carbon leakage, as their products can be easily substituted with energy-intensive goods from abroad. Moreover, the differences in technologies between the EU and rest of the world are a very important factor that affect the scale of carbon leakage. Therefore, it is very important to spread the more energy-efficient technologies to limit the negative impact of production reallocation on emission.

4. CONCLUSIONS

To assess the possible scale of carbon leakage using different assumptions and policy scenarios within the EU and identify channels of carbon leakage in order to have better knowledge on the possibilities to prevent this phenomenon in an efficient way, we determined the main channels of carbon leakage occurrence – such as demand, competitiveness and carbon intensity and analysed different options of climate policy implementation in the EU up to 2030 (three types of scenarios were implemented). Moreover, in order to examine how the assumptions on technical change affect the scale of carbon leakage, we made simulations using two versions of model – without and with technical progress.

As one of the results, we came to the conclusion that carbon leakage should be perceived as an important problem that can limit the effectiveness of EU ETS (including MSR), and the EU efforts at an overall level to reduce global emission and the implementation of the Paris Agreement. One of our base assumption of 'no external emission reduction target' was used as an example to show the potential carbon leakage phenomenon scale. Adoption of more stringent policies in the EU will create incentives for other countries to relax their own emission reduction commitments. Thus, not only would carbon leakage result in the loss of the EU industries by 'leaking' to places with weaker commitments, but it also means that global emission could even increase as shown in the results of this paper.

Other conclusion from this paper finds that differences in production structure and sector carbon intensity contribute to carbon leakage to a similar extent. Therefore, we should tackle both energy mix channels (e.g., by promoting fuel efficient technologies) and sectoral structure channel (e.g., through free allocation or border tax adjustment).

Implementation of technical progress greatly reduces the risk of carbon leakage. In the version without technical progress in all the scenarios, the total emission projection for the regions outside the EU rises about 70% between 2015 and 2030. If technical progress is taken into account, emission outside the EU rises about 20%. The largest increase in emission for the regions outside the EU is in the GHG45/MSR scenario (scenario with the most restrictive emission reduction target for the EU analysed in this paper).

In both versions of the model, introduction of MSR leads to an increase in the total emission outside the EU due to the shifts in sectoral structure and increased use of carbon intensive fuels outside the EU. Tightening the target to 45% will lead to an even higher emission growth outside the EU states, caused by an even higher shift in the sectoral structure of production. It means that emission reduction is achieved mainly through decrease of the use of fuels in the EU countries and the production of energy intensive goods is shifted outside the EU. In comparison to the baseline scenario in 2030 (results for the version of the model without technical progress), total emission outside the EU increases by 0.2% after implementation of MSR in EU ETS and additional by 0.3% after tightening the overall EU reduction target (0.5% in total).

It needs to be highlighted that even taking into account 'technical progress' does not alter the main conclusions, but shows how differences in technologies may affect leakage rates. Therefore, it is very important to support research on energy-efficient technologies and also make them available to rest of the world.

The highest leakage rates are observed in energy-intensive industrial sectors, such as non-metallic minerals, iron and steel and chemicals. The change in output by industry in the EU also shows that those sectors are the most exposed on carbon leakage. The size of production in these sectors is decreasing significantly after the tightening of the reduction targets. It follows that these sectors are the most carbon intensive and these goods are easily tradeable.

At the moment, in the European Union, the carbon leakage is prevented by the implementation within the EU ETS defence mechanisms, that is, free allocation of emission allowances and compensation for indirect carbon leakage (caused by an increase in the electricity prices). Mechanism of free emission allocation in the EU ETS is a safeguard against the carbon leakage and reallocation of production by sectors exposed to increase of the operating costs related to climate policy. Taking into consideration the increasing importance of the climate policy and the existing and planned GHG's emission reduction commitments within the EU, other instruments and mechanisms implemented on broader worldwide scale have to be analysed in order to prevent the potentially negative effects of carbon leakage, not only in terms of emission but also economically. There is a need for further analyses that take into account more realistically the legal conditions functioning in the EU (free allocations) and obligations under the Paris Agreement submitted by rest of the world in their NDCs. This issue will be analysed in the forthcoming paper planned for publication later this year.

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The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors, and not of the organization with which the authors are affiliated.

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