Centre for Climate
and Energy Analyses

THE CGE MODEL D-PLACE

TECHNICAL DOCUMENTATION FOR THE MODEL
VERSION 1.0

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The d-PLACE is based on the static CGE model called PLACE, which was created in 2013-2016 by the members of the Centre for Climate Policy Analysis (Polish acronym – CAK) working together with the Ministry of Economy, the Ministry of Environment and the Ministry of Finance of the Republic of Poland and the World Bank experts in cooperation with IOŚ - PIB.

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List of abbreviations

CAKE	Centre for Climate and Energy Analyses
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CGE model	Computable general equilibrium model
Carbon leakage list	The list of sectors and sub-sectors deemed to be exposed to a risk of carbon leakage in the EU
CLF	Carbon leakage factor (carbon leakage exposure factor)
CSCF	Cross-sectoral correction factor
EC	European Commission
EFTA	European Free Trade Association
ESD	Effort Sharing Decision
ESR	Effort Sharing Regulation
ETP	Version of d-PLACE model with exogenous energy technical progress
EU	European Union
EUA	European Union Allowances
EU ETS	European Union Emissions Trading Scheme
EU28	European Union of 28 Member States
GAINS	Greenhouse gas-Air pollution Interactions and Synergies
GDP	Gross Domestic Product
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
KOBiZE	The National Centre for Emissions Management
MSR	Market Stability Reserve
NDC	Nationally Determined Contribution
NER	New Entrants Reserve
Non-ETS	Sectors not covered by the European Union Emissions Trading Scheme
OPEC	Organization of the Petroleum Exporting Countries
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

Keywords: computable general equilibrium model, CGE, dynamic modelling, emissions, energy, GTAP, baseline scenario, climate policy, trade and the climate policy, EU ETS, non-ETS, low-emission transition.

1. General overview

The d-PLACE model is a recursive dynamic, global multi-sector (20 sectors/commodities) computable general equilibrium (CGE) model. d-PLACE model has been developed in the Centre for Climate and Energy Analyses (CAKE in its Polish acronym) set up in The National Centre for Emissions Management (KOBiZE), which is a part of the Institute of Environmental Protection - National Research Institute (IOŚ - PIB).

The d-PLACE is based on the static CGE model called PLACE, which was created by the Centre for Climate Policy Analysis (Polish acronym – CAK) consisting of experts from the Ministry of Economy, Ministry of Environment and Ministry of Finance of the Republic of Poland and the World Bank, in cooperation with IOŚ - PIB in 2013-2016.

d-PLACE is a global model. The global dimension of the model enables analysing international trade in a comprehensive way by distinguishing multiple countries and world regions. It also allows to account for carbon leakage, and analyse emission abatement at the global level. The d-PLACE model was created to examine the impact of energy and climate policy on the economy and therefore its main features have been designed to meet such specific needs. First, greenhouse gas emissions are modelled at high detail. Emissions originating from fuel combustion and process emissions are modelled separately. Likewise, uses and supplies of major fossil fuels are modelled explicitly. The model distinguishes between CO_2 emissions and emissions of other greenhouse gases, such as N_2O (nitrous oxide), CH_4 (methane), HFCs (hydrofluorocarbons). Inclusion of non-CO_2 emissions in d-PLACE corresponds with the fact that emission reduction targets of developed countries also include those gases.

A second distinguishing feature is a detailed modelling of climate policy in the EU Member States, including emission reduction targets in the EU ETS (European Union Emissions Trading Scheme) and non-ETS sectors. The model contains information on the supply of emission allowances on the EU ETS market. For non-ETS sectors, annual national reduction paths have been set to achieve emission reduction targets. The model also includes emission reduction targets for regions outside the EU, which have been derived from the NDCs submitted under the Paris Agreement.

In d-PLACE model, energy use is modelled in detail. Industries and consumers adjust their energy mix in response to changes in relative prices of different fuels (including the cost of emissions) and electricity. Additionally, producers may substitute energy for fixed capital (equipment). The production process is modelled using nested constant elasticity of substitution and Leontief production functions.

To investigate the impact of energy and climate policy, the model distinguishes energy intensive and trade exposed industries, such as production of refined oil products and coke, chemicals, non-metallic minerals (e.g. cement-lime-gypsum, glass), paper–pulp, iron and steel, and aluminium.

Since the model includes the labour-leisure choice, it allows for the analysis of impact of climate and energy policy on aggregate household welfare including calculation of compensation mechanisms to offset the increased costs of products for consumers.

The d-PLACE model makes it possible to analyse relative emission abatement potentials across sectors and countries, as it takes into account sector- and country-specific production technologies and consumption patterns. It allows to take a cost-minimization perspective on environmental and climate policy objectives, as well as compare burdens between countries.

The d-PLACE model is solved in a recursive-dynamic manner for the years 2011-2050, in 5 years steps (with the exception of the first step which spans 4 years). GTAP-9 (Global Trade Analysis Project) data have been used for benchmark calibration, i.e. they represent the initial state of the world economy in 2011. The baseline scenario (until 2050) conforms with external projections of GDP growth rates by country, energy use by fuel (which entails the related CO_2 and non-CO_2 emissions), fossil fuel prices at world-region level and the emission limits for the EU and rest of the world regions.

Impacts of specific analysed regulations under climate policy scenarios are presented as long-term deviations from the baseline scenario.

2. Technical description

This section contains the technical description of the d-PLACE model. First we discuss the static module, comprising the relationships within a given period. This includes implementation of households labour supply and consumption structure, industry-specific production technologies and demands for production inputs, revenue and expenditure of the government sector, and investment decisions. We also discuss the specification of trade, labour market and emissions. A separate section is dedicated to the dynamic structure of the model, comprising inter-period relationships. Finally, prospective developments of the model are briefly described.

2.1. Sectoral and regional disaggregation of the model

2.1.1. Sectors

The model distinguishes 20 sectors, of which 7 are directly related to energy. The energy sectors are linked to both primary energy (coal, crude oil, natural gas, biofuels) and secondary energy carriers (refined oil products, electricity, gas distribution and heating). Sectoral split is strictly dependent on the classification used in the GTAP database. Therefore, some energy industries are aggregated, e.g. “oil” sector include refined oil products, coke and nuclear fuels and “gdt” sector includes both gas distribution and heating. The GTAP database does not distinguish sectors of renewable energy sources and biofuels. Instead we specify the biofuels sector as an aggregate of 6 agriculture sub-sectors from the original GTAP data[1]. All energy sectors, except production of biofuels in agriculture, are covered by the EU ETS. There are 6 non-energy sectors also covered by the EU ETS: chemical, non-metallic minerals, iron and steel, nonferrous metals, pulp-paper, air transport.

Table 1 presents the sectoral disaggregation in the d-PLACE model.

Table 1. Sectors in d-PLACE model and respective codes

List of sectors in d-PLACE model		Corresponding sectors in GTAP Data Base[2]	EU ETS	non-ETS
Energy sectors				
Col	Coal (mining and agglomeration)	col	+	
Cru	Crude oil (extraction and service activities)	cru	+	
Gas	Natural gas (extraction and service activities)	gas	+	
Bio	Biofuels-related agriculture	pdr, wht, gro, osd, c_b, vol		+
Oil	Refined oil products, coke, nuclear fuels	oil	+	
Ele	Electricity	ely	+	
Gdt	Gas distribution and heating	gdt	+	
Non-energy sectors				
Agr	Rest of agriculture and fishing	pfb, ocr, ctl, oap, rmk, wol, fsh, v_f		+
Foo	Food industry	omt, mil, pcr, sgr, ofd, b_t, cmt	+	
Frs	Forestry	frs		+
Chm	Chemical industry	crp	+	

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[1] See: Taheripour et al. (2008a,b, 2011)

[2] See: Aguiar, Angel, Badri Narayanan, & Robert McDougall. "An Overview of the GTAP 9 Data Base." *Journal of Global Economic Analysis* 1, no. 1 (June 3,2016: 181-208)

Nmm	Non-metallic minerals	nmm	+	
Isi	Iron and steel industry	i_s	+	
Nem	Non-ferrous metals	nfm	+	
Ppp	Paper–pulp–print	ppp	+	
Con	Construction	cns		+
Oth	Other manufactures	mvh, otn, ome, omn, lum, tex, wa, lea, eeq, fmp, omf		+
Atr	Air transport	atp	+	
Trn	Other transport	otp, wtp		+
Srv	Services	trd, ofi, isr, obs, wtr, cmn, ros, osg, dwe		+

Source: CAKE/KOBiZE own study

2.1.2. Regions

The d-PLACE model is constructed to enable aggregation of the regions from GTAP database according to the needs of a specific analysis. In the case of regional aggregation, only computational tractability and availability of economic and energy data create some limitations.

An example of regional aggregation used in the report: "*The risk of carbon leakage in the context of increasing the EU greenhouse gas emission reduction target*"[3] is shown in Table 2. The d-PLACE model focuses on the analysis of energy and climate policy of the European Union, and hence the most of the regions are EU Member States. The remaining regions represent the largest global economies with significant impact on GHG emissions. As shown in Table 2, the regional breakdown includes 26 regions, of which 16 are members of the EU. The specific aggregation was based on expected regional distribution of policy impacts investigated in the Report.

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[3] Gąska, J., Pyrka, M., Rabiega, W., Jeszke, R., Mraz. M, Sekuła M. (2019). The risk of carbon leakage in the context of increasing the EU greenhouse gas emission reduction target, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw. http://climatecake.pl/wp-content/uploads/2019/07/CAKE_CL_Risk-of-CL_ENG.pdf

Table 2. Example of regional aggregation in d-PLACE model and respective codes

Country	Code
Republic of Poland	POL
Czech Republic	CZE
Germany	DEU
French Republic	FRA
Hungary	HUN
Romania	ROM
Slovak Republic	SKA
Bulgaria	BGR
Adriatic countries (Slovenia, Croatia)	ADR
Baltic countries (Republic of Lithuania, Republic of Latvia, Republic of Estonia)	BLT
Benelux countries (Belgium, the Netherlands, Luxembourg)+ Austria	BAT
Spain + Portugal (Iberic)	ESP
United Kingdom + Ireland	GBR
Greece + Republic of Cyprus	GRC
Italian Republic + Republic of Malta	ITA
Scandinavia (Denmark, Sweden, Finland)	SKA
EFTA countries involved in EU ETS (Kingdom of Norway, Principality of Liechtenstein, Republic of Iceland)	EFT
Commonwealth of Australia + New Zealand	AUS
Federative Republic of Brazil	BRA
People's Republic of China	CHN
Republic of India	IND
Japan	JPN
Russian Federation	RUS
United States of America + Canada	USA
OPEC	OPE
Rest of the world	RWW

Source: CAKE/KOBiZE own study

2.2. General structure of the static (one period) model

This section describes the structure of the static model which is solved in a single period. The dynamics will be described in the next section.

2.2.1. Households

A representative consumer maximize utility function subject to budget constraint. Utility is derived from consumption and leisure which are linked through CES utility function:

$$\max_{LE,C} U = (\beta LE^{\rho} + (1-\beta)C^{\rho})^{1/\rho}$$

$$s.t.\ P_c C + P_L LE = P_K K + P_L(L + LE) + P_R R + P_c trf$$

Where: LE denote leisure demand, C – consumption of goods, P_C – consumer price index, P_L – price of labour from the consumer's perspective, β – share of leisure in current consumption, trf – public and foreign transfers (in real terms), ρ –substitution parameter. This is a common formulation (see e.g. Dixon and Jorgenson, 2012). The solution of the above optimization problem yields demand functions for leisure or consumption of factor endowments and factor prices. The possibility to substitute between two types of employees is reflected by the elasticity of substitution $\sigma = 1/(1-\rho)$.

Consumption by commodity is determined as in the PLACE model (Antoszewski, et al., 2015), following the setting from ROCA model (see Böhringer & Rutherford, 2013). The model, therefore, distinguishes energy and non-energy consumption goods. Bundles of energy and non-energy goods are linked through Leontief function, so there is no possibility to substitute energy goods with non-energy goods (and vice versa). We can write that relationship as:

$$Q_{klem} = f(A, Q_{ener}) = \min\left(\frac{A}{a}, \frac{Q_{ener}}{q_{ener}}\right)$$

Where: a and q_{ener} represent the quantities of non-energy and energy good aggregates, respectively, per unit of the consumption bundle.

In the case of non-energy bundle, this is a Cobb-Douglas aggregate of individual non-energy goods (implying elasticity of substitution between different consumption goods is equal to 1). It can be written as:

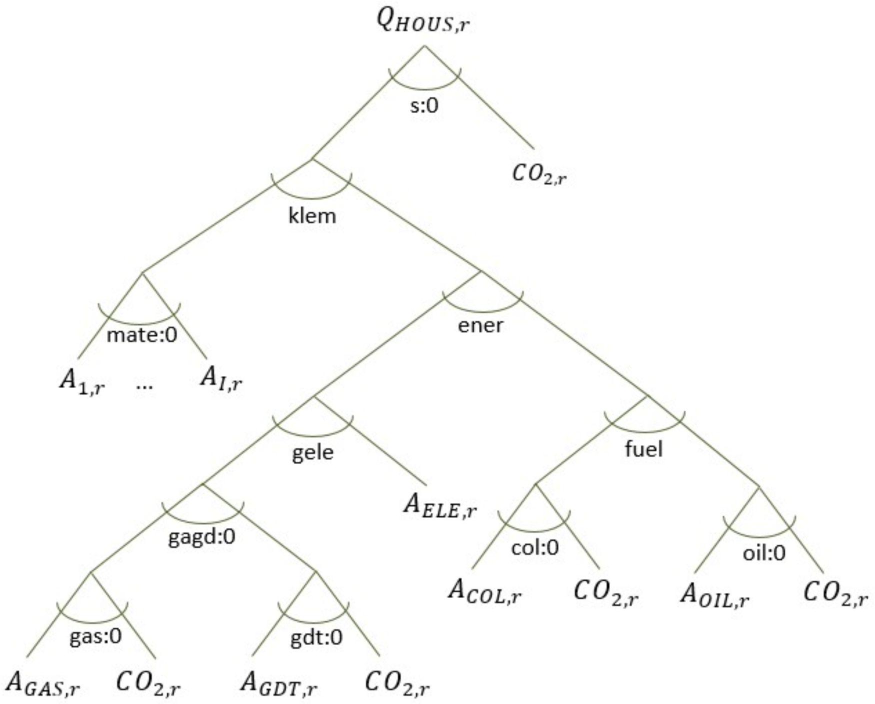
$$A = T \cdot \prod_i A_i^{\alpha_i}$$

$$i \in \{non - energy\ sectors\}$$

Where: A_i is the consumption of good i (itself being a bundle of goods produced domestically by sector i and imported, i.e. originating from foreign sectors i; that bundle is the so called Armington good), α_i is its share in total consumption expenditure, and T is a multiplicative constant.

Energy bundle is slightly more complicated – first comes the decision on the demand for oil/coal and electricity/gas energy bundles. Then the consumer decides on relative use of coal and oil (e.g. assuming that it is used for heating purposes), as well as relative use of electricity and gas. Emissions in the household sector are linked to fuel consumption in fixed proportions (it is therefore described by a Leontief function – see figure 1). Elasticities were adopted on the basis of expert knowledge and literature review (see Böhringer & Rutherford, 2013, for details).

Figure 1. Nested Leontief and CES consumption function structure for households



Source: Antoszewski et al. (2015)

As shown in Figure 1, formation of the consumption bundle is represented by a combination of Leontief functions and nested constant elasticity of substitution (CES) functions. The assumption of no substitution between non-energy goods is equivalent to zero elasticity of substitution, denoted *mate:0* in Figure 1.Similarly, proportionality of CO_2 emissions to fuel consumption is depicted by zero elasticities of substitution in the *gas*, *gdt*, *col* and *oil* nests. The same applies to the gagd nest in which gas as a fuel is bundled with distribution services. In the other cases (*gele*, *fuel*, *ener* and *klem*) a non-zero elasticity of substitution is adopted, indicating that inputs into a given bundle of goods are considered imperfect substitutes (as means of satisfying household needs). In this line, there is a non-zero constant elasticity of substitution σ_{fuel} between *col* and *oil* in the *fuel* nest. In the nest *gele* we can substitute the *gagd* bundle (composite of *gas* and *gdt*) with *ele*. In the next-level nest *gele* and *fuel* (composite of *col* and *oil*) are combined according to another CES function. Finally, in the top nest, *klem*, households are assumed to choose between non-energy and energy bundle (ener). The same consumption structure applies to representative household in each region. Similar trees are used to illustrate the production processes by industries. In that case, goods and services are treated as intermediate inputs rather than components of consumer demand, and moreover capital, labour and natural resource inputs are considered.

2.2.2. Production Activities

The specification of production technologies is also similar to the one used in PLACE model and its predecessor – ROCA (see Böhringer & Rutherford, 2013). It is based on nested CES functions, commonly used in CGE models. However, the nesting structure is specifically designed to appropriately reflect the use of energy, and emissions.

Each producer maximizes profits from production (minimizes the costs), where the production function is the constraint. We use the following general approach, related to Shephard's lemma, for calculating the demand for production factors and intermediate inputs:

$$C_{i,r}(P_{1,r},\dots,P_{s,r}) = Y_{i,r}\cdot c_{i,r}(P_{1,r},\dots,P_{s,r})$$

$$A_{i,j,r} = \frac{\partial C_{i,r}}{\partial P^A_{j,r}} = Y_{i,r}\frac{\partial c_{i,r}}{\partial P^A_{j,r}}$$

<u>Where:</u> $C_{i,r}(\dots)$ is the cost function in sector i and region r, $c_{i,r}(\dots)$ – unit cost function, $A_{i,j,r}$ represents the demand for intermediate input of good j , $P^A_{j,r}$ is the price of this good and $Y_{i,r}$ represents production.

Similarly, the demand for primary production factors ($F_{f,i,r}$) is calculated as:

$$C_{i,r}(w_{K,r}, w_{LL,r}, w_{LH,r}, w_{R,r}) = Y_{i,r} \cdot c_{i,r}(w_{K,r}, w_{LL,r}, w_{LH,r}, w_{R,r})$$

$$F_{f,i,r} = \frac{\partial C_{i,r}}{\partial w_{f,r}} = Y_{i,r} \frac{\partial c_{i,r}}{\partial w_{f,r}}, f \in \{K, LH, LL, R\}$$

There are four primary production factors in the model: capital and land (K), natural resources (R), skilled labour (LH) and unskilled labour (LL). These demands enter then the market clearing conditions as described in subsection 2.2.10.

Production functions, i.e. nesting structures, differ by sector, as specified below.

2.2.3. Manufacturing, agriculture, and services

The nesting structure for production and services sectors is shown in Figure 2. At the bottom level nests, emissions from combustion of fossil fuels are linked in fixed proportions to the use of fossil fuels – coal, gas and oil:

$$EM_i = \alpha_i A_i, i \in \{COL, GAS, OIL\}$$

Where: EM_i is energy-related emissions, α_i is emission intensity and A_i is energy consumption.

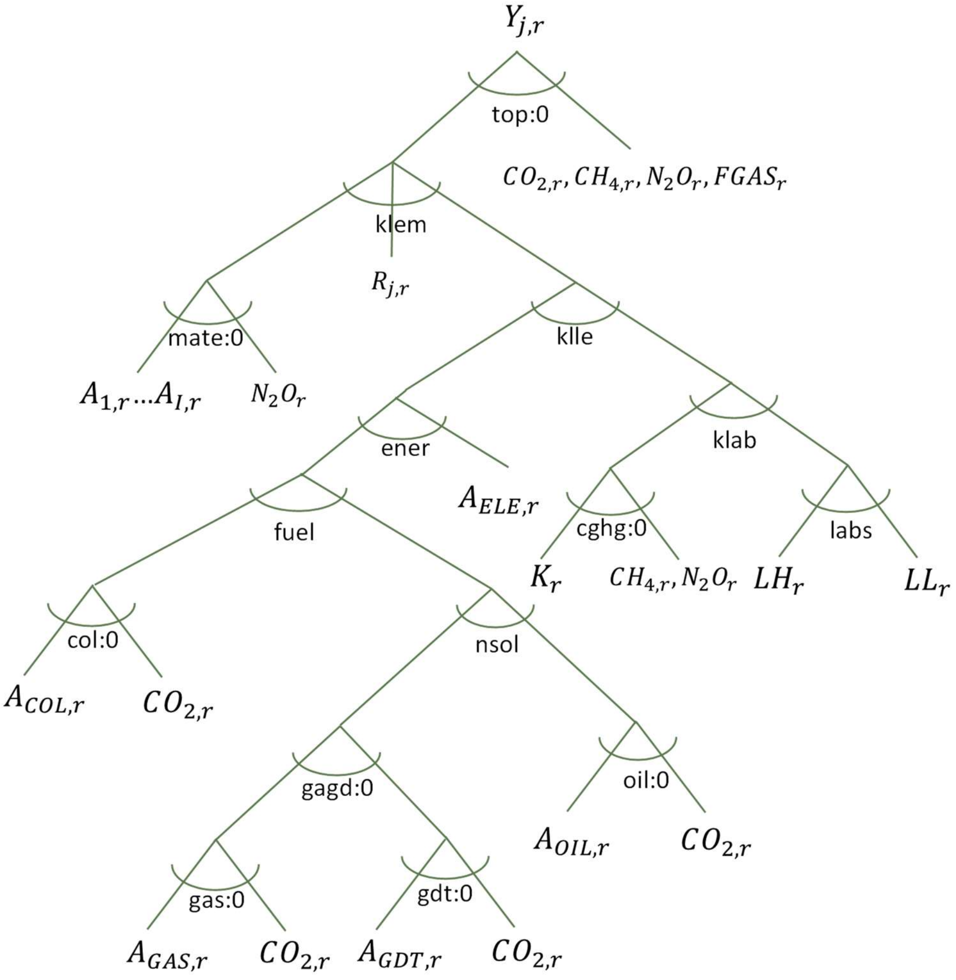
Gas, oil and coal, with the related emissions, form fuels aggregate. It is assumed that gas is directly substituted with oil, whereas the gas-oil bundle is substituted with coal. In turn, the fossil fuels aggregate is treated as a substitute of electricity (in *ener* nest).

At another branch of the nesting tree, skilled and unskilled labour are linked together into a labour bundle. The possibility to substitute between two types of employees is reflected by $\sigma_{labs} = 1/(1 - \rho_{labs})$:

$$Q_L = f(LH, LL) = T \cdot (\beta_{LH} LH^{\rho_{labs}} + \beta_{LL} LL^{\rho_{labs}})^{1/\rho_{labs}}$$

At the higher level, this labour aggregate is linked to capital, and then to aggregate energy – therefore, thus forming the capital-labour-energy (K-L-E) bundle. At the highest level, K-L-E bundle is linked with resources and materials (intermediate inputs), which are specified as Leontief aggregate of different goods and services (supplied by domestic production sectors and imported).

Figure 2. CES production technology for industrial and commercial sectors

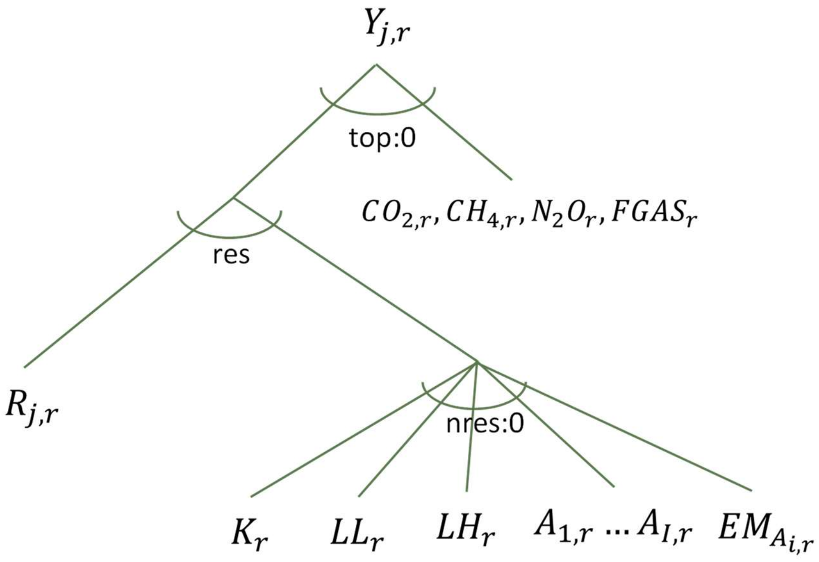


Source: Antoszewski et al. *(2015)*

2.2.4. Resource Sectors

The production structure for fossil fuel extraction sectors (CRU, GAS, COL) is different from the one assumed for other production sectors in the model. It was assumed that in such activities, there is no possibility to substitute between production factors (capital, natural resources, land and two types of labour), materials (Armington goods) and emissions. Substitution possibility is only permitted between the natural resource as such (representing fossil fuel deposits) and the Leontief bundle of other production inputs. With fixed endowment of the natural resource an increase in fossil fuel extraction is only possible with more than proportional increase in all other inputs (including capital, labour and intermediate inputs) which implies an increase in marginal production cost (i.e., fossil fuel price).

Figure 3. CES production technology for resource extraction



Source: Antoszewski et al. *(2015)*

Formally, the production function can be written as:

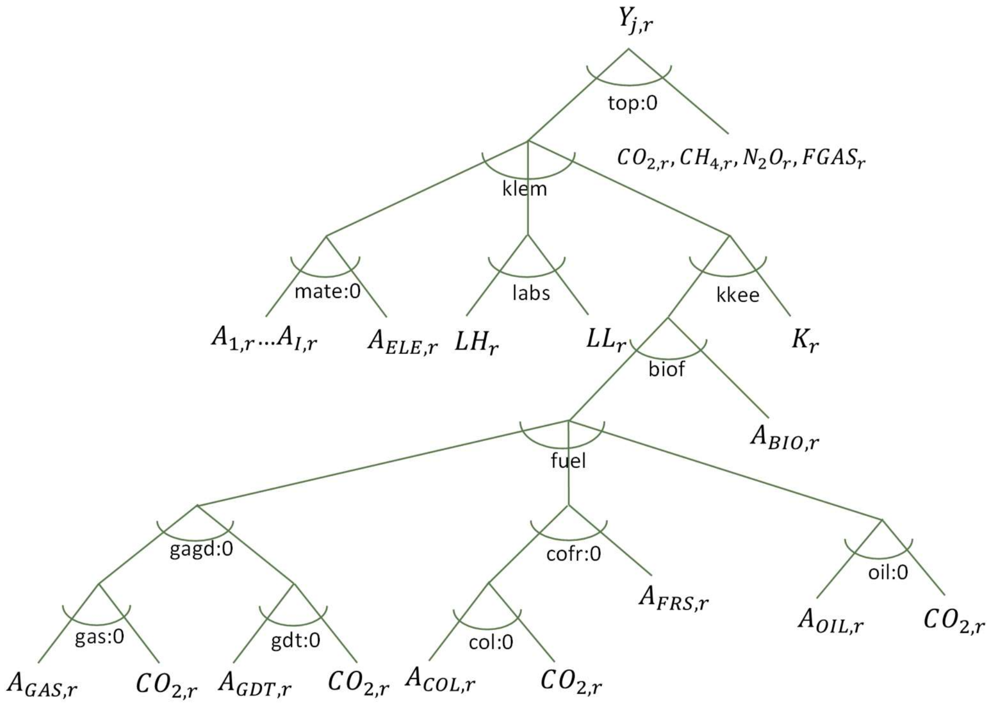
$$Y = f(R, IN) = T \cdot (\beta_R R^{\rho_{res}} + \beta_{IN} IN^{\rho_{res}})^{1/\rho_{res}}$$

Where: R are natural resources, IN – a bundle of other production inputs, which can be substituted with elasticity equal to $\sigma_{res} = 1/(1-\rho_{res})$. All other individual inputs enter the production function in fixed proportions.

2.2.5. Electricity Generation

Electricity sector, due to the future linkage with power sector model, is of crucial importance in the d-PLACE model. Biofuels are represented separately, built into the CES function as a substitute of fossil fuels.

Figure 4. Graphical representation of Leontief and CES production functions



Source: Antoszewski et al.(2015)

At the lowest level, emissions are linked to consumption of fossil fuels: gas, oil and coal (including lignite). Gas is linked to coal and oil forming the fossil fuel bundle. Fossil fuels are linked to biofuels creating an energy aggregate. This is then linked to capital at the *kkee* nest, which, in turn enters, with labour (consisting of the CES aggregate of skilled and unskilled labour) and set of materials (in constant proportions) to the *klem* nest. At the top nest, process emissions are linked to output in fixed proportion.

2.2.6. Government

The d-PLACE model distinguishes the government sector which collects taxes, makes and receives transfer payments (in particular, for emission allowances) and purchases goods and services. In the model, government expenditure is equal to government revenue, with implicit budget deficit included in the net transfers between government and households. Government consumption combines goods and services – in particular non-market services, such as public administration, health and education – in fixed proportions (in real terms). Using the model formalism, this assumption can be stated as that aggregate government consumption good (Y_{GOV}) is `produced' from goods and services (A_i) using Leontief technology:

$$Y_{GOV} = g(A_1, \dots, A_I) = \min\left(\frac{A_1}{a_1}, \dots, \frac{A_I}{a_I}\right)$$

The government receives revenues from the following sources:

- taxes on labour: $TL_i = \sum_L t_{L,i} P_L L_{L,i}$, where P_L denotes after-tax (net) wage, $t_{L,i}$–tax rate on labour,
- taxes on capital: $TK_i = t_{K,i} P_K K_i$, where P_K denotes after-tax (net) price of capital, $t_{K,i}$– tax rate on capital,
- taxes on natural resources and land: $TR_i = t_R P_R R_{R,i}$, where P_R denotes net price of natural resources, t_R- tax rate on natural resources,
- taxes on products: $TA_i = t_{IM,i} P_{IM,i} M_i + t_{D,i} P_{D,i} D_i$, where $P_{D,i}$ denotes the supplier price of the Armington composite's domestic component, $P_{IM,i}$ – the price of the Armington composite's imported component, $t_{IM,i}$ and $t_{D,i}$ – the tax rates on imported and domestic components, respectively,
- taxes on domestic production: $TY_i = t_{Y,i} P_{Y,i} Y_i$, where $P_{Y,i}$ denotes the producer price of domestic output Y_i, and $t_{Y,i}$ – the tax rate on production Y_i,
- import tariffs: $TM_i = t_{M,i}(1 - t_{X,i}) P_{M,i} M_i$, where $P_{M,i}$denotes the producer price of imported products, and M_i, $t_{M,i}$ – the tax rate on imported products M_i,
- taxes on exported products: $TX_i = t_{X,i} P_{X,i} X_i$, where P_X denotes the producer price of exported products X_i, and $t_{X,i}$ – the tax rate on exported products X_i,
- taxes on pollution emissions: $TEM_i = \sum_{EM}(t_{EM} + P_{EM}) EM_i$, where P_{EM} denotes the price of emission permits for greenhouse gases, and t_{EM} – the tax rate on pollution emissions. EM_i denotes the volume of emissions.

These taxes are reported net of subsidies. Consequently, government revenues are sum of the following taxes.

$$I_{GOV} = \sum_i (TL_i + TK_i + TR_i + TY_i + TA_i + TM_i + TX_i + TEM_i)$$

These taxes are indexed over sectors (index i). Moreover, government balance rule implies that the government expenditures are equal to revenues, so:

$$I_{GOV} = Y_{GOV} + S_{GOV}$$

In this equation, S_{GOV} is the actual transfers from the government *plus* government investments *plus* other government expenditures (e.g., interest on debt) *minus* other government revenues (e.g., property income) *minus* the government deficit (which is eliminated in the model by transfers between government and households). Public investments are covered by S_{GOV}. Government consumption is fixed in real terms. The commodity-structure of government consumption is also fixed in real terms. The same formulation is applied to each region (although government consumption structures differ across regions).

Therefore, each increase in government revenues is transferred to households and used for consumption purposes. Nevertheless, this assumption may be modified, if needed. Government expenditures are by default equal to government incomes and therefore the government deficit is not modelled explicitly. Transfers are adjusted, such that the government accounts are balanced.

2.2.7. Investment

Investment in the model depends on the price of investment good and the return to capital in given period, according to the following equation:

$$I_r = inv_r \cdot \left(\frac{RK_r}{PINV_r}\right)^{\varepsilon_{inv,r}}$$

In this equation I_r denotes the investment level RK_r is return to capital (capital rental rate) in region r and $PINV_r$ is the price of investment bundle, inv_r is a multiplicative constant, and $\varepsilon_{inv,r}$ is elasticity of investment with respect to rate of return.

Investment bundle is composed of goods linked in fixed proportions. Therefore, we have the following equation:

$$Y_{INV,r} = g(A_i, \dots, A_I) = \min\left(\frac{A_1}{a_1}, \dots, \frac{A_I}{a_I}\right)$$

Market clearing equation for investment takes the form: $I_r = Y_{INV,r}$. In the current setting investment is driven by changes in rate of return, while the supply of investment goods (and the funds) adjusts to investment demand.

The savings rate in the model adjusts to match investment. Concerning clarity and the proper welfare effects' calculation of the policies introduced, the international capital flows are not allowed in the model, so the country investment rate adjusts to match the investment rate.

2.2.8. Labour market

In the d-PLACE model, labour supply is modelled in a standard manner, as a choice between hours of work and leisure, given time constraint (leisure time is also referred to as voluntary unemployment). The time constraint takes the form:

$$TIME = L + LE + UN$$

Where: L is employment, LE – leisure time, and UN – unemployment.

The involuntary unemployment rate is determined by changes in real wages, in line with the Philips curve approach. Consequently, we have the following:

$$UR_r = \alpha_r \cdot \left(\frac{P_{L,r}}{P_{C,r}}\right)^{\epsilon_{un,r}}$$

Where: UR_r is the involuntary unemployment rate, $\frac{P_{L,r}}{P_{C,r}}$ denotes real wage in region r and α_r and $\epsilon_{un,r}$ are parameters describing the negative wage-unemployment relationship in a given region. The above relationship is often referred to as `wage curve'. Total time spent in involuntary unemployment is equal to the following:

$$UN_r = UR_r \cdot (TIME - LE)$$

The inclusion of wage curve in the model allows for more complex modelling of labour market adjustment, and more adequate labour market response in the case of "double" dividend reform.

2.2.9. Emissions

Emissions are linked to fuel consumption or production from a specific sector, which means that emission reduction can take place by decreasing the output or by decreasing the consumption of fuels. In the d-PLACE model, sectoral transformation to less-emission technologies are modelled by substitution between more and less emission intensive fuels (e.g. switching coal to gas) or by substitution of fuels for capital and labour. We do not explicitly model abatement technologies such as renewable energy sources applied directly in the sectors (small installations) or CCS/CCU (the latter reduce emissions with no impact on fuel consumption).

There are several types of emissions in the d-PLACE model:

- Energy-related emissions bound to the use of fossil fuels in fixed proportion,
- Process-related emissions bound to sectoral output in fixed proportion,
- Process-related emissions linked to sectoral capital in fixed proportion.

Therefore, abatement techniques aiming at e.g. the introduction of better technologies (keeping the use of fuels at the same level with decrease in emissions) is not explicitly modelled. However, they can be modelled implicitly as the substitution between capital and fossil fuels use.

Within the EU the emissions must be covered in EU ETS by European Emissions Allowances (EUA), purchased by industries. In the case of the EU ETS system, emissions from different industries and regions are indistinguishable – therefore there is one cap of EU ETS emissions. In the case of non-ETS, an emission cap is granted to each region (country) individually (as described above), so countries cannot trade their non-ETS targets or NDCs. Consequently, the price of the non-ETS emissions is region (country) specific. In the case of NDCs for regions outside the EU, all sectors in a given region use the same emission cap, which is calculated using NDCs – so there is only one price of greenhouse gas emissions for a given region (country).

2.3. Dynamics in the PLACE model

2.3.1. Capital formation

The dynamics in the d-PLACE model are implemented according to the following steps:

1. Building baseline scenario for the intermediate years between the base year and the target years.
2. Solving the model for all intermediate steps.
3. Changing the capital endowment in each period to evolve in line with model solution in the previous period, according to the following equation (in the base version):

   $$\mathrm{K}_{g,r,t} = (1 - \delta_{g,r})\mathrm{K}_{g,r,t-1} + \mathrm{I}_{g,r,t-1}$$

   Where: $\mathrm{K}_{g,r,t}$ is capital in period t, sector g and region r, $\mathrm{I}_{g,r,t}$ is investment in period t, sector g and region r and $\delta_{g,r}$ is capital depreciation rate. Investment can constitute a constant share of income.

4. Adding investment function, that is dependent on the price of capital related to the price of investment good and limited flows of capital between regions.

The baseline scenario for the dynamic model includes change in energy and fuel consumption, GDP growth developments, the target fuel prices are based on WEO and Primes (listed in chapter 6) projections.

The dynamics in the d-PLACE model is recursive – what means that model is solved in a loop, iteratively, using results from previous period as input data. In specific, investment in one period determines the capital stock in the following period, while the level of investment as such depends on the current return from capital and the price of investment good. Such a formulation is adopted inter alia in GTAP class of models and MONASH-style[4] models.

Therefore, the dynamics in the model are implemented as standard capital formation mechanism (using the equation from point 3 it can be formulated):

$$K_{i,r,t} = (1 - \delta)\ K_{i,r,t-1} + KN_{i,r,t}$$

Where: $K_{i,r,t}$ is the total capital available for production activities, $KN_{i,r,t}$ is the new capital, created from previous period investment. Aggregate new capital is equal to previous period investment in given region, namely:

$$KN_{r,t} = I_{r,t-1}$$

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[4] The Centre of Policy Studies (CoPS) has developed MONASH, a dynamic computable general equilibrium (CGE) model of the Australian economy designed for forecasting and for policy analysis.

In each period total new capital is distributed across sectors with infinite transformation elasticity. Therefore, while the “old” capital is locked and bound to the specific sector, the “new” one is allocated freely to the all sectors of the economy. Such a setting implies that there is a free flow of „new” capital between sectors and no flow of capital between regions. Construction and calibration of the dynamic equations was based on the note by Rutherford.[5]

In the Rutherford’s note there are three kinds of capital holdings:

- Extant capital, which is completely immobile,
- New regional capital, which is immobile between regions (but is allowed to flow between sectors) – each year new international capital is converted into that vintage of capital,
- New international capital, which is perfectly mobile between regions and sectors (equal to previous year investment).

The current version of the model (distinguishes only the first two types of capital – therefore „new” capital in region *r* is equal to investment in that region in the previous period. After it is converted to sectoral capital, it stays in that sector forever (until it depreciates).

The elasticity of demand for consumption and investment goods is equal to one, so share of investment expenditures in total households spending is kept constant. This is economically justified as it assumes constant *marginal propensity to save (MPS)*. Initially, it was considered to build a fully dynamic model with perfect foresight, but it was not implemented due to, inter alia, computational constraints as well as time constraints related to the project. Additionally in the literature some authors dispute whether the perfect foresight assumption is realistic, and so useful for applied work. Another solution, which was finally implemented is adopted in MONASH style CGE models, where the capital stock growth rate is a logistic function of current rate of return or profitability of a given industry. We relate the investment to return on capital (ROC) in line with MONASH model[6] and Lemelin (2014)[7], which uses Q-Tobin coefficient. The Q-Tobin coefficient is defined as the price (or return) of capital divided by current price of investment good . Therefore, the higher the return on investment now, the higher the investment demand. This function implies myopic expectations – expected future return on capital is equal to the current, observed one. Elasticity of investment demand was assumed to be $\epsilon_{inv,r} = 0.2$ – this rather low value prevents unrealistic changes in capital growth rates in response to changes in ROC.

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[5] http://www.mpsge.org/dynamics/note.htm

[6] https://www.copsmodels.com/ftp/workpapr/g-201.pdf

[7] https://cirano.qc.ca/files/publications/2014s-38.pdf

2.3.2. Calibration to the balanced growth path

Calibration to the balanced growth path was made on the basis of input output table data – return on capital (i.e. gross operating surplus) and investment expenditure – as well as universal assumption on interest rate (on the basis of historical data / behavioural assumptions) and depreciation of capital (calculated, economy average):

$$gop_{i,r,t} = (r_r + \delta_r) \cdot K_{i,r,t}$$

$$I_{i,r,t} = \delta_r \cdot K_{i,r,t}$$

$$K_{r,t} = \frac{\sum gop_{i,r,t} - inv_{r,t}}{r}$$

$$\delta_r = \frac{inv_{r,t}}{K_{r,t}}$$

$$K_{i,t} = \frac{gop_{i,t}}{r_r + \delta_r}$$

Where: $gop_{i,r,t}$ is gross operating surplus, δ_r is regional average depreciation rate, $I_{i,r,t}$ is investment, $K_{r,t}$ is capital in period t and region r.

The dynamics in the model allow for different temporal model resolutions – the basic setting was assumed to be 5-year time period, but for some applications annual time period seems to be better and, if needed, can be applied.

In general, there are two variables in the model, related to the capital level – sector specific extant capital, which is depreciated, and the new capital, which is allowed to flow freely between sectors. In the multiannual setting, the extant capital must be depreciated multiannually and the new capital must be also depreciated.

The extant capital is simply depreciated multiannually – therefore we have (“i" is the number of years):

$$KXD_{i,r,t} = (1 - \delta_r)^i K_{i,r,t-1}$$

The new capital is previous period investment – but they must be also depreciated. The equation for the *n-th* partial sum of geometric sequence: $S_n = a_1 \frac{1-q^i}{1-q}$, in our case $a_1 = I_{r,t}$ and $q = (1 - \delta_r)$. Therefore we have:

$$KN_{r,t} = \frac{(1 - (1 - \delta_r)^i)}{\delta_r} I_{r,t-1}$$

To reflect the economic growth, these values need to be updated, therefore, they are also multiplied by $(1+g_r)$ where g_r is target GDP growth between subsequent periods. Consequently, technical progress is *implicitly* reflected in the „value" of capital, there is no separate variable reflecting the changes in efficiency. This may change in future versions of the model, according to the specific simulation need.

2.3.3. Prospective developments of dynamics towards the upcoming needs

Prospective developments of the dynamics in the model will depend on the needs for simulations. However, there are a few potential directions that can be explored in the future:

1. If the model would be used for the analysis of adaptation to climate change, the depreciation rate should have a different value across sectors. However, in the literature, there are various estimates of such rates and they should be carefully defined to properly reflect the structure of capital in the Polish economy.
2. The modelling of international capital flows should be improved to reflect the financing needs in case of analysing financial resources for adaptation to climate change and mitigation policy.
3. Also, capital-embodied technical progress with different vintages of capital would be very useful in modelling policy instruments aimed at increase in energy efficiency.
4. The dynamics in the model can be extended also to the human capital (in case of analysing the impact of mitigation policies on human capital) or to adaptation capital (in case of analysing the impact of adaptation to climate change on the economy).
5. In case of specific analysis devoted to human capital, *learning-by-doing* mechanisms or endogenous, energy-saving technical progress can be added to the dynamics of the model.

3. Baseline scenario

3.1. EU climate policy implementation (emission reduction targets)

Baseline scenarios assume implementation of the EU's climate policy targets for GHG emission reductions by 20% in 2020 and by 40% in 2030 compared to 1990. These targets concern emissions from all sectors. Additionally, we define long-term targets to put the EU on the way to achieve low-carbon economy in the future. Our proposal for the EU progress on cutting emissions is in line with the 2050 EU long-term strategy (see: European Commission 2018). We assumed GHG emission reductions by 60% in 2040 and by 80% in 2050 compared to 1990.

Total GHG emission reductions are allocated among sectors covered by EU ETS and non-ETS. Emissions in the EU ETS are to be reduced by: 21% in 2020, 43% in 2030, 65% in 2040 and 85% in 2050 relative to 2005. The non-ETS sectors would need to cut emissions by: 10% in 2020, 30% in 2030, 50% in 2040 and 75% in 2050 relative to 2005.

Table 3. Total GHG emissions reduction with the separate targets for EU ETS and non-ETS for EU-28 in the baseline scenario

Year	Total GHG emissions reduction compared to 1990	Emission reduction target in EU ETS compared to 2005	Emission reduction target in non-ETS compared to 2005
2020	20%	21%	10%
2030	40%	43%	30%
2040	60%	65%	50%
2050	80%	85%	75%

Source: CAKE/KOBiZE own study

3.2. EU Emissions Trading System (EU ETS)

In this section, we describe how the reduction targets are converted into the number of emission allowances available in the EU ETS. At the technical level, EU ETS is a “cap and trade” system. A cap is defined by the total number of emission allowances and it determines the amount of greenhouse gases that can be emitted. The total number of emission allowances enters the modelling simulations as exogenous parameter.

In the EU ETS one EU-wide emission limit is set. The solutions adopted in the system enable free flow of emission allowances both between sectors and the EU Member States. Moreover, sectors included in the EU ETS (in EU-28, and three EFTA countries) have to surrender emission allowances equivalent to their emissions. Emissions allowances are generally divided into three categories:

- allocated free of charge (including New Entrant Reserve, NER[8]),
- auctioned (by EU Member States),
- available in the specific funds in the EU ETS (these allowances are also auctioned), i.e.:
  - ✓ in the period 2013-2020: Innovation Fund (NER300),
  - ✓ in the period 2021-2030: Innovation Fund, Modernization Fund and Fund for Greece,
  - ✓ in the period 2031-2040 and 2041-2050: Modernization Fund.

The obligations imposed on entities covered by the EU ETS are divided into certain trading periods (phases), which are differentiated by specific rules regulating, among other things, how the requirement to surrender emission allowances is shaped:

- *First trading period* - lasted from the launch of the EU ETS in 2005 until the end of 2007,
- *Second trading period* - began in 2008 and ended in 2012 (coinciding with the first commitment period under the Kyoto Protocol),
- *Third trading period* - the main difference between phases 1 and 2 and the current phase 3 (2013-2020) is that there is no free allocation for electricity production (with some exceptions for electricity modernisation in the new Member States pursuant to Article 10c of the EU ETS Directive) and that the free allocation to industry is based on EU harmonised rules outlined in the Benchmarking Decision,
- *Fourth trading period* - the upcoming phase IV will start in 2021 and run until 2030. The declared aims of EU ETS phase IV is e.g. to increase the pace of emissions cuts.

3.2.1. Total number of emission allowances in the EU ETS in the years 2013 – 2020

The emissions from installations in the EU ETS are reduced by 21% to 2020 compared to 2005 levels. The total number of allowances in 2013 from installations covered by the EU ETS in 28 EU Member States and three EFTA countries was set to 2 084 million. In subsequent years, 2013-2020, this number has been reduced annually by a fixed amount, which constitutes 1.74% of the average number of allowances issued to installations in the years 2008-2012. In absolute terms, this means that the number of allowances is reduced each year

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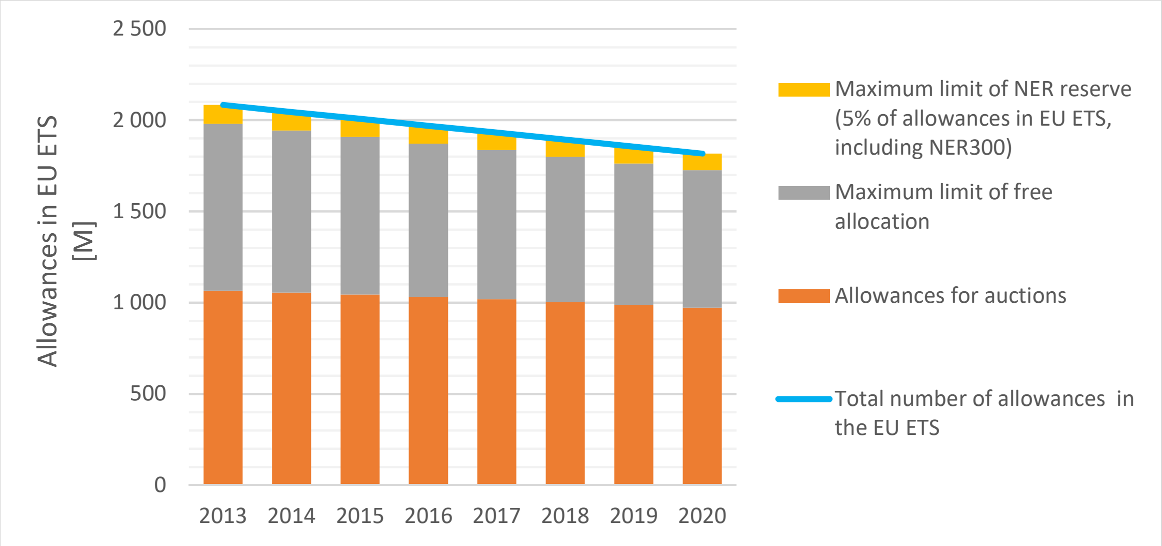
[8] Allowances set aside for new installations and installations that increase capacity, which allows for additional free allocation in the EU ETS.

by approx. 38 million (1 allowance covers 1 tonne of CO_2 equivalent)[9]. Hence, emission cap decreases linearly with time.

Figure 5 presents the total number of allowances issued in the EU ETS in the years 2013-2020, split into free allocation, auction and reserve for new installations - New Entrant Reserve (NER) included NER300. It is worth noting that the Modernization Fund will be implemented since 2021.

Figure 5. Total available number of emission allowances for EU ETS sectors in the period 2013-2020*



* *Without taking into account backloading[10] and the Market Stability Reserve[11].*

Source: CAKE/KOBiZE own calculations based on the Directive 2003/87/EC

The number of allowances being auctioned in the years 2013-2020 is the difference between the total number for the EU ETS and sum of allowances allocated free of charge to different sectors and NER reserve (included NER300). Allowances for auction have been allocated among the EU Member States on the basis of Article 10 (2) of the EU ETS Directive (of 88%/10%/2% rule). This directive (on the basis of the art. 10a par. 5 and par. 4) sets a limit (industry cap) for distribution of the emission allowances free of charge to the installations, which represents the maximum annual number of emission allowances issued to all sectors in the EU ETS.

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[9] https://ec.europa.eu/clima/policies/ets/cap_en

[10] Backloading means that emission allowances are "discontinued" temporarily, i.e. taken from the market for a specified period of time.

[11] It serves as the transparent and predictable indicator to determine how many allowances will be placed in the reserve as long as the surplus exceeds the level set in the legislation.

The volume of free allocation for 2013-2020 consists of allowances issued on the basis of art. 10a (4 and 5) of EU ETS Directive:

1. Based on art. 10a (5) the EU ETS sets a limit (industry cap), which, according to the EU ETS Directive cannot be exceeded. The limit set for 2013 is 809 million of emission allowances and in subsequent years it is reduced by a fixed amount of allowances (14 million) per year. The value of 14 million results from the multiplying 809 million by the linear reduction factor which equals 1.74%.

   This limit consists of the sum of the two values listed below:

   - Average number of allowances issued in the second period of the EU ETS reduced by 1.74% which means that, the average number of allowances from second period was lowered by 1.74% annually until 2013. The estimated volume of allowances, 1 976 million (after reduction by 1.74%), was multiplied by 34.78% – the share of emissions from those installations that are entitled to free allocations under Art. 10a (5) in the total verified emission in the second period of the EU ETS. This part was equal to 687 million of emission allowances in 2013.
   - The total amount of average verified emissions in the years 2005-2007 from installations covered by the system from 2013 (121 million of emission allowances).

   Taking into account the methodology described above, we calculated the maximum number of free allowances in the period 2013-2020 on the bases of art. 10a (5) of the EU ETS Directive in mln EUA:

2013	2014	2015	2016	2017	2018	2019	2020
809	794	780	765	750	735	720	705

2. Free allocation of allowances for heat production (art. 10a (4) EU ETS Directive) is based on the EC documents – Commission Decision of 5 September 2013, concerning national implementation measures for the transitional free allocation of greenhouse gas emission allowances in accordance with Article 11(3) of Directive 2003/87/EC of the European Parliament and of the Council (according to table below in mln EUA):

2013	2014	2015	2016	2017	2018	2019	2020
104	94	84	76	68	61	54	48

The sum of emission allowances from points 1 and 2 results in the maximum number of allowances which could be allocated to industry free of charge in the period 2013 – 2020 in mln EUA:

2013	2014	2015	2016	2017	2018	2019	2020
914	888	864	840	818	796	774	753

In addition to the free allocation in the EU ETS sectors, there is a reserve for new installations - New Entrant Reserve (NER), which was defined as 5% of the total number of allowances available in the EU ETS. From the initial number of emission allowances included in NER (around 780 million allowances) 300 million of allowances were transferred into Innovation Fund NER300[12] for funding low carbon energy demonstration projects.

From the total number of emission allowances in the period 2013-2020 (see Figure 2. above) we have withdrawn (in the baseline scenario) 900 million emission allowances from the auction pool due to the backloading[13] and remaining emission allowances which will not be allocated free of charge (on the basis of data from 2015 – the first year of the projection)[14]. Unallocated allowances are allowances which had been not allocated for free to the installations and set aside. The main source of unallocated allowances is closures or significant reduction of capacities by installation in the EU ETS.

3.2.2. Total number of emission allowances in the EU ETS in the years 2021 – 2030

Baseline scenario assumes that in 2030 emissions from sectors covered by the EU ETS are lower by 43% than in 2005. Achieving such a target is associated with decrease in the available number of allowances.

In order to achieve the 43% target by 2030, the total number of emission allowances in the period 2021-2030 will be reduced annually by approx. 48 million[15]. The value of 48 million results from multiplying the average number of emission allowances issued to the installations in the years 2008-2012 by the linear reduction factor, 2.2%.

Figure 6 presents the allocation of emission allowances in the EU ETS in the years 2021-2030.

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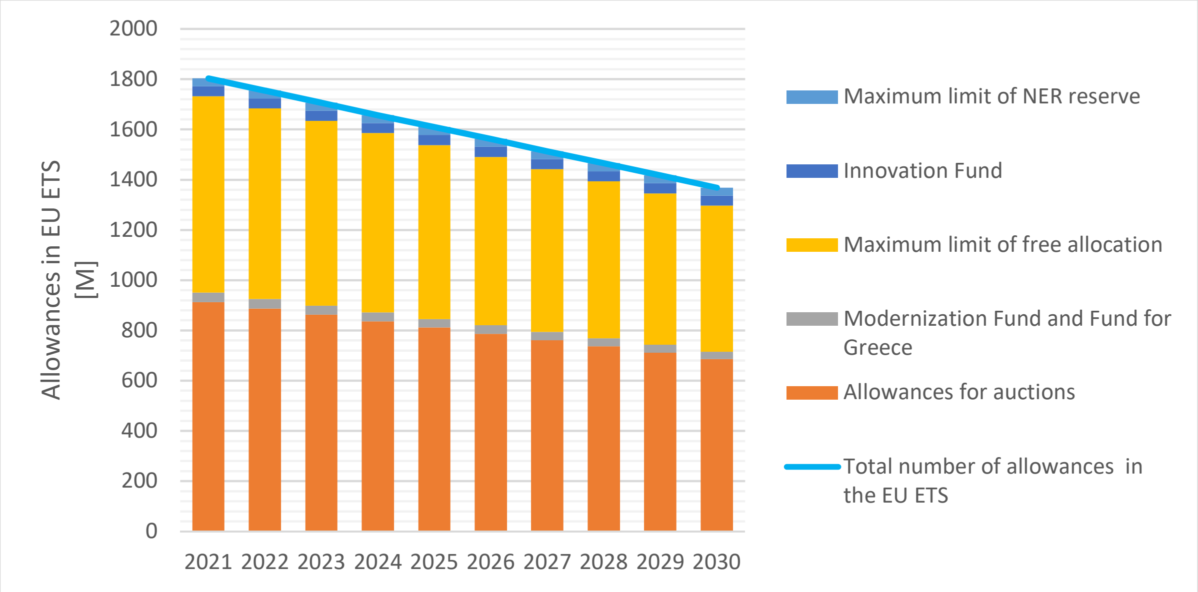
[12] https://ec.europa.eu/clima/policies/lowcarbon/ner300_en

[13] See Regulation (EU) No 176/2014.

[14] From New Entrants Reserve (NER) and pursuant to art. 10a EU ETS Directive.

[15] https://ec.europa.eu/clima/policies/ets/ETPp_en

Figure 6. Total available number of allowances for EU ETS sectors in the period 2021-2030* [mln EUA]



** Without taking into account the Market Stability Reserve.*

Source: CAKE/KOBiZE own calculations based on the Directive (EU) 2018/410

The number of allowances allocated for auctions in years 2021 - 2030 is set as 57% of the total number of allowances in the EU ETS, pursuant to the revised EU ETS Directive (Directive 2018/410)[16]. We assumed that the share of the auction allowances would be reduced by 3 percentage points (p.p.) to increase the free allocation[17] (in fact, this decision will be known in 2020). In accordance with the EU ETS Directive, the auction volume share can be reduced if the free allocation to the sectors is insufficient in the period 2021-2030. Part of the allowances may be transferred from auctions to counteract the effect of cross-sectoral correction factor (CSCF), which is used to ensure that total allocation of free allowances at the sectoral level remains below the maximum amount allowed in the EU ETS. It is worth to mention that the preliminary free allocation for each installation in reality is calculated by multiplication of benchmark, production activity and carbon leakage exposure factor. If the total number of preliminary free allocation on installation level across the total number of free allowances it is necessary to impose CSCF to adjust preliminary free allocation on installations level (reduce the allocation of free allowances). Our assumption to increase the maximum amount of free allocation is made due to the fact that in the period 2013-2020 it was necessary to apply CSCF and it is very likely that such a need will also occur in the next period of the EU ETS

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[16] 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

[17] Based on the art. 10a 5a) of EU ETS Directive (2003/87/EC)

2021-2030. This assumption results also from the following fact. Free allocation mainly covers industrial sectors in which the reduction is more difficult than in energy generation sector.

The Modernization Fund is a part of the auction cap. The Modernization Fund will be operational since 2021 and it will account for 2% of the total number of allowances available in the years 2021-2030 (310 million EUA). The Fund for Greece (25 million EUA that will come from the unallocated allowances until 2020) supplements the Modernization Fund.

The final share of the auction allowances (used in our modelling simulations) has been reduced by 5 p.p. (3 p.p. to increase free allocation due to our assumption and 2 p.p. for Modernization Fund pursuant to article 10d of the EU ETS Directive) and set at the level of 52% of the total number of allowances in the EU ETS in the period 2021 – 2030.

The reserve for new installations NER (New Entrants Reserve) in the years 2021-2030 will be composed of 200 million allowances from the Market Stability Reserve plus approx. 120 million allowances from unallocated allowances (according to KOBiZE estimates) which were not allocated free of charge until 2020 and were transferred to the following years.

The Innovation Fund (NER450) was set at the level of 450 million allowances (325 million from the allowances which should be allocated free of charge, 75 million allowances from auctions and 50 million allowances from MSR reserve). In the d-PLACE model, the revenue from the sale of emission allowances included in NER450 is a part of government income, distributed among the Member States.

Under the EU ETS for the years 2021-2030, all allowances that are not sold at auctions and are not allocated to the Modernization Fund or the Innovation Fund will be distributed free of charge to industries.

3.2.3. Total number of emission allowances in the EU ETS for the next decades: 2031 – 2040, 2041 – 2050

We assumed that the general rules in the EU ETS will not change until 2050. Total number of emission allowances will decline by 48 million per year from 2031 onwards, with the same rules for free allocation as in the previous period. The share of allowances to be auctioned will be equal to 57%. Out of these, 2% (of total allowances) will be allocated to the Modernization Fund. A few small differences in the shape of the EU ETS (concerning Innovation Fund and NER) are listed below:

- Innovation Fund will constitute 2%[18] of the total number of emission allowances in the EU ETS available each year,

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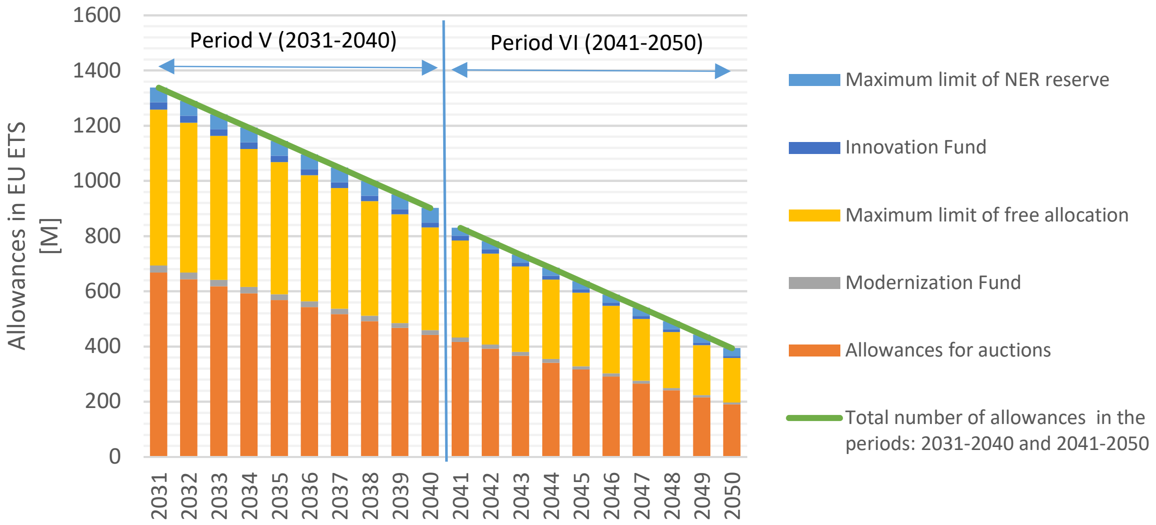
[18] The assumed percentage value corresponding to a share of 400 million in the total number of allowances in the period 2021-2030. The 400 million will be sold in 2021 – 2030 to create Innovation Fund. Additional 50 million of

- The reserve for new installations will amount to 5% of the total number of allowances available in 2031-2040 and 2041-2050 and it will be distributed equally over the periods (53 million allowances each year in 2031-2040 and 29 million allowances each year in 2041-2050),
- We do not assume an additional reduction of the auction share by 3 p.p. to increase the free allocation (counteract applying of cross-sectoral correction factor, CSCF) as in the period 2021-2030, because it is even more difficult to foresee the situation in the EU ETS after 2030.

Figure 7 presents the allocation of emission allowances in the EU ETS in the period 2031-2050.

Figure 7. Total available number of allowances for EU ETS sectors in the period 2031-2050 [mln EUA]



Source: CAKE/KOBiZE own calculations based on the Directive (EU) 2018/410

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allowances for Innovation Fund in the period 2021-2030 come from MSR so we do not count this value for next decades.

3.2.4. Emission allowances transferred to Market Stability Reserve

Starting from 2019, part of allowances is deducted from auction volumes and added to the Market Stability Reserve (MSR)[19] when a significant excess supply of allowances occurs[20].

Following emission projections from the *EU Reference Scenario 2016* we estimate that by 2020 around 760 million of emission allowances will be transferred from auctions into the MSR. In the next period, the MSR will have a slightly weaker impact on the market - during the years 2021-2030, 690 million allowances will be put in the reserve.

The transfer of emission allowances from auctions to the MSR corresponds with an annual reduction of 95 million in the period 2013-2020 and 69 million in the period 2021-2030, on average. Emission allowances placed in reserve will not be available for the sectors in the EU ETS[21].

For the next periods: 2031-2040, 2041-2050, we assumed that emission allowances will not be transferred to the MSR (and hence withdrawn from the market).

MSR does not affect the volume of emission allowances allocated free of charge to industrial sectors, as well as the volume of 2% reserve of emission allowances for Modernization Fund and the volume of emission allowances dedicated to the Innovation Fund.

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

[20] If there are more than 833 million allowances on the market, the auction pool designated for sale by Member States will be reduced by 24% from the number of allowances in circulation (from 2024 the rate is reduced to 12%) . However, if the number of allowances in circulation reaches a value of less than 400 million, 100 million allowances will be transferred from the MSR to the auction pool. In addition, emission allowances withdrawn from the auctions due to the backloading and emission allowances which were not allocated free of charge to the installations in the period 2013-2020 at the amount of 900 million will be transferred to the MSR. From 2024 all emission allowances in the MSR exceeding the amount of emission allowances auctioned in the previous year will be cancelled.

[21] The transfer of emission allowances from MSR to the auction is a problematic issue. According to an analysis made by Carbon Tracker [an independent financial think tank that carries out in-depth analysis on the impact of the energy transition on capital markets] the emission allowances will never came back to the auction due to the way in which the surplus of allowances is calculated. The definition of surplus does not take into account the deficit of emission allowances caused by aviation. Carbon Tracker said: "*we are still projecting a cumulative deficit for aviation of 600Mt by 2030 – this means that the cumulative surplus for fixed installations (otherwise known as the TNAC) cannot fall below 600m by 2030*" (page 16, "Carbon Countdown", Mark C. Lewis, August 2018). According to the definition of surplus (TNAC) adopted in MSR Decision lower threshold 400 million will never be reached. We take into account this issue in our calculations of surplus in the EU ETS.

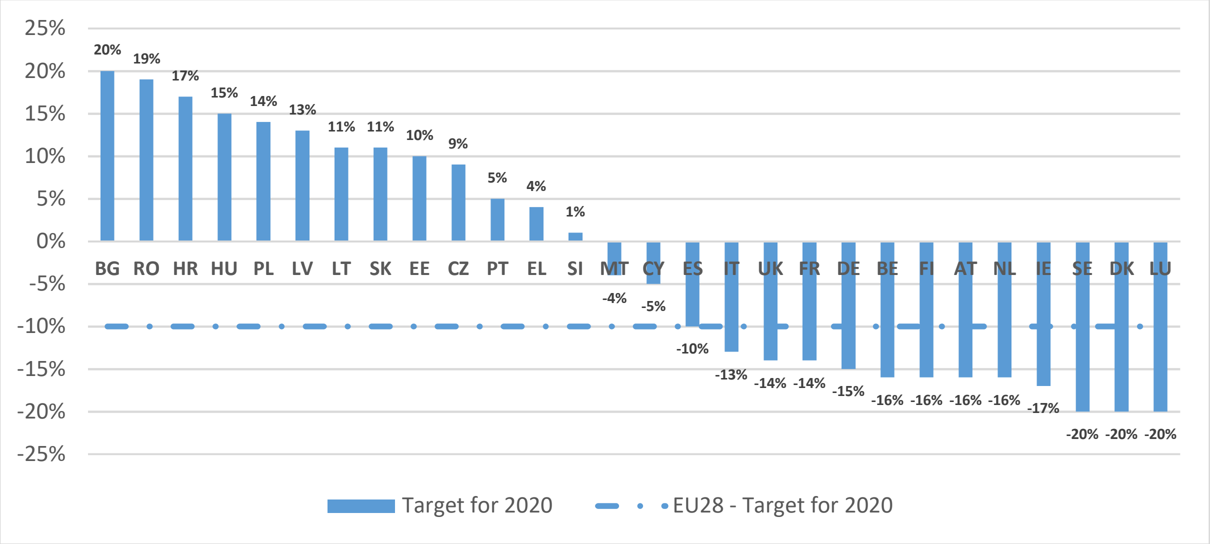
3.3. Emissions limits for sectors not included in the EU Emissions Trading System

In this section we explain how the adopted reduction targets in the non-ETS for the EU are converted into national emission limits imposed in the baseline scenario. Emission in non-ETS sectors in each EU Member State cannot exceed a national limit. National emission limits enter the model simulations as exogenous parameters.

3.3.1. Emissions limits in the non-ETS in the years 2013 – 2020

In 2020, the EU GHG emission reduction target for the non-ETS sectors is set to 10%, relative to 2005 levels. Distribution of country-level GHG emission reduction efforts is determined considering gross domestic product (GDP) per capita differentials, leading to targets ranging from -20% to +20% across the EU Member States.

Figure 8. Emission reduction targets in the non-ETS sectors for each EU Member State in 2020 relative to 2005



Source: Based on Decision 2009/406 /EC

Emission reduction targets covering sectors outside the EU ETS is regulated by the Decision 2009/406/EC[22] (hereinafter the non-ETS Decision). These targets were used to determine annual emission limits for the Member States. The trajectory for annual emission limits used in the baseline scenario is adopted from the Decision 2013/162/EU and Decision 2013/634/EU.

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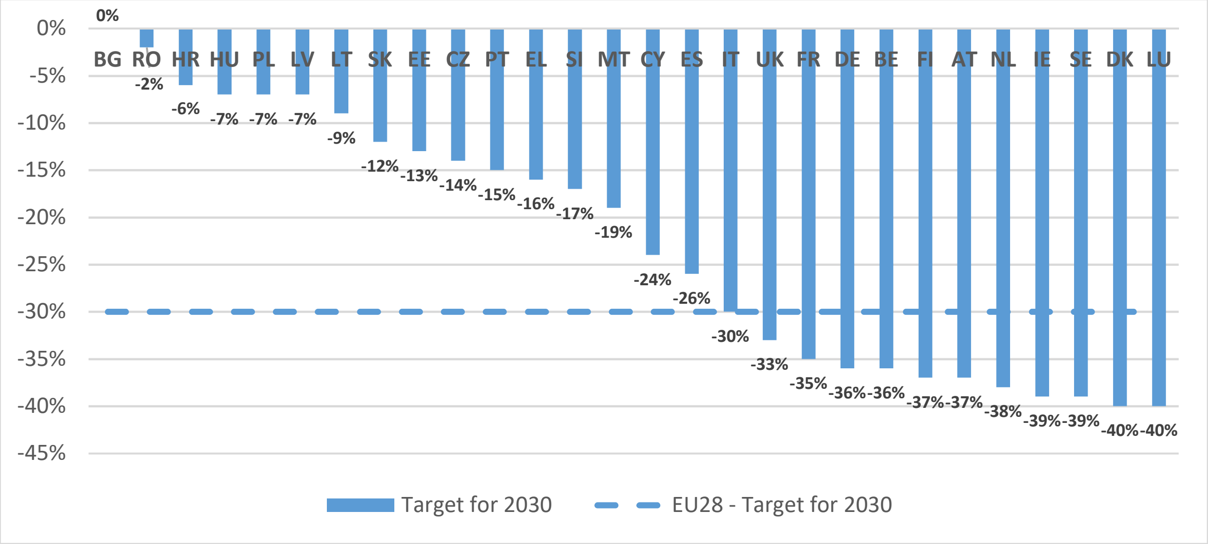
[22] Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020

3.3.2. Emissions limits in the non-ETS in the years 2021 – 2030

According to the Effort Sharing Regulation[23], emission reduction target in 2030 in the non-ETS sectors is equal to 30%, relative to 2005 levels. This target is converted into national emission reduction targets in 2030 for individual Member States, ranging from 0% to 40%. The way of distribution of the emission reduction targets among the EU Member States was based on the same principles as for the year 2020 (taking into account GDP per capita).

Figure 9. Emission reduction targets in the non-ETS sectors for each EU Member State in 2030 relative to 2005 [%]



Source: Based on Regulation (EU) 2018/842 (Effort Sharing Regulation)

For the period 2021–2030 the limits for GHG emissions were also calculated on the basis of the adopted GHG emission reduction targets for each EU Member State. Annual emission reductions for the years 2021-2030 for each EU Member State is represented by a straight line that connects the following starting and end points[24]:

- starting point - average emissions between 2016-2018[25] placed on the time axis within five twelfths of the distance from 2019 to 2020 (or at 2020 if this results in further reductions for specific Member State),
- end point - set on the basis of the 2030 target compared to 2005.

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[23] See Regulation (EU) 2018/842.

[24] Based on information available on the EC website (link: https://ec.europa.eu/clima/policies/effort/proposal_en).

[25] Emission projection based on EU Reference Scenario 2016 – Energy, transport and GHG emissions Trends to 2050.

3.3.3. Emissions limits in the non-ETS for the next decades: 2031 – 2040, 2041 – 2050

We assume that non-ETS sectors would need to reduce their emissions by 50% in 2040 and by 75% in 2050 compared to 2005. To achieve the overall EU target in the non-ETS we determined individual binding targets for each individual EU Member State. The distribution of reduction efforts is based on GDP per capita projections according to Primes Reference scenario 2016. In our calculation we use GDP per capita estimated for 2023 and 2033[26]. It was assumed that the EU Member States will achieve targets ranging from -20% to -65% and from -40 to -85% respectively in the years 2040 and 2050.

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 -50% in 2040 and -75% in 2050). Countries with GDP per capita below the average in the EU are assigned targets less ambitious than the overall EU target. Countries with GDP per capita above average are assigned targets more ambitious than the overall EU target. In our approach the reduction target for individual Member States remains proportional to their GDP per capita (with the exception of two states with the highest GDP per capita – Denmark and Luxembourg – which have the same maximum reduction targets).

In the baseline scenario, the limits of annual emission reduction for each EU Member State in the period 2031-2040 and 2041-2050 are calculated using the same method as the one used for 2021-2030. For example, the limit in the period 2031-2040 is determined by a straight line linking the two points:

- starting point – projected average emissions from each EU Member State within 2026-2028 placed in the timeline within five twelfth of the distance from 2029 to 2030 (or at 2030, if this results in further reductions for specific Member State),
- end point - set on the basis of the new emission reduction targets in 2040 compared to 2005.

4. GHGs emission reduction targets for the rest of the world

We assume that regions outside the EU considered in the modelling scenario would adopt a binding emission limitation/reduction targets included in the NDCs (Nationally Determined Contributions) submitted under the Paris Agreement. GHG reduction targets for regions outside the EU, resulting from NDCs, were estimated based on CARBON BRIEFS/NDC TRACKER[27] and emission forecasts prepared by PBL Netherlands Environmental Assessment

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[26] It makes our calculation consistent with the previous period. National reduction targets in non-ETS sectors in 2030 were determined on the bases of GDP per capita in 2013.

[27] https://www.carbonbrief.org/paris-2015-tracking-country-climate-pledges

Agency[28] In our calculations we used historical GHG emissions published by the European Commission in EDGAR – Emissions Database for Global Atmospheric Research[29].

The NDCs submitted under the Paris Agreement have been divided into two different categories, i.e .:

- NDCs submitted as GHG reduction targets,
- NDCs submitted as the targets of GDP emission intensity (reduction in emissions per unit of GDP), emission in relation to the BAU projection or in other forms.

All NDCs submitted in a form of GHG reduction targets relative to the base year have been included in the baseline scenario. We also take into account NDCs submitted in other forms than GHG reduction targets, but only for countries with shares in global emissions above 1% in 2012. Those NDCs were transformed into GHG reduction targets using a tool prepared by the PBL Netherlands Environmental Assessment Agency.

5. Free allocation of emission allowances in the EU ETS

In the EU ETS sectors exposed to a significant risk of carbon leakage receive part of emission allowances free of charge. Those free emission allowances are exogenous in d-PLACE model, i.e. their allocation does not change as industry output or emissions change in the course of simulations. The following industrial sectors are entitled to free emission allowances:

- Refined oil products, coke,
- Paper–pulp–print,
- Non-metallic minerals,
- Food industry,
- Chemical industry,
- Iron and steel industry,
- Non-ferrous metals.

We calculate potential distribution of free allowances for the years 2015 and 2050, with 5 year step. In 2015 free allocation of emission allowances is based on historical data from EEA (European Environment Agency)[30].

In the current version of the model, from 2020 free allowances are allocated to sectors based on both gross value added (in fact, in the EU ETS it is activity level) and benchmark, which is supposed to reproduce actual mechanism of free allocation in the EU ETS. In the context of the EU ETS benchmarks reflect emission intensity of production and they are based on 10%

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[28] https://themasites.pbl.nl/climate-ndc-policies-tool/

[29] https://edgar.jrc.ec.europa.eu/

[30] EU ETS data viewer: https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

of the best installations covered by the system. All values of projected variables, such as GVA or GHG emissions in the EU ETS sectors, were adopted from the Primes Reference scenario 2016 (European Commission 2016).

Free allocation of emission allowances is expressed by the formula:

$$FREE_{g,r,t} = BM_{g,r,t} \cdot \ GVA_{g,r,t-5} \cdot CSCF_t$$

Where: $FREE_{g,r,t}$ is free allocation in period t, sector g and region r, BM is benchmark, $GVA_{g,r,t-5}$ is projected gross value added in period t-5 (*which is a proxy of a change in the* level of activity), sector g and region *r* and $CSCF_t$ is cross-sectoral correction factor in period t.

Cross-sectoral correction factor (CSCF) ensures that total allocation among sectors remains below the maximum amount pursuant to the analyzed scenario.

$$CSCF_t = \frac{FREE_{MAX,t}}{\sum FREE_{PRE,g,r,t}}$$

$$FREE_{PRE_{g,r,t}} \ = BM_{g,r,t} \cdot \ GVA_{g,r,t-5}$$

Where: $FREE_{MA \quad t}$ is maximum free allocation in period t, $FREE_{PRE_{g,r,t}}$ is preliminary free allocation.

Benchmark for each sector within the Member States is elaborated based on gross value added and historical level of free allocation in 2015 taken from EEA database (EU ETS data viewer).

$$BM_{g,r,2015} = \frac{\frac{FREE_{HIS_{g,r,2015}}}{CSCF_{2015}}}{GVA_{g,r,2010}}$$

Where: $FREE_{HI \quad g,r,2015}$ is historical free allocation in 2015, sector g, region r, $GVA_{g,r,2010}$ is gross value added in 2010 (this year is selected as the closest year to 2007-2008, which have actually been used to determine the real benchmarks in the EU ETS), sector g and region r, $CSCF_{2015}$ is cross-sectoral correction factor in 2015.

The improvement of the benchmark, to be applied for the free allocation after 2020, is based in our calculation using the gross added value and emission projection from Primes Reference scenario 2016 (European Commission 2016).

$$BM_{RATIO_{g,r,t}} \ = \frac{\frac{EMIS_{g,r,t}}{GVA_{g,r,t}}}{\frac{EMIS_{g,r,2010}}{GVA_{g,r,2010}}}$$

The benchmarks after 2020 are expressed by the formula

$$BM_{g,r,t} = BM_{g,r,2015} \cdot BM_{RATE_{g,r,t}}$$

We assume for the years 2015, 2020 that benchmarks and preliminary free allocation will not change:

$$BM_{g,r,2020} = BM_{g,r,2010}$$

$$FREE_{PR\ \ g,r,2020} = FREE_{PRE_{g,r,2015}}$$

The equal value of preliminary free allocation ($FREE_{PRE}$) in the years 2015 and 2020 is based on the assumption that all sectors covered by the free allocation are threatened with the same carbon leakage intensity (we do not include different carbon leakage exposure factor (CLF) between the sectors)[31].

6. Data sources

6.1. GTAP data

The core of the d-PLACE model is a multi-regional input-output table (IO) based on from the GTAP 9 Data Base. The GTAP Data Base includes worldwide IO table that presents global data on industry-level production processes, inter-industry linkages through intermediate inputs, final demand (including consumption and investment), and international trade (including transportation and protection data), distinguishing 140 regions and 57 commodities (industries), for the years 2004, 2007 and 2011. The database also includes information on different types of taxes and subsidies.[32] Accompanying data tools allow for easy aggregation of sectors and regions which facilitates development of CGE models tailored to specific analytical needs.

The GTAP database also contains several complementary extensions. For our model, the most important extension is GTAP-E which augments economic data with the data on energy use and CO_2 emissions.

The GTAP 9 Data Base includes[33]:

- Macro-economic data for 2004, 2007, and 2011,

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[31] In the EU ETS carbon leakage exposure factor (CLF) is different for sectors exposed to carbon leakage (on the CL list) and not exposed to carbon leakage (not on the CL list). According to the EU ETS Directive, CLF is 100% for the sectors exposed to carbon leakage. Those sectors which are not no CL list have CLF equal 30 %, up to 2026, after this year CLF gradually decrease to 0 in 2030.

[32] See: Angel Aguiar, Badri Narayanan and Robert McDougall

[33] See: https://www.gtap.agecon.purdue.edu/databases/v9/default.asp

- Bilateral merchandise trade data for 2004, 2007, 2011,
- Protection data (e.g. domestic support, agriculture export subsidies) for 2007 and 2011,
- Time-Series Bilateral Trade data from 1995-2013,
- Improved bilateral services trade data for 2004, 2007, and 2011,
- Improved energy data for 2004, 2007, and 2011,
- Decomposition of tariffs (into ad valorem and specific),
- CO_2 emissions dataset integrated into the core data base.

6.2. Other data sources

6.2.1. Economic

The global IO table in the d-PLACE model is supplemented by additional data sources concerning economy, energy and emissions. The economic data used in the d-PLACE model to generate baseline scenario include GDP and unemployment rate projections. Table 4 shows information on data sources used for different projections.

Table 4. Economic data sources

	EU States	**Non-EU**
GDP	Primes Reference scenario 2016, EUROSTAT	OECD
Unemployment rate	Ageing Report 2015, Primes Reference scenario 2016	IMF, The World Bank, UN and Ageing Report 2015

Source: CAKE/KOBiZE own study

Historical changes in the GDP are taken from Eurostat (2018a). This data are supplemented by projections from Primes Reference scenario 2016. The Primes Reference scenario 2016 uses Aging Report (EC, 2015a) as a data source for long-term projection of trends in GDP growth and population. In Primes Reference scenario 2016 short- and medium-term GDP growth projections come from DG ECFIN.

GDP growth rates for non-EU countries are calculated based on OECD (2014) and IMF (2014) data. Initially we adopt GDP growth rates from OECD (2014). For regions for which projection from OECD (2014) is missing, the growth rate from IMF (2014) is adopted and extrapolated to 2050.

We used projections of unemployment rates for the EU Member States published in the Ageing Report (EC, 2015). For all regions outside the EU, the unemployment rates are prepared on the basis of The World Bank historical data and IMF (2017) projection to 2022. Projections going beyond 2022 are in line with the Ageing Report and for regions outside the EU from United Nations Report.

6.2.2. Energy

Energy demand projections come from several sources: Primes Reference scenario 2016 (European Commission 2016), World Energy Outlook (WEO) 2016 Current Policies scenario (IEA 2016) and Energy Balances (IEA 2014a,b). All data is aggregated into d-PLACE model format (which contains the following energy carries/sectors: coal, crude oil, natural gas, biofuels, refined oil products, electricity, gas distribution and heating) and provided as a time series until 2050.

Table 5. Energy demand data sources

Energy carriers/ sectors	EU States	Non-EU
Coal, crude oil, natural gas, biofuels, refined oil products, electricity, gas distribution and heating	Primes Reference scenario 2016	WEO 2016 Current Policies scenario, IEA Energy Balances

Source: CAKE/KOBiZE own study

Trends in energy demand for EU Member States are based on the Primes Reference scenario 2016 (European Commission 2016). The Reference scenario is characterized by continuous decrease of energy consumption. That trend is strengthened by the legislation until 2020. After 2020, energy consumption still declines, though more slowly. In that period, reduction of energy demand is not primarily policy-driven, but it arises due to market trends and improvements in technology. Primes Reference scenario 2016 assumes that binding GHG and RES targets for 2020 will be achieved and all policies agreed at the EU and Member State level by December 2014 will be implemented (see European Commission 2016).

Trends in energy demand for non-EU regions are based on WEO 2016 Current Policies scenario (IEA 2016). Part of the assumptions concerning policy implementation for this scenario is very similar to the Primes Reference scenario 2016. WEO 2016 Current Policies scenario (IEA 2016) is based on the policies formally enacted or adopted up to mid-2016.

In general, energy demand for non-EU regions as a whole is set to rise over the projection period due to the industrialisation and urbanisation process in developing countries. Energy consumption in developed economies is decreasing in line with energy efficiency improvements.

To determine change in trends used for baseline projection, historical energy demand for non-EU regions in 2011 is taken from WEO 2016 (IEA 2016) and Energy Balances (EB) (IEA 2014a,b).

6.2.3. Emissions

The d-PLACE model includes GHG emissions such as CO_2, CH_4 and N_2O. Emissions from the different gases are converted into CO_2-equivalent volumes. The emissions are classified into two different categories:

- Related to fuel combustion – emission is proportional to the energy/fuel used,
- Process emissions (e.g. CO_2 emission from cement production) – is related to the activity level and proportional to output.

Historical and projected GHG emissions data sources are shown in Table 6.

Table 6. Emission data sources

Emissions	EU States	Non-EU
CO_2 from fuel combustion	Primes Reference scenario 2016 European Environment Agency	EDGAR (EC JRC)
CO_2 process emissions	Primes Reference scenario 2016 European Environment Agency	EDGAR (EC JRC)
Non-CO_2 from fuel combustion	GAINS Reference scenario 2016	Environmental Protection Agency (of the United States)
Non-CO_2 process emissions	GAINS Reference scenario 2016	Environmental Protection Agency (of the United States)

Source: CAKE/KOBiZE own study

Time series data for emission are obtained in several different ways. For the EU Member States the energy-related CO_2 emission projections are in line with Primes Reference scenario 2016. To maintain consistency between energy and emissions, CO_2 emission projections are generated based on energy demand projections and emission intensity coefficients as of GTAP 2009. In the next step CO_2 emissions is scaled to match aggregate Primes data.

Energy-related CO_2 emission projections for non-EU regions are based on future energy use taken from WEO 2016 Current Policies scenario and multiplied by fixed emission intensity coefficients from GTAP 9.

Projections of non-CO_2 gases for EU Member States are adopted from the GAINS data (Reference scenario 2016) and for regions outside the EU forecasts prepared by the US Environmental Protection Agency (EPA 2014) are used. In both cases the estimated annual emission change rate is applied to the data from 2011. Additionally, for the EU Member States, the emission projections are scaled to match the levels from GAINS data (Reference scenario 2016). This is necessary to reflect emission reduction targets proposed for the EU Member States.

References

Antoszewski, M., Boratyński, J., Zachłod-Jelec, M., Wójtowicz, K., Cygler, M., Jeszke, R., Gąska J., Rabiega W. & Kąsek, L. (2015). CGE model PLACE. MF Working Paper Series, no 22-2015.

Böhringer, C., & Rutherford, T. F. (2013). Transition towards a low carbon economy: A computable general equilibrium analysis for Poland. Energy Policy, 55, 16-26.

Dixon, P. B., & Jorgenson, D. (Eds.). (2012). Handbook of computable general equilibrium modelling. Newnes.

Rutherford, T. (2002). Lecture notes on constant elasticity functions. University of Colorado.

Eurostat (2018a), Annual national accounts – GDP and main aggregates – volumes and current prices, Database by themes – Economy and finance, update May, http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database

EPA (2014), Non-CO_2 Greenhouse Gases: International Emissions and Projections, Washington, http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html

OECD (2014) Economic Outlook No 95 - May 2014 - Long-term baseline projections https://stats.oecd.org/Index.aspx?DataSetCode=EO95_LTB#

IMF (2014), World Economic Outlook Database, October 2014 Edition, https://www.imf.org/external/pubs/ft/weo/2014/02/weodata/index.aspx

European Commission (2015), "The 2015 Ageing Report. Economic and budgetary projections for the 28 EU Member States (2013-2060)", European Economy 3, Brussels, http://ec.europa.eu/economy_finance/publications/european_economy/2015/pdf/ee3_en.pdf

IMF (2017), World Economic Outlook Database, July 2017, https://www.imf.org/external/pubs/ft/weo/2017/02/weodata/index.aspx

European Commission (2016), "EU Reference Scenario 2016. Energy, transport and GHG emissions Trends to 2050"

European Commission (2018), "A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy" , Brussels

IEA (2016), "World Energy Outlook", annual, Paris, https://webstore.iea.org/world-energy-outlook-2016

IEA (2014a), Energy balances of OECD countries 2014, annual, Paris, https://www.oecd-ilibrary.org/energy/energy-balances-of-oecd-countries-2014_energy_bal_oecd-2014-en

IEA (2014b), Energy balances of non-OECD countries 2014, annual, Paris, https://www.oecd-ilibrary.org/energy/energy-balances-of-non-oecd-countries-2014_energy_bal_non-oecd-2014-en