Alternative Options for the Design of Carbon Allowances Trading Scheme in Ukraine

Abstract

In my PhD paper I address the issue of feasibility and implications of domestic trading scheme in Ukraine. There are a wide range of issues and options associated with its design. A major issue is how to arrange it? The leading options for achieving cost-efficiency in emission reductions and to minimize the adverse adjustment effects in energy-intensive industries (that have the greatest share in the national export structure and gross domestic product) is to address the design of domestic emissions trading scheme. In order to address the economic effect of the domestic emissions trading scheme in Ukraine, I examine the design of alternative allocation methods of emissions allowances. The estimates of possible scenarios are based on a general equilibrium model. The model foresees the key features of Ukrainian imperfect markets.

Introduction

Ukraine is one of Eastern European countries that could reap the most benefits of the Kyoto Protocol implementation. According to the National Strategy of Ukraine for Joint Implementation and Emissions Trading (2003), Ukraine will have surplus emission rights of about 1.5 billion tones of CO_2-equivalent in the first commitment period 2008-12. Besides, the country has a tremendous JI potential for further emission reductions of approximately 750 $MtCO_2$ in the period 2008-2012 at abatement costs below 8 $/t. The realization and sale of these additional emissions reductions could yield further gross revenues of between $ 3.5 and $ 7.5 billion. The sale of these emission rights on the international GHG market could generate substantial revenues for Ukraine.

On the other hand, the country is characterized by a very high carbon intensity of its GDP, see table 1.

Table 1. Emission intensity per unit of GDP in different countries

Country	t C /$ bln. GDP	Dynamics, % (1990 – 2000)	
		Carbon emissions intensity	GDP
Ukraine	483	28	–57
Russia	427	3	–34
Poland	230	–41	43
China	201	–47	162
Canada	172	–8	32
United States	162	–14	38
Germany	111	–28	18
European Union (25)	107	–21	22
Japan	104	–2	15

Also, Ukraine has very strained structure of GDP and the obsolete capital stock in main exporting sectors, see Box 1.

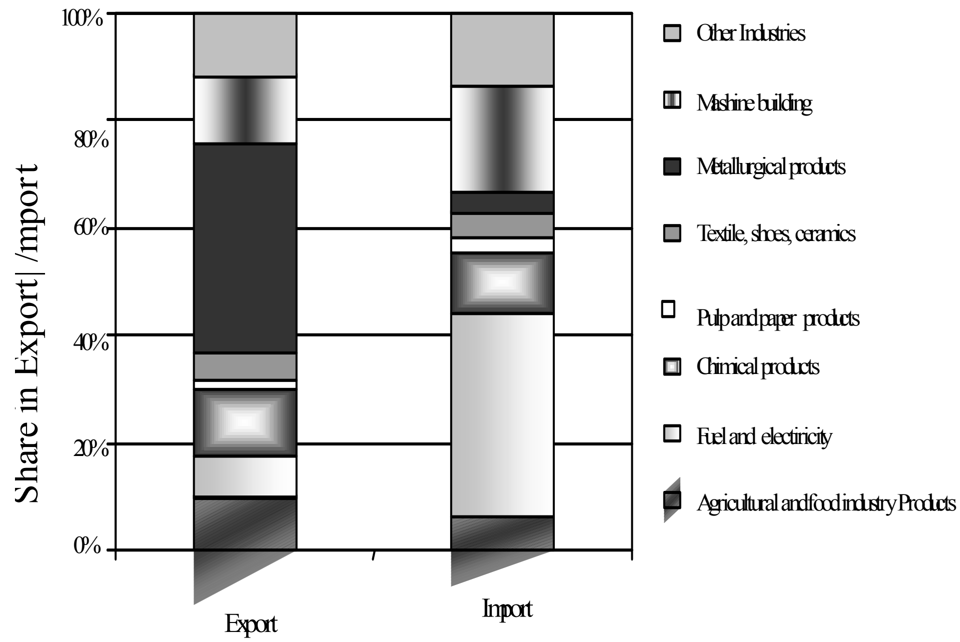
Box 1. Current state of capital stock in Ukraine's power sector

Drop in power unit capacity and performance reliability resulted in increase of emissions

- Bigger part of power units has been installed in 1960s and 1970s
- 97% of power units installed at thermal power plants worked for their design life (100,000 hours)
- 78,8% of power units installed at thermal power plants worked for their design time-limit (170,000 hours).
- 30% of transforming stations and transmission facilities worked for their design life
- most of power units have performance index of 28-30% and even 24% instead of planned 36%
- It has been forecasted that their reconstruction of Ukrainian power sector requires more than $460 bln.
- Share of thermal power plants in total emissions from stationary sources amounts to 39% (including 59% of SO2, 12% of NOx and 27% of ashes Presently none of the thermal power plants has desulfurization and/or degasification systems that meet the requirements of the EU.
- The majority of Ukrainian gas pipelines (including compressor plants and gascompressor units) have been disigned in 1960-1970s and installed in 1970-1980s. About 80% of gascompressor units become obsolete. Today they have average performance index of 22% instead of planned 30-36%. One third of 703 gascompressor units worked for their design life and must be rehabilitated. Around 15% of gascompressor units worked for their design time-limit and now must be replaced.
- According to technical experts, depreciation of gas pipelines is close to 60%. So, during the nearest 2 or 3 years Ukraine has to take all the nesessary measures to prevent the collaps of the whole gas transport system.

The last but not the least, Ukraine has to settle the problem of embodied carbon, figure 1.

Figure 1. Structure of Ukrainian export vs. import in 2004



Ukraine has adopted several programs of economic revitalization and increase of GDP. Unfortunately, nobody care about growing carbon intensity of GDP and export, see Table 2 and Table 3.

Table 2. Structure of Ukrainian industrial output within the two groups of sectors, %

Groups of industrial sectors	Share in output, %			
	1991	1994	1998	2002
I group: Fuel and energy complex, ferrous metallurgy, chemical, petrochemical and cement industry	23,2	49,5	55,8	59,1
II group: Machine building and metal processing, forestry, wood and paper production, light and food industry	76,8	50,5	44,2	40,9
Total	**100**	**100**	**100**	**100**

Table 3. **Structure of Ukraine's industrial output according to the "clean" and "dirty" scenarios of economic development**

Scenario	Share in Total Produciton, %		
	2005	2010	2015

“Dirty” scenario			
I group	60	66	75
II group	40	34	25
Total	100	100	100
“Clean” scenario			
I group	45	35	30
II group	55	65	70
Total	**100**	**100**	**100**

Both scenarios assure the same rates of the GDP growth (Figure 2). However, the carbon emissions vary considerably because of the different energy and carbon intensity between the I and II groups of industry, see Figure 3.

Figure 2. **Ukrainian GDP dymamics forecast**

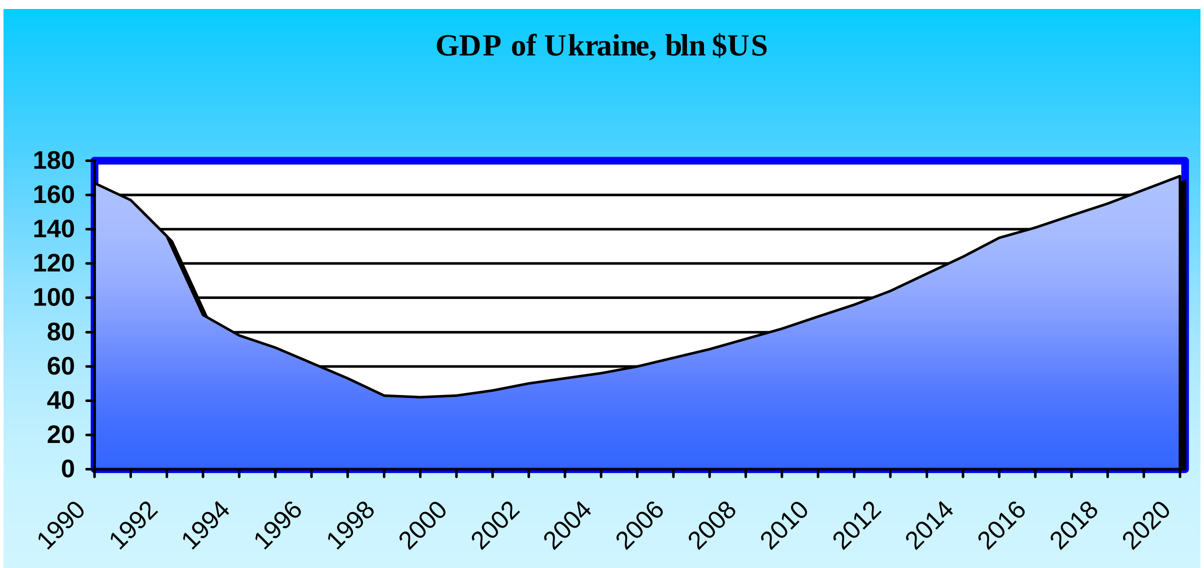
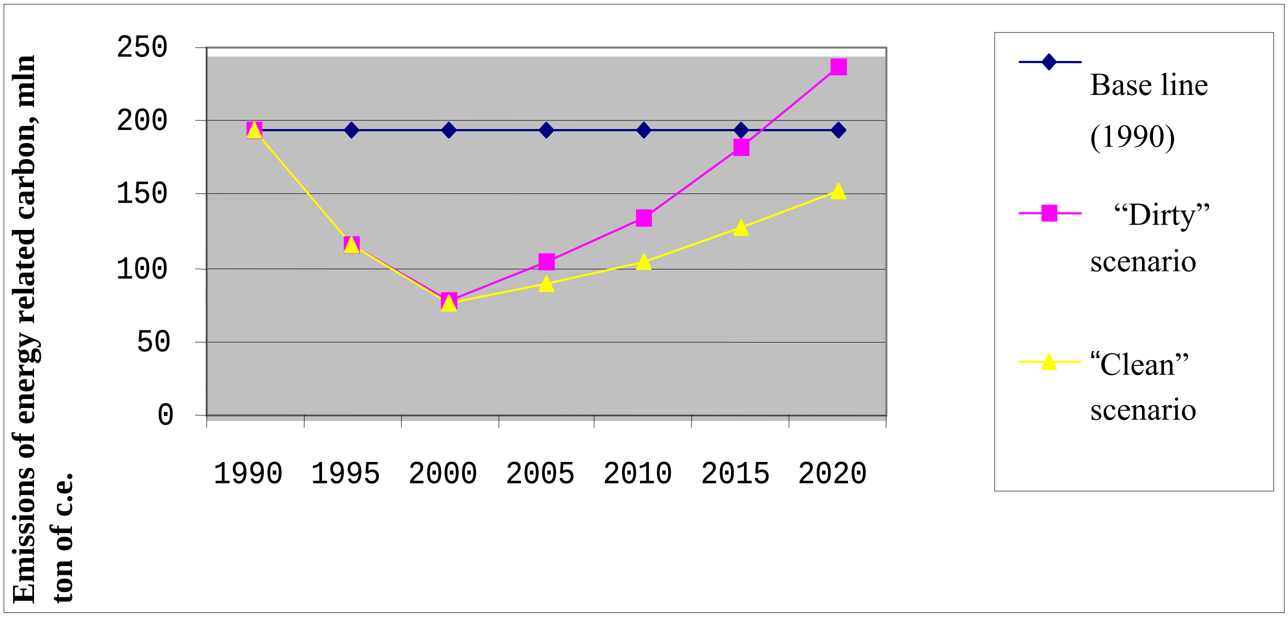


Figure 3. **Forecasts of Ukrainian carbon emissions in accordance with “dirty” and “clean” scenarios**



In August 2005 Ukrainian Cabinet of Ministers adopted the National Action Plan for the implementation of Kyoto flexible mechanisms in the country. Among the other issues it foresees elaboration of the National Allocation Plan (NAP). In accordance with this plan, the Ministry for Environmental Protection has to allocate carbon emission allowances among the most carbon intensive sectors of the economy, i.e. metallurgical sector, power sector, coal-mining sector, etc. To do so, the Ministry wants to know the possible impact of various allocation schemes on competitiveness, unemployment, export potential, etc.[1]

To perform this investigation and estimate the possible economic effect on energy intensive industries under different allocation options, in my Ph.D. thesis, I will use the general equilibrium model.

In the model I will test the following options:

- Allowances are grandfathered according to the output-based rule;
- Allowances are grandfathered according to the emission-based rule;

[1] It should be mentioned that eligibility of domestic emissions trading scheme and the mode of carbon allowances allocation will depend not merely on social and economic considerations but on future political context as well.

- Energy-intensive industries purchase allowances on the auction at the international allowance price.

Under the emissions-based rule, allowances are allocated to energy intensive sectors in proportion of their base-year emissions. Under the output-based rule, allowances per-unit of output are allocated in proportion to the benchmark market share of the energy intensive sectors.
Under auctioning of allowances, energy-intensive sectors buys them at the international market price and do not receive any revenue rebate, which is transferred to the household sector.

All these scenarios will be tested for two cases which are crucial for Ukraine:

1) The emission trading scheme is based on domestic emissions market.

2) Domestic emissions trading system is open for the international emissions market.

The results of the simulations will be compared with the reference scenario under the absence of domestic and international emissions trading when emissions of the energy-intensive industries are taxed at the rate of international allowance price.

The underlying idea of domestic emissions trading scheme implementation is to allow more abatement to be undertaken where the marginal cost of abatement, at the given allowances allocation, is the lowest. The purpose is to combine an administrative instrument (amount of allowances; regulation target) with efficiency features of market-based instruments (emissions have a market price in terms of allowance's prices; taxes).

The choice of the total quantity of allowances for the domestic emissions trading scheme (in other words, emissions ceiling) is a crucial element in the scheme design. Taking into account substantial national potential for low-cost emissions reductions, I will test the assumption that total quantity of allowances for domestic trading scheme is 10 % less than the base-year emissions of the energy-intensive sectors.

When households consume energy-intensive services (e.g., heating, lighting, hot and cold water supply, etc.) they inevitably pollute. However, under the current political context in the country (rapidly growing prices for imported gas, increasing volumes of electricity export to the EU countries, growing opposition to the president and so-called "orange coalition") it is very risky to force households to invest in pollution abatement and/or purchase emission allowances. Thus under all model scenarios, the Ukrainian households are not required to submit allowances for their CO2 emissions and their emissions are not taxed.

The model structure and specifications

A computer general equilibrium model, that incorporates economies of scale and imperfect competition, will be employed in order to provide evaluation of possible design issues of the Ukrainian domestic emissions trading scheme and in order to determine the most economically beneficial (and thus politically acceptable) method of allowances allocation.

Ukraine is modeled like a multi-sector small open economy model. This assumption implies that changes in the volumes of Ukrainian exports and imports have no effect on the terms of trade - international prices are exogenously fixed in foreign currency, i.e. export demand and import supply functions are horizontal.

The model is indended to incorporate key features of Ukrainian imperfect markets as well as disaggregate structures of production and factor use structure, that will allow representing relevant substitution possibilities and difference in carbon intensity of goods decisive for policy responds. All model scenarios for perfect competitive settings would be compared with the case of imperfect competition. The main functional forms and key model assumptions of the model are similar to Christoph Böhringer and Andreas Lange (2003).

In Ukraine energy-intensive sectors have the greatest share in national export as well as in formation of the national GDP. They function under imperfect competition and are subject to a regular governmental intervention regarding the prices and tariffs. Also, in Ukraine, it is very difficalt to identify the real configuration of markets. Industry structures are heavily distorted because of vertical and horizontal integration. Given the data limitations, and shortage state of the official statistics on market structure it is not easy to define what type competition is at Ukrainian energy-intensive sectors. To capture imperfect competition, the pricing behavior of the energy-intensive industries that participate in emissions trading are modeled like oligopoly with homogenous goods and free entry, i.e. Cournot competition. The model is calibrated assuming zero (pure) profits. Imperfect competition due to the fixed costs is modeled like a Cournot oligopoly with a free market entry/exit, i.e. each domestic industry consists of identical firms, whose number is determined by zero-profit connditition according to the fixed costs and free market entry-exit.

The initial model is consider the perfect competitive conditions, later it will be extended to capture the imperfect competitive markets. It is planned to make the model dynamic, when historical output or emission levels as a basis for allowance allocation within continuous period-by-period planning.

Production is represented by 10 composite sectors: extraction of fossil fuels (coal, gas, gas and oil), production of energy goods (gas, oil, coal and electricity), chemical, iron and steel, non-ferrous metals, pulp and paper production, and other industries (the aggregate of remaining manufactures and services). These 10 composite sectors are the biggest polluters and thus potential candidates for a domestic trading system.

A representative agent is endowed with three primary factors: fossil fuel resources, labor and capital. Labor and capital are intersectorally, but not internationally mobile, that is mean that there are no wage rate in the sector and no sectoral price of capital services. Fossil–fuel resources are assumed to be in a fixed supply within a sector. Factor markets are assumed to be perfectly competitive. A representative agent maximizes utility from consumption of a CES composite of its demand for energy and non-energy commodities. His total income consists of factor income and governmental transfers (including revenues from carbon taxes or auctioned allowances which constitute lump-sum rebate of a representative agent).

Production structure is described by industry production functions that include both primary factors and intermediate products provided by other production sectors, as inputs. Each production sector is modeled by a nested (hierarchical) production function. It means that special functional forms as, for instance, constant elasticity of substitution (CES), Cobb-Douglas or Leontief functions can be contained within the production functions, and many layers of hierarchy can be employed. This allows a flexible representation of the degree of substitution between inputs to the production process. The output of one production sector is produced by the combination of energy goods, not-energy intermediate goods, and the primary factors: labor and capital and fossil-fuel resources. Producer goods are directly demanded by the households, investment sector, other industries and the export sector. It is assumed that the governmental demand and balance of payment surplus/deficit are fixed at the benchmark level.

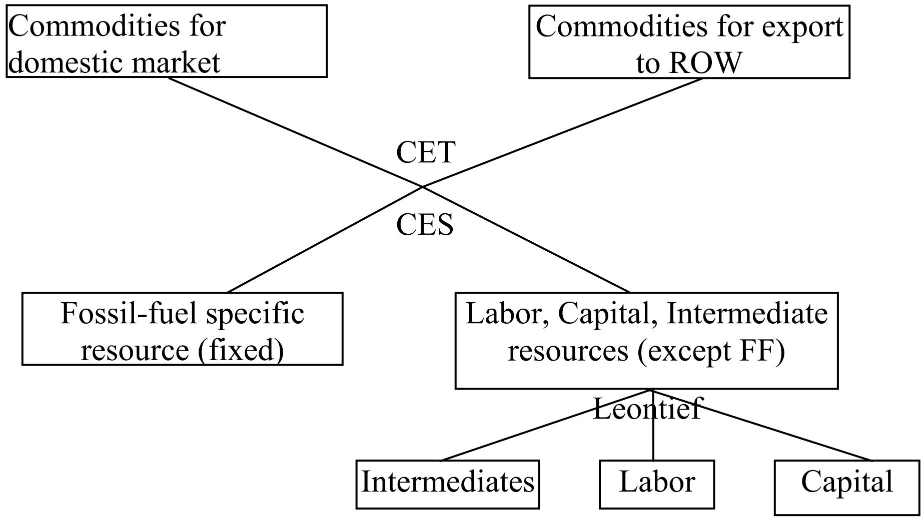
The differentiation between energy and non-energy intermediate products is useful in the context of climate policy. Energy use during the production and consumption of goods and services produces varying amounts of the carbon dioxide (CO2) depending on the fossil source and the policies assumed to be in place. The use of a unit of a fossil fuel will lead to a certain share of emissions in each greenhouse gas. CO_2 emissions are computed proportional to the fossil fuel consumption in each production sector. Gas, coal and oil each have fixed carbon content. To calculate the associated carbon dioxide emissions one simply has to multiply the physical quantity of gas, coal and oil used in domestic production and by its emission coefficient.

Carbon dioxide is the major emissions source in Ukraine; it is responsible for 70% of national GHG emissions, thus, other GHGs gases are not considered in this model. Economic activities such as consumption and production require a certain amount of fossil fuel use.

Model is described by the following three classes of conditions, which characterize the standard Arrow-Debreu equilibrium: market demand equals supply for each commodity (market clearance condition). Profit maximization in the constant-returns-to-scale case implies that no activity earns a positive profit (zero profit condition). The income balance condition requires that at equilibrium, the value of each agent's income must equal the total value of expenditures.

The domestic output *Yi* and imports *Mi* constitutes the Aggregate Armington good *Ai*, which is the main commodity for use in production and final demand. According to Armington assumption these goods are treated as imperfect substitutes. Production sectors substitute between domestic and foreign goods in order to minimize the cost of obtaining a given Armington composite good. On the output side, the sectoral output represents composite production of domestically used goods and exported goods which are treated as imperfect substitutes produced subject to a constant elasticity of transformation.

In the **extraction of fossil fuels**, Constant Elasticity of Transformation (CET) functions differentiate sectoral output Y*i* between goods destined for the domestic market and those for the export market, which are assumed to be imperfect substitutes (Armington). At the lowest nest the Intermediate resources (except the fossil-fuel specific resource) trade off in fixed coefficients (Leontief) with Labor and Capital. On the second level, their aggregate trades off with the fossil-fuel specific resource with a constant elasticity of substitution.



$$\prod_i^Y = \boldsymbol{CET}\,(P_{EXPi}\,,\,P_{DOMi}) - \boldsymbol{CES}\,[\,P_{FF}i,\ LT\,(PK,PL,PA_{FF}i)\,] = 0,\ i \in FF$$

$\prod_i^Y$ is unit profit function of industrial sector *i, $i \in FF$*

P_{DOMi} is the domestic output price of good *i*

P_{EXPi} is the export price of good *i*

PK- price of capital services

PL -price of labor

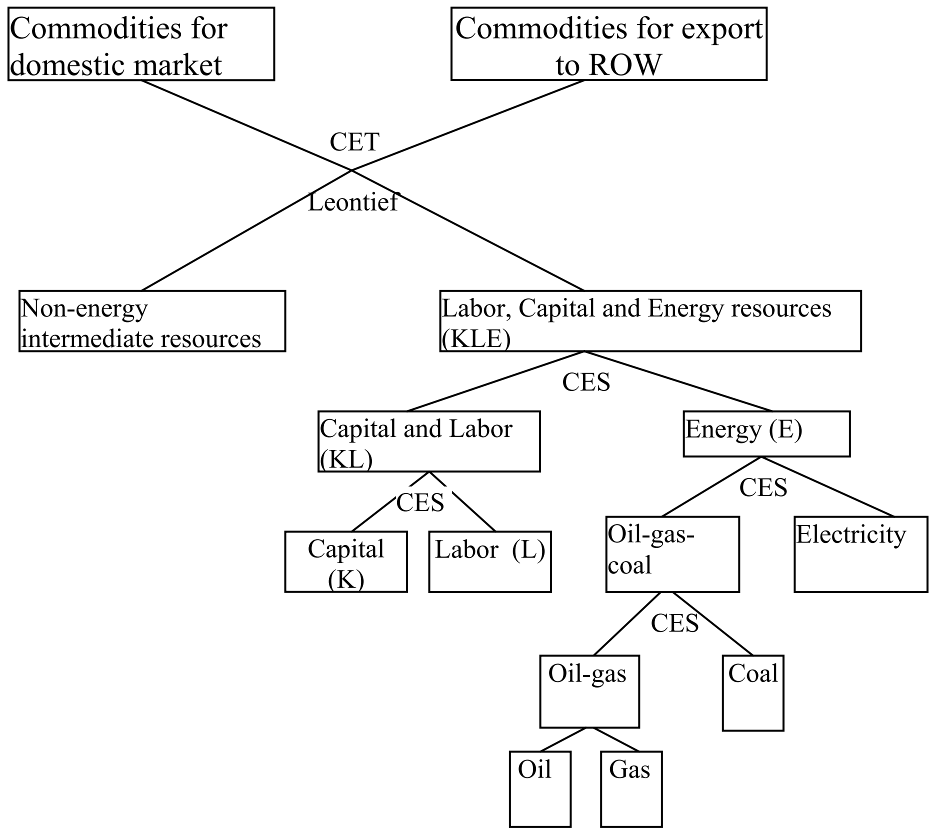
$PA_{FF}i$ represents the Armington price aggregate of fossil-fuel (FF) intermediate input *i*

$P_{FF}i$ is price of the fossil fuel sector-specific resource

Yi ($i \in FF$) is the index of production activity, and a complementary variable

Non-fossil fuel production is described by aggregate production functions that characterize technology through substitution possibilities between various inputs. It is assumed that all Non-fossil fuels producers produce one commodity and have a common production structure. Thus, the functional form of the production and cost function is the same for each non-fossil fuel sector, but the value shares differ between industry sectors according to the benchmark data.

Three-level nested cost functions are employed to specify the substitution possibilities in domestic production between capital, labor, energy and non-energy intermediate inputs. At the top level, non-energy inputs are employed in fixed proportions with an aggregate of energy, capital and labor aggregates. The second level is a CES function of energy aggregate, labor and capital. At the third level capital and labor trade off with a constant elasticity of substitution.



$$\prod_i^Y = \textbf{CET}(P_{EXP}i,\ Pi) - \textbf{LT}[PA_{nEn}i,\ \textbf{CES}(PEi,\ CES(PK,PL)]=0$$

$\prod_i^Y$ is unit profit function of industrial sector *i*, $i \notin FF$

P_i is the domestic output price of good *i*

P_{EXPi} is the export price of good *i*(expressed in domestic currency)[2]

$PA_{nEn}i$ is the Armington price aggregate of the non-energy (*nEn*) intermediate input in sector *i*, $i \notin EG$

EG- composite of energy goods,

nEn- composite of non-energy goods

PE*i* –price of aggregate energy in sector *i*

PK- price of capital services

PL -price of labor

Yi is the of production activity $(i \notin FF)$ is a complementary variable

[2] The prices for exports P_{EXPi} and imports P_{IMPi} are expressed in domestic currency. Export prices $\overline{P_{EXPi}}$ and import prices $\overline{P_{IMPi}}$ in international currency are exogenous for the small open economy. The real exchange rate μ relates international prices to domestic prices, i. e. $\mu\overline{P_{EXPi}} = P_{EXPi}$; $\mu\overline{P_{IMPi}} = P_{IMPi}$.

The **Sector-specific energy aggregate** is the energy supply to the production sectors; it is specified by a three level CES functions to reflect substitution between primary energy types as well as substitution between a primary energy composite and electricity. At the bottom level inputs of gas and oil trade off with the coal inputs with a constant elasticity of substitution. At the next level the coal and oil-gas aggregate trade off with the Electricity with a constant elasticity of substitution.

$$\prod_i^E = PE_i - CES[PA_{ELE}, CES(PA_{COA}, CES(PA_{OIL}, PA_{GAS}))]=0$$

$\prod_i^E$ - unit profit function of energy production

PE*i* –Price of aggregate energy of secor *i*

PA_{ELE} - Armington price of electricity
PA_{COA} - Armington price of coal

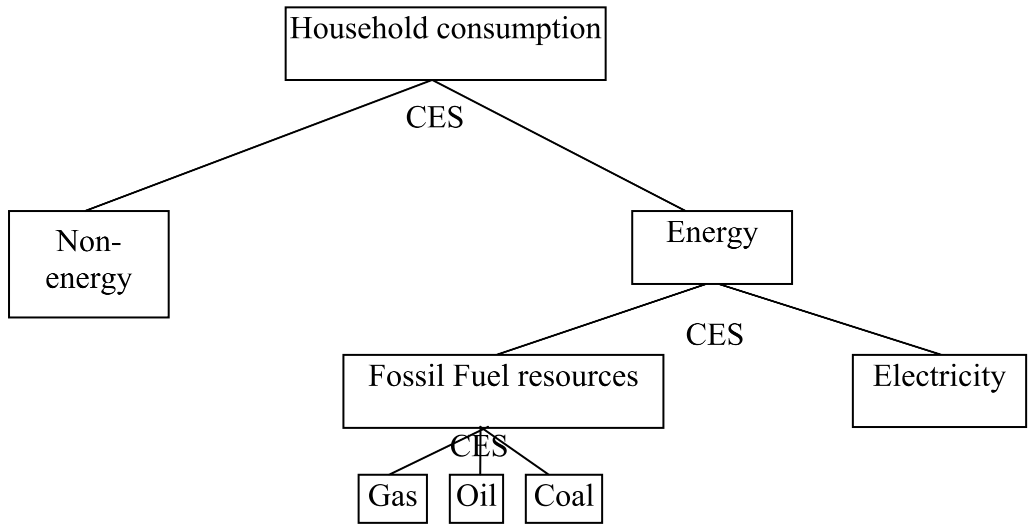
PA_{OIL} - Armington price of oil

PA_{GAS} - Armington price of gas

E*i*-energy composite for sector *i*, a complementary variable

Household consumption

Final demand C is determined by a representative agent RA, that maximizes its utility subject to a budget constraint with fixed investment. The final demand of the representative household is a CES composite which combines consumption of an energy aggregate and the composite of non-energy goods. Total income of the representative household consists of factor income and tax revenues (including revenues from carbon taxation and auctioning of the emissions allowances). Within the energy consumption composite, substitution possibilities are described by a CES function of electricity and fossil fuel resources. On the bottom level the substitution possibilities between the oil, gas and coal is given by CES function. The resulting unit zero profit condition for „producing“ consumption of the private household, *C,* is given by the next equation:



$$\prod^{C} = PC- \boldsymbol{CES}\ [\boldsymbol{CES}(PA_{nEn}), \boldsymbol{CES}\ (PA_{ELE}, \mathbf{CES}\ (PA_{COAL}, PA_{GAS}, PA_{OIL}))]=0$$

$\prod^{C}$ is the unit profit function for the private consumption activity, C

PC- is the composite price for consumption demand

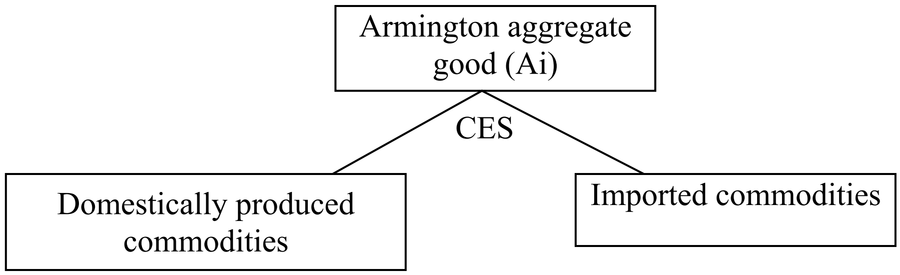
PA_{nEn} is the Armington price aggregate of the non-energy (nEn) good i in the consumption sector C

PA_{ELE} the Armington price of electricity in the consumption sector C

PA_{COAL} the Armington price of coal in the consumption sector C
PA_{GAS} the Armington price of gas in the consumption sector C
PA_{OIL} the Armington price of oil in the consumption sector C

C is the associated complementary variable which indicates the activity level of consumption

The model adopts Armington's representation of the **import demand.** An Armington good, A_i, is a composite of domestically produced and imported goods, which are treated as imperfect substitutes. Armington assumption is adopted for trade in all goods because it accommodates intra-industry trade and is convenient in picturing world trade flows by employing only one exogenous parameter, i.e. the Armington elasticity of substitution. Thus, we assume that Ukrainian goods are imperfect substitutes for similar goods at the world market. CES functions characterize the choice between Ukrainian and imported varieties. Therefore, it is no substitution of one intermediate good for another, it will be substitution between domestic demand and import demand depending on the relative prices. On the export side, Constant Elasticity of Transformation (CET) functions differentiate domestic output between goods designated for domestic market and those for **export** market. The import aggregate and the domestic output of good *i* can be substituted with a constant elasticity, resulting zero-profit condition for the production of a unit of the Armington good *i* used by the agent:



$$\prod_i^A = PAi\text{-}CES(P_i\ ,\ P_{IMP}i) - p^{co2}\, a_i^{\ co2} = 0$$ [3]

PA*i*= is the Armington price of good *i,*
P*i* price for domestically produced commodity *i*

$P_{IMP}i$ import price of commodity *i*

p^{co2} price of one carbon allowance (auctioning) or a carbon tax rate (carbon taxation)

$a_i^{\ co2}$ carbon emission coefficient of good *i*

Ai is the associated dual variable, indicates the activity level of Armington good production.

International trade

Ukraine is treated like a smal open economy relative to the international market.[4] SOE assumption implies that changes in the level of Ukrainian exports and imports have no effect on the terms of trade. International prices are exogenously fixed in foreign currency, i.e. export demand and import supply functions are horizontal, so they can be omitted within the algebraic model formulation.

[3] Under the scenarios of emission-based and output-based grandfathering, the constituent $p^{co2}\, a_i^{\ co2}$ does not enters the Armington equation, instead there is there is another, positive constituent which is a subsidy.
Under the emission-based grandfathering,
Under the output-based grandfathering, the output subsity is
[4] The model does not consider the hot air trade of emission quotas. On this market Ukraine and Russia may be the major monopolists.

Investments

Composite investment is a Leontief aggregation of Armington inputs by each industry sector. The investment good is treated as a non-tradable and it does not require direct primary factor inputs.

$\prod_i^I$ = P*I*-LT (PA*i*)=0

$\prod_i^I$ -unit profit function for the investment activity, I

P*I* –domestic price index for the investment good

PA*i* = Armington price aggregate of input good i in the investment sector , $i \in$ I

I – associated complementary variable which indicates the activity level of the investment sector

Government

In this model government is treated as a passive entity that collects tax revenue (i.e. revenue from auctioning of allowances and CO2 emission taxation) and immediately recycles it to the single representative household as a lump-sum supplement to the income from factor returns. In a case of grandfathering, the value of allowances is a payment transfer to the industries that participate in a domestic emissions-trading system. Therefore, the model may omit government as an explicit sector, specifying just the revenue transfers the representative producers or households.

Market Clearance Conditions

Market clearance condition states that market demand equals supply for each commodity. In the model two types of markets are distinguished: the factor market and the goods market.

Applying Hotelling's lemma to the unit profit function, i.e. differentiating the unit profit function with respect to factor prices, the factor market clearance condition can be derived. Factor market clearance conditions say that at equilibrium prices and equilibrium activity levels, the total demand of factor must balance or fall short of the factor endowment.

Factor markets are perfectly competitive and full employment of all factors is assumed. Hence, factor prices adjust so that supply equals demand. Labor is assumed to be a homogenous good, mobile across industrial sectors within a country but internationally immobile. The equilibrium condition of the solution requires that the sum of all sectoral demands for labor is equal to the exogenous labor supply of it . Hence, the supply-demand balance for the labor market can be written in a following way:

$$\overline{L} = \sum_i Y_i \frac{\partial \prod_i^Y}{\partial w}$$

Where $\overline{L}$ denotes the exogenously given labor supply,
w– is wage rate

It is assumed that capital is inter-sectorally but not internationally mobile. . The capital stock is given exogenously and there is no sector-specific capital. The capital stock of a country earns a correspondent amount of income measured by physical units in terms of capital services. The supply-demand balance for capital in is written:

$$\overline{K} = \sum_i Y_i \frac{\partial \prod_i^Y}{\partial v}$$

where $\overline{K}$ is the aggregate supply of capital services for domestic production in one time period,
v is the price of capital services

The fossil-fuel is sector specific resource and used only for fossil-fuel production, so it is fixed and exogenously given. The supply-demand balance for fossil fuel resources can be written:

$$\overline{Q_i} = Y_i \frac{\partial \prod_i^Y}{\partial q}$$

$i \in FF$

where *q* denotes the exogenous supply of fossil fuel resource *i* in fossil-fuel production sectors.
$\overline{Q_i}$ is the endowment of fossil fuel resource
q_i – rent of natural resource *I*

The market clearance condition says that at equilibrium prices and equilibrium activity levels the supply of any good must balance or exceed the demand by agents. By applying Hotelling's lemma (i.e. differentiating the unit profit function with respect to price of good *î*, the market clearance condition for good *î* (excluding the primary factors *L,K,FF*) can be derived.

Commodity *i* produced for domestic market enters the aggregate Armington commodity. Thus, the market clearance condition for each domestically produced commodity is written as:

$$Y_i \frac{\partial \prod_i^Y}{\partial P_i} = \sum_i A_i \frac{\partial \prod_i^A}{\partial P_i}$$

where P_i –output price of domestic good *i*

Intermediate energy supply

The sector-specific energy aggregate enters production. Market clearing condition for sectoral energy aggregate is given as:

$$E_i = Y_i \frac{\partial \prod_i^Y}{\partial PE_i}$$

PE*i* –Price of aggregate energy of secor *i*

Import aggregate

The market for imported goods is analogous to the market of domestic outputs. Imported goods enter Armington production. The supply-demand balance for each imported good is written:

$$M_i = A_i \frac{\partial \prod_i^A}{\partial \mathrm{P}_{\mathrm{IMP\,i}}}$$

M*i* – is the level of imports of good *i*.
P_{IMPi} import price for good *i*

Export

Domestic output is exported to ROW. The supply-demand balance for exported good is:

$$EXP_i = Y_i \frac{\partial \prod_i^Y}{\partial P_{EXP\,i}}$$

EXP_i - is the level of exports of good *i*

P_{EXPi} - price of exported good *i*

Supply of Armington goods:

Armington goods enter the intermediate demand by the production sectors, households and investment demand:

$$A_i = \sum_j Y_j \frac{\partial \prod_j^Y}{\partial p_i^A} + I \frac{\partial \prod^I}{\partial p_i^A} + C_i \frac{\partial \prod_i^C}{\partial p_i^A}$$

p_i^A - price of Armington aggregate

$\sum_j Y_j \frac{\partial \prod_j^Y}{\partial p_i^A}$ total intermediate demand for this Armington good *i* in all industry sectors *j*

$I \frac{\partial \prod^I}{\partial p_i^A}$ Investment demand of Armington commodity

$C \frac{\partial \prod^C}{\partial p_i^A}$ Household demand for Armington commodity

Aggregate investments

$\bar{I} = I$

Household consumption:

The total income of the representative household in each region is a sum of factor incomes, abalance of payment deficit/surplus and tax revenues (from auctioning and emissions taxation) :

$$Cp^C = w\bar{L} + v\bar{K} + \sum_{j \in FF} q_j \bar{Q}_j + p^{CO2}\overline{CO2} + p^I \bar{I} + \bar{B}$$ [5]

where C- aggregate household consumption
p^C - price of aggregate household consumption

$\bar{L}$ is the exogenously given labor supply,
w–wage rate

$\bar{K}$ is the aggregate supply of capital services for domestic production.

v is the price of capital services

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[5] $p^{CO2}\overline{CO2}$ - is the lump-sum rebate to households in the case of auctioning of allowances and CO_2 -emissions taxation. In the scenarios with grandfathering of allowances the constituent $p^{CO2}\overline{CO2}$ does not enter the household income.

$\overline{Q_i}$ is the endowment of fossil fuel resource
q_i is the rent of natural resource *i*
$\overline{CO2}$ - endowment of carbon emissions allowances

p^{CO2} price of one carbon emissions allowance

$\bar{I}$ aggregate investment

p^{I} price of aggregate investment

$\overline{B}$ - balance of payment deficit/surplus

CO_2Emissions :

$$\overline{CO2} = \sum_i A_i a_i^{CO2}$$

$\overline{CO2}$ is the total carbon dioxide emissions of the Armington good, endowment of emission allowances

a_i^{CO2} - carbon dioxide emission coefficient

ROW closure:

In a SOE framework, export supply from Ukraine is equal to the import demand by ROW plus payment surplus/deficit.

$$\sum_i \overline{P_{EXP}} EXPi = \sum_i \overline{P_{IMP}} IMPi + \overline{B}$$

EXP_i - is the level of exports of good *i*
$\overline{P_{EXPi}}$ -exogenous price of exported good *i*
M*i* – is the level of imports of good *i*.
$\overline{P_{IMPi}}$ exogenous import price for good *i*

$\overline{B}$ is the net balance of payment surplus or deficit

The integration of a national carbon dioxide emissions trading scheme

On the output side, emission allowances linked in fixed proportions to the output of the producing sectors which participate in the domestic emissions trading scheme. According to the model scenarios, allowances are assigned according to the benchmark sectoral emissions, in proportion to the sectoral output, auctioned, and taxed. CO_2 emissions originate from the use of fossil energy as input factors (oil, gas and coal), each of them has its own emission factor. Therefore, carbon dioxide demand of sector i is expressed by means of the sector-specific energy aggregate

$$CO2i = E_i \sum_{j \in FF} \frac{\partial \prod_i^E}{\partial (P_j + a_j^{CO2} p_j^{CO2})}$$

where a_j^{CO2} is the Carbon emissions coefficient for fossil fuel j, $j \in FF$

p_j^{CO2} Is the price of one allowance

According to the overall emission cap $\overline{CO2}^T$, allowances are alocated to the sectors, covered by the emissions trading scheme, on the rate of 90% of their base year emissions. Whereas for emission taxes and for auctioned allowances, the recycling of revenues is an important issue, in the case of grandfathering it is not, because the initial endowment of allowances constitues the payment transfer to the incumbent firms. Let p^{CO2} be the exogenous international price for one emission allowance. Than $p^{CO2}\,\overline{CO2}^T$ is the total value of emission allowances which constitutes the lump-sum recycled profit to the emissions-trading sectors, and the total allowances revenue, that government captures under auctioning and carbon-dioxide taxation.

When permits are allocated free, the government is forgoing potential auction revenues, which could be used to reduce other taxes and associated distortions.

Auctioning and Carbon taxation. The government captures the entire revenue from auctioning/carbon taxation, and rebates it lump-sum to the representative households. Auctioned allowances and carbon taxes are incorporaded like a tax on Armington good.

The output-based and emissions-based grandfatheing is incorporated through the production function as a tax/subsidy, which is equal to the value of freely allocated allowances. This subsidy enters zero-profit condition of sectoral production.

Under emissions-based granfathering allowance are allocated proportional to initial emissions, and their value constitutes a subsidy which increases with the emissions intensity of the sector. Such allocation corresponds to a lump sum profit to owners of the incumbent firms. Firms choose a level of emissions where their marginal cost of emissions reduction equals he market price for allowances.

The total value of transfer payments to the each production sector eligible for emission-trading, which are equal to the alocated fraction of total value of grandfathered emission allowances.

$$Tr_i = p^{CO2}\,\overline{CO2}^T \theta_i^{CO2}$$

Where θ_i^{CO2} is the fraction of grandfathered allowances alocated to the sector *i,*

The input subsidy is equal to the the endogenous average emission assignment factor per unit of emission.

Under the output-based allowances alocation sectors eligible for trade receive alowances according to their market share production in the base year. As output-based allocation is tied to the level of production, this allocation rule corresponds to a sector-specific ad valorem subsidy to output. The quantity of allowances to the production sector, $CO2_i$ is expressed by the next equation:

$$CO2_i = \overline{CO2}^T \frac{Y_i}{\sum_i Y_i}$$

The subsidization rate, S*i* equals the value of the allowances allocation per unit of revenue.

$$Si = \frac{CO2_i}{Pi\sum_i Y_i}$$

where P*i* is the price of output in sector *i*.

The competitive assumption requires that firms take the subsidization rate as given. This would be the case if firms consider their sectoral total output, or equivalently average sectoral emissions, as given. Then firms choose a level of production where the producer price of output plus the subsidization rate is equal to the marginal cost of production.

Database and calibration

For the numerical specification of the model parameters and model calibration, the Social Accounting Matrix for Ukraine on the base of latest available 2003 sector Input-Output Table and the National Accounts for Ukraine will be constructed. Specification of elasticity values and the mark-ups will be taken from the available empirical evidence. The model will be solved by Rutherford`s method (1999), that treats general equilibrium model as a mixed complementarity problem implemented with GAMS\MPSGE.