ECONOMIC-ECOLOGICAL MODEL FOR POLAND

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Applied mathematical models are tools used to support policy and decision making processes in economy. In the late sixties and at the beginning of the seventies, following the rising interest of economists in environmental results of economic activities, first economic-ecological models appeared. They concerned economies at various level of aggregation, such as:

- regional level (e.g. Cumberland 1966),
- interregional level (e.g. Isard 1968, 1971),
- country level (e.g. Daly 1968, Victor 1972),
- global level (e.g. Leontief 1973, Carter at. al. 1976).

There are more and more applied mathematical models which depict the economic structures linked with the environment (e.g. Conrad and Schmidt 1995, Meyer 1998, Barker 1999). Input-output techniques are widely used in models of this type because of their simplicity and the clarity of depicting links between elements in complex systems. The possibility of dividing economy as well as the environment into many sectors is crucial however.

Economic modeling has over thirty year tradition in Poland, but until mid-1990s no empirical economic-ecological models had been built. The explanation of this is that in the past in Poland, like in all countries under the centrally planned economy regime, the environment was not metered as the most important task was to "fulfill" the production plans. The situation changed in the nineties, when the transition from a centrally planned economy to a market one was started. The rising interest in the environmental effects of economic activity is caused not only by the rising awareness in the society but also by the necessity to fulfill high standards which is a precondition of the accession process to the European Union.

The economic-ecological model presented in the paper is the pioneer approach to build a versatile model of this type for Poland. The model is an IMPEC extension being a macroeconomic sectoral model of the Inforum type for Poland (Orłowski and Tomaszewicz 1991), so the main features of the IMPEC model are described first. Then approaches to economic-ecological modeling are discussed and the environmental block of the IMPEC model[1] is characterized. Finally, to exemplify the model use, government plans to reduce CO_2 emissions are verified using the model results.

[1]IMPEC is an acronym standing for Interindustry Model of the Polish EConomy.

1 The inforum-type model of Polish economy

The model IMPEC is a multisectoral macro model. This means that both industrial and macroeconomic variables are considered within the model. The model builds macroeconomic variables using industrial details (a "bottom up" approach). It is constructed around an input-output core but it also makes use of behavioral equations. The author of the approach is Clopper Almon who developed this model for the US economy in the early 1960s, and continues his effort within the project INFORUM (Almon 1991).

The history of the IMPEC model started in the early eighties. From the beginning the model builders have collaborated with the INFORUM team. In the near future IMPEC will be integrated into the INFORUM International Forecasting System.

IMPEC uses much of INFORUM philosophy. On the other hand, there are some areas where IMPEC differs from the INFORUM approach. In 1980's the differences resulted mainly from different economic systems being described by the original model (market economy) and the IMPEC (centrally planed economy). Although market economy regulations were introduced in Poland in 1990's, but Poland is still in transition from one economic regime to another. The main reasons for the modeling of economies in transition being different from the modeling of developed economies are listed below (Balcerak at al. 1997).

1. The *lack of the transfition period theory*, hence the problem to what extent the theory of market economy can be applied, when the economy is described by means of econometric equations. This problem should be taken into account when analyzing the proposed specification of equations in the IMPEC model.

2. *Unavailability of long enough time-series data* on the new economic regime, as the "old" time series reflect the period of the supply economy.

    - The lack of time series is also due to the switch from the old classification of economy (Classification of National Economy) to the new one (NACE). Since the beginning of the '90s the official statistical system has been adjusted to the new social and economic environment and harmonized with standards applied in international statistics. Old methodologies, classifications and terminology are replaced by the UN, Eurostat and the OECD.
    - The use of the previous data makes it necessary to adopt special procedures in order to unify the statistical information, for example: guess-estimates disequilibrium indicators, procedures aimed at reducing the number of explanatory variables, etc. In the model presented below we adopt some of the procedures mentioned above with different lengths of time-series for different categories.

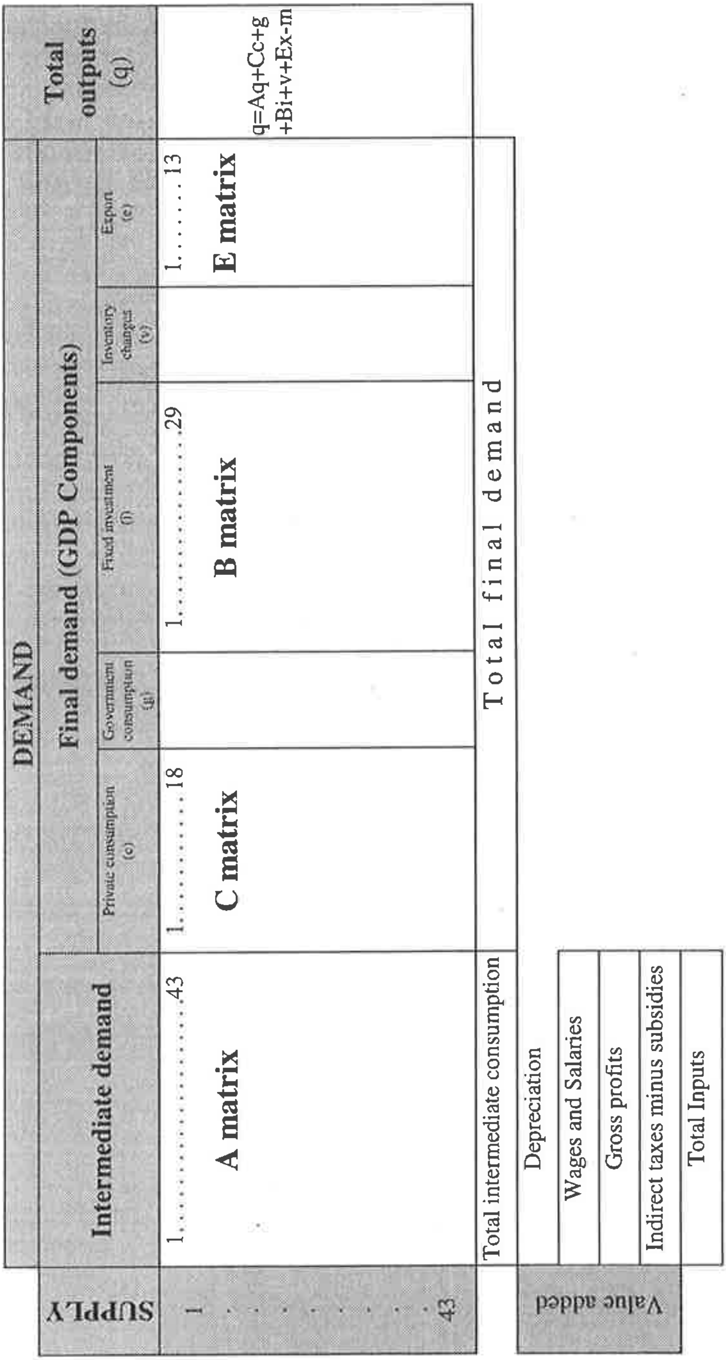


Figure 1. Input-output accounting framework for the IMPEC model

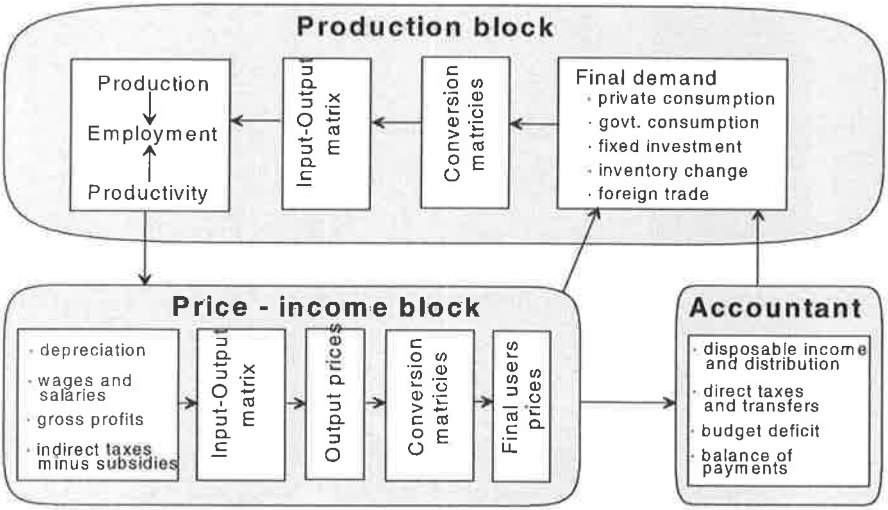
3. Unavailability of new input-output tables. The switch from MPS to SNA, which poses especially difficult tasks for the input-output modelers. In the case of the IMPEC model, we used an input-output table close to the 1990 SNA statistics. It was constructed by the Center of Economic and Statistical Research, Central Statistical Office, on IMPEC-group's special order. Official SNA input-output tables were unavailable until 1999, when the matrix of interindustry flows for the year of 1995 was published.

The input-output accounting framework of the IMPEC model is shown in *Figure 1*. The current version of the model consists of 38 types of activities in the sphere of the so-called material production and 5 activities belonging to the sphere of non-material services. The disaggregation is in agreement with the sector-activity classification for Polish economy to be found in the SNA input-output table for 1990.

Equations for the final demand elements are either at the level of categories typical of a given group of final users' (households' consumption – 18 categories, exports by 13 groups of products, investment demand in 29 groups of sectors) or they are expressed globally (inventories, government expenditures). Relevant conversion matrices (or vectors) link categories of final demand (households', government, investment and export demand) with sectors of economic activity.

Value added is disggregated into the following categories: wages, depreciation, gross profits and indirect taxes minus subsidies.

The model operates as follows (*see Figure 2*):



Source: Prepared by the author

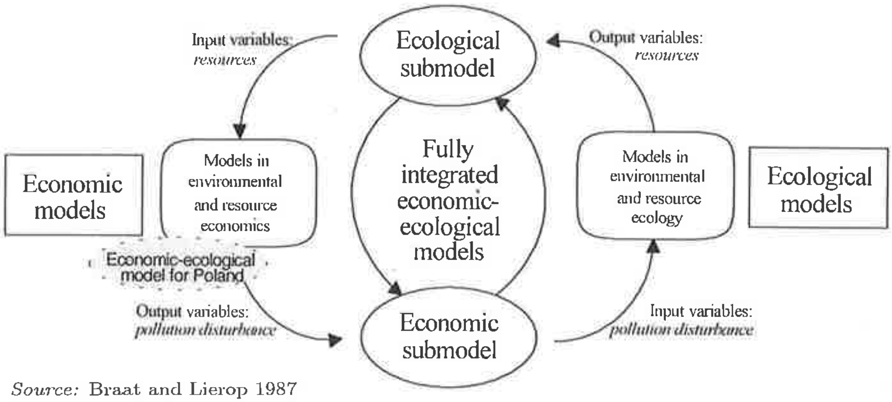
Figure 2. The solution process of the IMPEC model

- Final demand categories are generated:
  - household demand, "driven" by incomes and relative prices,
  - investment demand, determined by changes in economic activity, the foreign direct investment and the lagged investment outlays,
  - inventories, determined by the volume of output,
  - exports, determined by the world demand, relative prices and foreign direct investment,
  - government demand (exogenous).
- Demand for products is generated using input-output relationships.
- Imports, which depend on the volume of output and relative prices, are obtained in a feedback with the volume of output.
- Labor productivity is computed as the function of capital efficiency and time variable.
- Demand for products and labor productivity determines employment.
- Wages by industry depend on inflation and labor productivity.
- Unit value added by industry is the sum of its components and depends mainly on labor costs.
- To determine both producers prices and prices of final demand categories the input - output price approach is used.
- Incomes (households, corporations and government) are determined by a set of identities. The elements of the identities are calculated in other parts of the model or found using given parameters (such as tax rates) some of them are completely exogenous to the model.

2 Economic-ecological models

There are different ways to build a model accounting for both economic and environmental problems. The difficulty in overcoming the building problems of such a model is that economic variables are usually measured in monetary units whereas ecological variables require to be measured in natural units. Typically economic-ecological models are developed as extensions of the existing models. This situation is shown in *Figure 3*.

At the extreme left and right hand sides of the figure two different mono disciplinary models are shown: economic and ecological models, respectively. In the center of the figure there are fully integrated economic-ecological models. They can be treated as separate sub models, linked by the resource and pollution data flow.



Source: Braat and Lierop 1987

Figure 3. Mono disciplinary and multidisciplinary model types

The economic-ecological model for Poland considered in the paper is an IMPEC extension which is a typical economic model. That is why the economic-ecological model for Poland is marked to the left from the central point of Figure 3.

As it was mentioned above flows between the environment and economy relate to resources used and pollutants emitted by the economic system. This is shown in *Figure 4*.

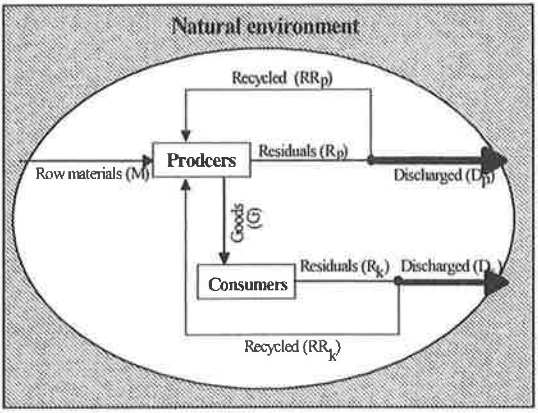
The present economic-ecological model for Poland only includes the pollution block and the resource block will be developed in the future. There are no "recycling" sectors in the input-output table used in the model. This means that now only discharged parts of residuals are included in the model, which is depicted in Figure 4 using thick lines. Nevertheless, the changes in the recycling activity of the economy can be reflected in the model by changes in the emission coefficients.

Economy both depends on and influences all the natural environment components, that is

- lithosphere (soil, rocks),
- hydrosphere (waters),
- atmosphere (air).

This means that the components are used by the economy as resource "containers" (dependency of economy on environment) as well as "containers" for externalities (pollution) being a result of production and consumption (influence of economy on the environment) — see Figure 4. Using the environment as the container for pollution may have many negative effects on its components. Generally, they are classified as:

– local
– regional
– global



Source: Field 1997

Figure 4. The Environment and the Economy

The larger geographical area the problem concerns, the more difficult it is to solve. The difficulties become extreme, when the problem affects more countries. That is why global environmental problems seem to be particularly hazardous for the mankind. Air pollution is seldom the local problem, because various kinds of air pollutants may be easily carried for long distances, from one place to another. They can travel across the continents. They can circulate in the Earth's atmosphere. In addition they can be raised to the stratosphere and violate its natural composition. This is why air pollution control is treated as one of the most vital problems that the mankind confronts today.

The possible dangers which result from an uncontrolled emission of gases are shown in *Table 1*.

	Global			Regional	Local
	Greenhouse effect		Ozone layer depletion		
	directly	indirectly			
CO_2	•				
CH_4	•	•			
N_2O	•		•		
CFCs	•	•	•		
NO_x		•	•	•	•
CO		•		•	•
NMVOC		•		•	•
SO_2	•			•	•
NH_2	•			•	•
Dust	•			•	•

Source: Air Pollution..., 1997

Table 1. Influence of air pollutants on the environment

3 Environmental block of the IMPEC model

The first stage to build a simple emission block for an existing sectoral model is to use the data on emissions and the output by sectors to estimate direct pollutants coefficients (emission factors):

$$ec_{zjt} = \frac{e_{zjt}}{X_{jt}} , \tag{1}$$

where:

- ec emission coefficient,
- e emission (in natural units),
- X value of output,
- z pollutant,
- j sector of economy,
- t time.

Changes of the emission factors over time can be estimated econometrically and then forecasted. Future changes of the coefficients can be also estimated by experts from different branches of economy. Emissions can be easily calculated as the product of the emission coefficients and output:

$$E_t = EC_t \cdot X_t , \tag{2}$$

where:

- $\mathbf{E}$ vector of emissions,
- $\mathbf{EC}$ direct pollutants coefficients matrix,
- $\mathbf{X}$ vector of output taken from the sectoral model.

This used to be the way of modeling and forecasting emissions, especially concerning the air, within the model for Poland (Plich 1995). Data on pollution were compiled with the data on the Polish economy used in the IMPEC model. Due to the differences in sector classifications a lot of estimations had to be performed to arrive at the final result. Classification of pollutants and sectors used in the first environmentally extended version of the IMPEC model can be found in *Tables 2* and *3*.

Pollutant of...	Name	Abbreviation
Air	Dust	Dust
Air	Sulphur dioxide	SO_2
Air	Carbon oxide	CO
Air	Carbon dioxide	CO_2
Water	Waste water treated mechanicly	MechTreated
Water	Waste water treated chemically	ChemTreated
Water	Waste water treated biologically	BioTreated
Water	Crude waste water	Waste water
Land	Utilized waste	Utilized waste
Land	Neutralized waste	NeutralWaste
Land	Stored waste	Stored waste

Source: **Prepared by the author**

Table 2. Classification of pollutants in the model

No.	Name of the sector	Abbreviation
1	Coal mining	Coal
2	Fuel industry	Fuel
3	Power engineering	Power
4	Ferrous metallurgy	Ferrous
5	Nonferrous metallurgy	Nonferrous
6	Metal products	Metal
7	Machinery	Machinery
8	Precise equipment	Precise
9	Transportation means	TranspMeans
10	Electrical and electronic app.	ElectrElectronic
11	Chemicals (I)	Chemicals (I)
12	Chemicals (II)	Chemicals (II)
13	Construction materials	BuildMaterials
14	Glass	Glass
15	Ceramics	Ceramics
16	Wood products	WoodProd
17	Paper products	PaperProd
18	Textiles	Textiles
19	Clothing	Clothing
20	Leather	Leather
21	Food processing - animal	FoodAnimals
22	Food processing - plant	FoodPlant
23	Feed and utilization	Fodder
24	Printing	Printing
25	Other branches of industry	OthManuf
26	Residential building	ResConstr
27	Industrial construction	IndConstr
28	Special constructions	SpecConstr
29	Other branches of building construction	OtherConst
30	Agriculture - plant production	AgrPlant
31	Agriculture - animal production	AgrAnimal
32	Agricultural services	AgrServ
33	Forestry	Forestry
34	Transportation	Transport
35	Communication	Comme
36	Trade	Trade
37	Other industries	OtherInd
38	Municipal services	MunicServ
39	Housing	Housing
40	Education services	Education
41	Health services	Health
42	Other market services	MarketServ
43	Government services	GovtServ

Source: Prepared by the author

Table 3. Classification of sectors in the model

Lately, a new and more sophisticated modeling approach to air pollutants has been introduced. It follows the experiences of the German Inforum team in the construction of their PANTA RHEI model (Meyer and Ewerhart 1998).

Sources of air pollution

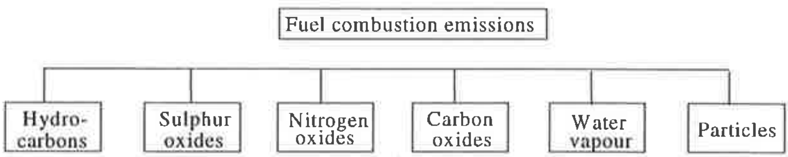
Sources of air pollution can be classified using a number of classification criteria. The most general partitions are the following:

- natural and anthropogenic (man-made) sources,
- stationary and mobile sources.

Anthropogenic sources of air pollution can be subdivided using types of economic activity as the criteria:

- energy production (fuels combustion, volatile fuel emission),
- industrial processes,
- solvent application,
- agriculture,
- changes in land use and forestry,
- wastes (waste sites, sewage treatment plants, waste combustion).

Taking into account only the anthropogenic sources it is easy to prove that the energy processes give off most of air pollution regardless of the methodology used in a survey, so in air pollution modeling one can concentrate on emissions from fuel combustion. Possible pollutants resulting from fuel combustion are shown in Figure 5.



Source: Air Pollution... 1997

Figure 5. Emissions resulting from the combustion processes

Emission from stationary sources

The emission of pollutants from stationary sources depends on many factors:

- Fuel type and quality,
  - the content of carbon, sulfur, nitrogen and mineral matters,
  - heating value.
- Method for reducing pollutant emission

- Type of technology:
- type of installation (boiler, furnace, gas turbine),
- type of burner,
- size, age and technical condition of the installation.

- Operating conditions:
- load,
- temperature,
- excess air,
- additions (water, ammonia, lime).

Emissions from mobile sources

Most means of transport (road, water and air) are defined as mobile sources of emissions. Means of transport are numbered among the greatest polluters of CO_2, NO_x, CO and VOCs as well as Pb (in the case leaded benzines are used).

As in the case of stationary sources emissions from mobile sources depend on many factors:

- engine size,
- age,
- emission reduction technology,
- type of fuel used
- other, such as: traffic conditions, average speeds, weather conditions, etc.

In our model only some of the emission determinants mentioned above are taken into consideration. The total emission of any pollutant under consideration depends on two factors:

- emission coefficients
- amount of fuel used

Only two main determinants of emission coefficients are taken into account:

- type of fuel
- sector of economy.

The equation for the volume of emission of any pollutant discharged by any sector using any energy carrier is the following:

$$e_{zkjt} = ec_{zkjt} \cdot f_{kjt} \ , \tag{3}$$

where:

- e emission (in natural units),
- ec emission factor (coefficient) - emission per unit of fuel used,
- f fuel consumption (in energy units),
- z type of pollutant,
- j sector of economy,
- k fuel type,
- t year.

Other factors determining emission which are not explicitly taken into consideration in the above equation, such as the pollution reduction method at the end of pipe or the combustion method, can induce emission coefficients change. Their influence can be estimated using econometric methods.

The amount of fuel used by an individual installation or machine depends on the technical parameters. One of the parameters is the kind of fuel beeing used. Installations and machines in the sectors of economy can be grouped by the combusted fuel. "Average" technical parameters can be assigned to the groups (e.g., unit fuel use). The total amount of energy used by a sector of economy depends on the number of installations and machines and their "average" technical parameters. Additionally, the amount of emissions in a sector depends on the structure of fuel used in the sector. This structure can change over time varying market conditions (availability of particular fuel, prices) and the environmental protection legislation.

In the model the fuel use is determined on the basis of the following equation:

$$f_{kjt} = ff_{kjt} \cdot a_{ijt}^{(k)} X_{jt} \ , \tag{4}$$

where:

- ff fuel factor
- f fuel consumption (in energy units),
- a fuel input coefficient
- X value of output taken from the sectoral model
- j sector of economy,
- k fuel type,
- t year.

Fuel factors and fuel input coefficients are defined as follows:

$$ff_{kjt} = \frac{f_{kjt}}{x_{ijt}^{(k)}} \qquad \text{and} \qquad a_{ijt}^{(k)} = \frac{x_{ijt}^{(k)}}{X_{jt}} \ , \tag{5}$$

where $x^{(k)}$ is the value of an interindustry flow from the energy sector which produces fuel k.

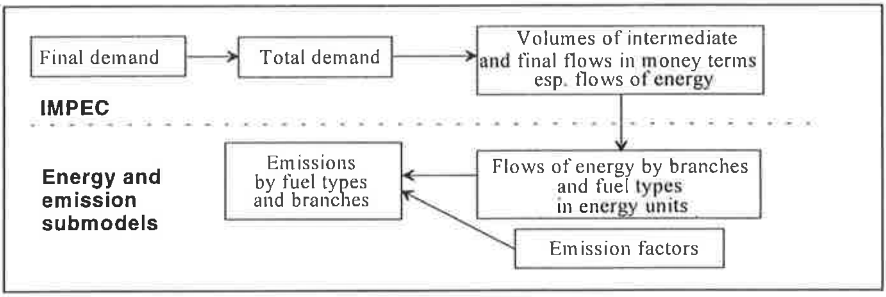
Changes in the fuel input coefficients can be estimated with econometric methods:

$$a_{ijt}^{(k)} = f\left(\frac{p_{kt}}{p_{Kt}}, t\right) , \tag{6}$$

where:

p prices,
K other fuels.

The links between the IMPEC model and the energy and emission submodels are presented in *Figure 6*.



Source: Prepared by the author

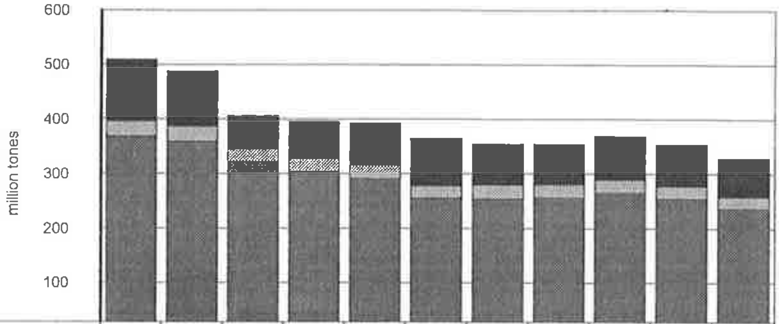
Figure 6. From final demand to emissions

4 CO_2 emission in Poland – evidence and scenarios

Let us concentrate on one pollutant – carbon dioxide, which is considered to be the main gas causing the greenhouse effect. In the past in Poland, like in all countries under a centrally planned economy regime, the emissions were not metered as the most important task was to "fulfill" production plans.

Environmental charges were introduced in Poland in the seventies, but in a centrally planned economy financial instruments failed due to the administered allocation of inputs and low price responsiveness of economic agents. Because in the 1970s and 1980s the environmental policy was ineffective, the charges were always treated as "too low" regardless of how high they really were (Zylicz 1994). It seems that the situation changed in 1990s, when the transition from a centrally planned to a market economy started. Despite very high fees introduced in 1990, in 1990 and 1991 the high rate of inflation and the rule of collecting charges after the end of the year in which they were assessed caused that the situation did not change. A modified legislation, which became effective in 1992, caused that positive changes can be observed. Now Poland belongs to the group of countries with the highest rates of pollution fees.

We illustrate the problem mentioned above in *Figures 7* and *8*. Figure 7 shows CO_2 emission between 1988 and 1998.

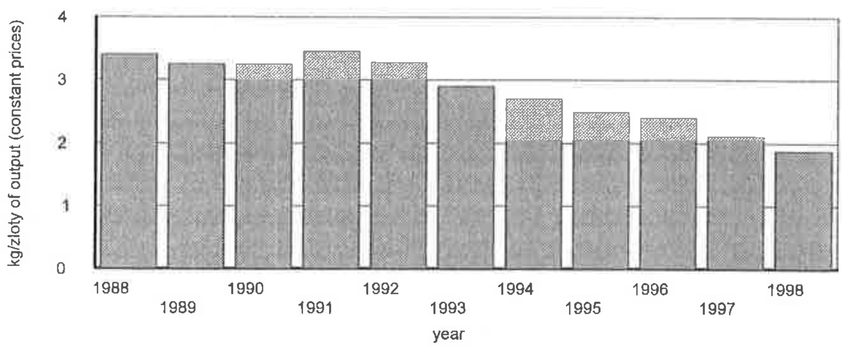


	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Industry	369,2	359,9	322,9	304,4	291,3	255,5	254,9	256,7	265,6	254,9	237,0
Transport	27,2	27,2	22,6	23,8	25,0	23,2	25,1	24,3	23,9	22,9	21,3
Other sources	113,1	100,9	61,4	68,7	76,8	87,4	75,7	74,5	80,4	77,2	71,7

Source: Prepared by the author on the basis of Air Pollution... 1991-1997

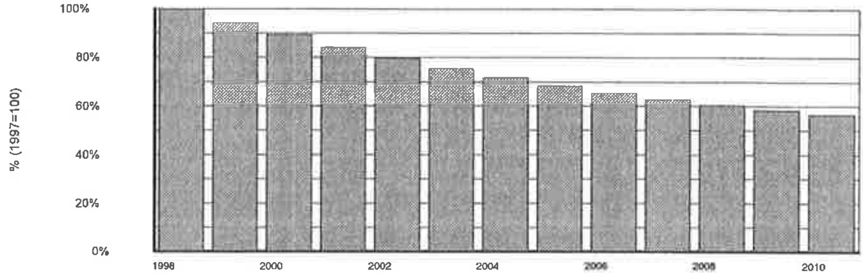
Figure 7. Emission of CO_2 in Poland

The decline in emissions observed between 1988 and 1991 is mainly due to the declining activity of Polish economy in that period. Another fall in the period 1992-1995 was due to positive changes (decline) in unit emission, which are shown in Figure 8. Although in Poland there are no charges on CO_2 emission but there are charges on other air pollutants such as carbon monoxide and sulfur dioxide, emitted together with carbon dioxide in fuels combustion processes. As we can see in Figure 8 the only reason for the increase in the level of emission after 1995 is the high activity of Polish economy.



Source: Prepared by the author on the basis of model's results

Figure 8. CO_2 emission/output ratio in Poland



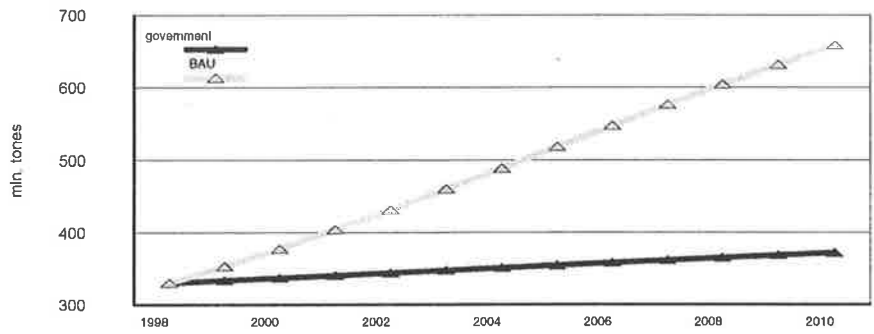
Source: Prepared by the author on the basis of model's results

Figure 9. CO_2 emission coefficients' decline according to governmental plans

According to the Polish governmental documents (Energy Policy Assumptions ... 1995), CO_2 emission in Poland in 2010 will be at the level of 372 million tons, that is almost 10% below the 1990 level.

In that document no policy measures to achieve the ambitious plans are presented. To see how daring the plans are, especially taking into account the high growth rate of the economy (5% to 6% annually) forecasted for the next ten years, we have to investigate how they translate into CO_2 emission coefficients. *Figure 9* shows a time path of those coefficients to achieve the government plans.

As we can see, the CO_2 emission coefficients have to do down almost by half in the period 1999-2010 to fulfill the plans (data for 1999 has been not published yet). This means that they should be declining more or less at the rate of the output growth. An opposite assumption could be formulated such as a "business as usual" (BAU) scenario, in which the coefficients remains unchanged in the period under consideration. Emissions under the BAU scenario as well as under "governmental" scenario are shown in *Figure 10*.



Source: Prepared by the author on the basis of model's results

Figure 10. Scenarios of CO_2 emission for Poland

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