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Renewable energy targets in the EU: the case of fuels for transport

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Abstract: Transport is a crucial economic sector both in terms of people and goods movement and of employment. Negative environmental impacts, not limited to, but certainly stigmatised by, emissions and almost full dependence on finite fossil fuel sources bring it under the lens of the EU regulator in the definition and adoption of the objectives and the instruments to move towards the "low-carbon society".

A scenario-based study is presented, jointly developed by JRC, EUCAR[*] and CONCAWE[**], targeting theoretical scenarios towards achieving the mandatory 10% renewable energy target in transport by 2020. Focus of the analysis is road transport although other transport modes are considered. Expected road vehicle (passenger and goods) fleet development in 29 European countries constitutes the basis on which penetration and distribution of alternative motor fuels – and availability thereof – are analysed, including energy efficiency pace of development, CO_2 emissions, identification of the most sensitive parameters as well as relevant regulatory measures as either hindrances or spurs towards alternative fuels in transport target achievement.

Starting from reasonable assumptions results are robust and provide both information and material for further investigation in several research areas at the crossroads of energy and transport.

Keywords: EU renewable energy policies, transport, alternative motor fuels transport demand.

[1] **Disclaimer:** the views expressed in this article are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

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1 Introduction

1.1 What is JEC

The JEC research collaboration started in the year 2000 bringing together the Joint Research Centre of the European Commission, EUCAR (the European Council for Automotive Research and Development) and CONCAWE (the Oil Companies' European organisation for environment, Health and Safety). The three organisations have collaborated in the field of sustainability of European vehicle and oil industry, providing facts relating to the energy use and efficiency and emissions from a broad range of road vehicle powertrain and fuel options. The JEC Well-to-wheels methodology has become a scientific reference in the European energy research landscape.

1.2 JEC Biofuels Programme and content of this article

The JEC Biofuels Programme is a three-year (2008-2010) technical exercise intended to assess possible biofuel implementation scenarios for achieving renewable energy targets in the European Union in the transport sector by 2020. This technical exercise was not intended to commit the JEC partners to deliver any particular scenario or conclusion included in the study and presented in this article.

In this article the authors assess the potential role of alternative fuels in the European transport sector with a specific focus on biofuels. Following a review of the EU regulatory framework in Section 2, Section 3 describes the fleet and fuel scenario assessment tool developed by JEC and includes details of the reference scenario. Section 4 discusses the role of a selection of technically feasible scenarios. Section 5 outlines biofuels supply projections and compares with demand described in Section 4 thus providing an indication of the achievability of EU regulatory targets before drawing conclusions in Section 6.

1.2.1 Objectives and scope of JEC Biofuels Programme

The objectives of the JEC Biofuels Programme are the following:

- To clarify the opportunities and barriers to achieve 10% renewable energy (on an energy basis) in the transport sector by 2020, by developing a realistic and consensual fuel demand reference and supply of biofuel types and availability;
- To focus on fuel blends with conventional and advanced biofuels while accounting for growth in alternative motor fuels till 2020 and considering both domestic production and imports;
- To ensure that the introduction of biofuel blends to meet regulatory targets results in no detrimental impact on vehicle performance and emissions, while including in the analysis the most recent updates on Well-to-wheels energy and Greenhouse Gases implications.

The scope of the JEC Biofuels Programme can be summarised as:

- Focusing analysis on road transport energy demand while at the same time including non-dynamic analysis of other transport modes;
- Analysing possible implementation scenarios within the 2010-2020 time horizon focusing on fuel alternatives in terms of requirements to road vehicle fleet developments, and;
- Considering standardisation requirements, (fuelling) infrastructure requirements, fuel production and distribution requirements, user/customer acceptance, and availability of demanded amounts of fuels (supply).

1.2.2 Approach of the JEC Biofuels Programme

In line with the objectives and scope of the JEC Biofuels Programme, partner organisations have proceeded to develop a consensus demand and supply picture of biofuel types and demand to meet the 2020 10% renewable energy target in the transport sector adopted by the Renewable Energies Directive of 23 April 2009 (EC 2009a) . The approach has therefore been one of

- Reviewing and analysing projections and other data for the period 2008-2020, covering:
  - biodiesel, ethanol and others, including conventional and advanced products
  - domestic production and imports
  - most recent updates on well-to-wheels energy and greenhouse gases implications
- Analysing possible biofuel implementation scenarios within the 2010-2020 timeframe and subject to the existing regulatory framework.

2 EU Regulatory Framework

The reference regulatory framework within which the JEC Biofuels Programme was defined is the so-called "EU Energy Package", and more specifically the RED Directive and the FQD Directive.

The Renewable Energies Directive of 23 April 2009 (RED Directive) poses two key requirements for the uptake of renewable energy and – more specifically – biofuels in the transport sector.

EU Member States are required to meet 10% renewable energy share in the transport sector by 2020. All transport modes are included in this target and different renewable energy sources are factored in differently, namely the contribution of advanced biofuels[2] towards achieving the 10% target are accounted twice whereas electricity from renewable energy sources for road transport counts 2.5 times[3].

Biofuels sustainability is required for feedstock and biofuels production as well as minimum greenhouse gases (GHG) savings per energy unit.

Each Member State is requested to establish a national renewable energy action plan including information on sectoral targets. In addition, Member States are expected to set out measures to achieve those targets, assessing the contribution of both energy efficiency and energy saving measures.

of technical specifications for fuel content and binding targets to reduce fuels' life cycle greenhouse gases emissions. The directive places the responsibility for reducing GHG emissions on fuel suppliers.

Fuel suppliers will have to gradually reduce fuel greenhouse gases emissions of 6% by 2020. Member States may choose to expand this reduction up to 10%. They may also choose to set the intermediate targets of 2% by 2014 and 4% by 2017.

Suppliers will also have to reach an additional indicative reduction target of 2% by 2020 by either supplying electric vehicles or using GHG reduction technologies (including carbon capture and storage technology). Another indicative target of 2% by 2020 is to be achieved by the purchase of credits through the Clean Development Mechanism under the Kyoto Protocol[4]. The last two targets are subject to review.

From 2011 fuel suppliers will be bound to report annually to Member States on the life cycle greenhouse gas emissions per unit of fuel supplied.

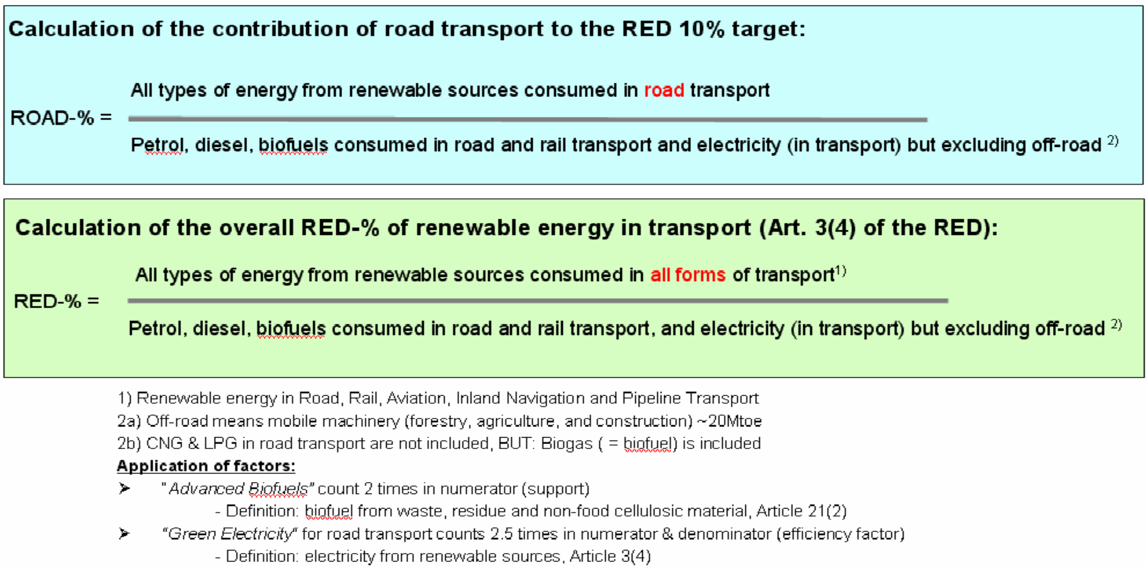

Figure 1. Renewable Energy Calculations in the RED Directive.

The Fuel Quality Directive of 23 April 2009 (EC 2009b) sets environmental requirements for petrol and diesel fuel in order to reduce their air pollutant emissions. These requirements consist

Regulation on CO2 from light duty vehicles is addressed by Regulation 443/2009 (EC 2009c) setting emission performance standards for new passenger cars as part of the Community's integrated approach to educe CO2 emissions from light-duty vehicles. Car manufacturers have to gradually reduce CO2 emissions in the new

[2] See Art. 21.2 of the RED "biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material"
[3] See Art. 3.4 of the RED

[4] http://cdm.unfccc.int/index.html

fleet of passenger cars reaching new fleet averages of 130g/km in 2015 and 95g/km[5] in 2020.

The regulation places the burden of complying with the target on car manufacturers and recognises the role of alternative motor fuels (namely E85) and innovative technologies, by accounting for additional CO2 reductions on overall emissions. Regarding E85 vehicles, the Regulation foresees that the CO2 emission reduction may be applied providing at least 30% of filling stations provide E85 and that E85 meets sustainability criteria: there again yet another reason for car manufacturers and fuel producers and distributors to work together, e.g. by sharing a common knowledge basis.

Regulation on CO2 from light commercial vehicles (vans) has been proposed by the European Commission in October 2009 (EC 2009e). The targeted EU fleet average for all new light commercial vehicles (vans) of 175 g/km is expected to be applied to its full extent as of 2016. The requirement will be phased-in as of 2014 when 75% of each manufacturer's newly registered vans will have to comply on average with the limit value curve set by the legislation then rising to 80% in 2015, and 100% from 2016 onwards.

2.1 Emission standards for passenger cars and heavy duty vehicles

Regulation 715/2007 (EC 2007) introduces new common requirements for emissions from motor vehicles and their specific replacement parts (Euro 5 and Euro 6 standards[6]) for passenger cars, vans and light duty commercial vehicles (categories M1, M2, N1 and N2) (EC 2001). The regulation covers a wide range of pollutant emissions with specifications for each category of pollutant emissions and for the different regulated vehicle types.

Euro VI standard for Heavy Duty vehicles (categories N2, N3, M2 and M3) has been introduced by Regulation 595/2009 (EC 2009d) with new emission limits coming into force on 1 January 2013 (new type approvals) and 2014 (new registrations)[7].

European CEN fuel specifications are also relevant elements factored in the analysis presented in this article insofar as they determine specifications for fuel and biofuel blending.[8]

2.2 Member States initiatives

Initiatives at Member State level provide a somewhat more diversified, heterogeneous situation. Examples range from E10 approved in France in 2009 while B7 had already been approved in the same country in 2008 and B30 for captive fleets. Similarly in Germany, B7 plus 3% renewable diesel was equally approved in 2008 whereas it was still not approved at European level and B100 was also approved for specially adapted vehicles. Examples from other countries range from B20 in Poland and B30 in the Czech Republic for captive fleets to E85 in Austria, France, Germany and Sweden.

Standardisation of high-quality fuels containing sustainable bio-components is essential not only to ensure trouble-free performance in the current and future European road vehicle fleet but impacts equally on the internal market.

3 Description of model and methodology

The JEC "Fleet and Fuels" (F&F) model is a spreadsheet-based simulation tool covering EU27+2 (Norway and Switzerland) vehicle fleet development and the resulting demand for fossil fuels and biofuels. The model has been developed to enable projections to the year 2020 based on a set of assumptions.

The F&F model is a scenario assessment tool based on a 2010 reference case and assuming realistic trends in the fleet, fuel and market developments over the coming decade. It further allows the evaluation of the Renewable Energy Directive and Fuel Quality Directive targets as well as the sensitivity of main parameters considered.

[5] The 95g/m target is a proposal at regulatory level and subject to review

[6] Euro 5 standard has come into force on 1st September 2009 for type approval, and will come into force from 1st January 2011 for the registration and sale of new types of cars. Euro 6 standard will come into force on 1 September 2014 for type approval, and from 1st January 2015 for the registration and sale of new types of cars.

[7] Technical details will be specified in the implementing Regulation being developed by the European Commission in the course of year 2010.

[8] For ethanol, EN15376 for blending up to 5% in gasoline
For Fatty Acid Methyl Esters (FAME), EN 14214
Gasoline: 5% v/v (E5) ethanol and 2.7% oxygen (EN228)
Diesel 7% v/v (B7) FAME in road diesel fuel (EN590)
Generally, there are no standard limiting the addition of 2nd generation renewable diesel fuels, namely Hydrogenated Vegetable Oils (HVO) and animal fats and Biomass-to-Liquids (BtL).

EU27+2 Transport Energy Demand: [Mtoe]	2008 EuroStat	2020 JEC F&F Reference Scenario	2020 DG TREN
1. Road mode	**303**	**281**	**350**
1.1 Diesel	188	186	
1.1.1 Light Duty		69	
1.1.2 Heavy Duty incl. Vans		117	
1.2 Gasoline	100	66	
1.3 Biofuels	10	21.5	
1.4 Other: CNG, LPG, electricity	5	7.8	
2. Other modes	**84**	**109**	**89**
2.1 Rail (Diesel & Electricity)	9.5	10	10
2.2 Aviation	54	73	73
2.3 Inland navigation	6.5	6	6
3. Off-road (Diesel)	14	20	
Total	**387**	**390**	**439**

Table 1. Transport demand projections (Mtoe), including JEC F&F Reference Scenario

The model does not lead to a single globally optimised solution but does allow a side-by-side comparison of various scenarios of fleet and fuel development. Very importantly, the model does not assess the cost implications associated with the various scenarios. Due to the assumptions and simplifications introduced in the JEC Biofuels Programme – and subsequently in the F&F model as its main analytical tool – the model can not be considered as a quantitative tool for predicting the future. In fact, no model can truly do this.

On the other hand, the F&F model can be used to simulate different parameter combinations of vehicle, fuels and biofuels to assess renewable energy implementation scenarios looking at:

- Total fuel demand and gasoline/diesel balance;
- Total biofuels (conventional and advanced) demand;
- Total renewable energy demand, including electricity, biogas for transport, etc.
- Renewable energy demand for road transport to be used for achieving the RED and FQD respective targets.

Key parameters relevant to fuel demand included in the F&F model cover the following areas:

- Passenger car, van, bus&coach, heavy duty truck fleet segments;
- Vehicle efficiency and projected efficiency improvement over time;
- Percentage of diesel in new car sales;
- Fleet introduction of alternative vehicles;
- Vehicle model year (vintage) assumed to be compatible with specific fuel blending grades for biofuels;

3.1 Reference data sources

The reference source used to provide historical input on per vintage vehicle fleet module is TREMOVE, Version 2.7b[9], yet revised via both referenced studies (iTREN2030 2010, EC 2008) and ACEA sales data. Comparisons of energy demand projections towards 2020 were not straightforward due to differences in underlying assumptions. Despite inevitable uncertainties, considerable efforts were made while developing the F&F model to ensure the highest degree of transparency regarding assumptions and data used.

TREMOVE has been used to model information on fleet composition, and activity (vehicle-km and tonne-km), per vintage and year. JEC Well-to-wheel data[10] have been used to model fuel efficiency of passenger cars and fuel specifications.

The 2008-2009 economic recession has been factored in the F&F model using input from the iTREN2030 analysis.

3.1.1 Vehicle classes and fuel options

The F&F model considers the following vehicle classes and related fuel type options:

Seven light duty passenger car types (and related fuel type options)

- Gasoline, Diesel and Flexi-Fuel Vehicles (FFV)
- Compressed Natural Gas (CNG), Liquefied Propane Gas (LPG)

[9] http://www.tremove.org/documentation/index.htm
[10] http://ies.jrc.ec.europa.eu/jec-research-collaboration/activities-jec/jec-well-to-wheels-analyses-wtw.html

– Plug-in Hybrid electric vehicle (PHEV), Battery Electric Vehicle (BEV)

Three van classes (and related fuel type options)
– Gasoline (Gasoline, CNG, LPG, xEV[11])
– Small Diesel <2.5 tonnes Gross Vehicle Weight (GVW) (Diesel, CNG, LPG, xEV)[12]
– Large Diesel >2.5 tonnes GVW (Diesel, CNG, LPG, xEV)

Five heavy-duty vehicle classes (and related fuel type options)
– 3.5 to 7.5 tonnes GVW (Diesel, CNG)
– 7.5-16 tonnes GVW (Diesel, CNG)
– 16 to 32 tonnes GVW (Diesel, CNG, E95, DME)
– > 32 tonnes GVW (Diesel)
– Buses and coaches (Diesel, CNG, E95)

– Alternative vehicles sales start year and therefore final stock composition (fleet penetration) in the year 2020
– % replacement of gasoline or diesel passenger cars by alternative vehicles
– % use (on total activity) of alternative fuels in alternative fuel vehicles (e.g. E85 take-up rate for FFV).

With regard to fuel implementation in the F&F model, it is worth highlighting an assumption, which determines the functioning of the model by assuming biofuel blending by volume at the maximum allowed specification. To clarify with an example, this assumption means in practice that there will be no fuel quality and quantity variation throughout Europe for all biofuel blending.

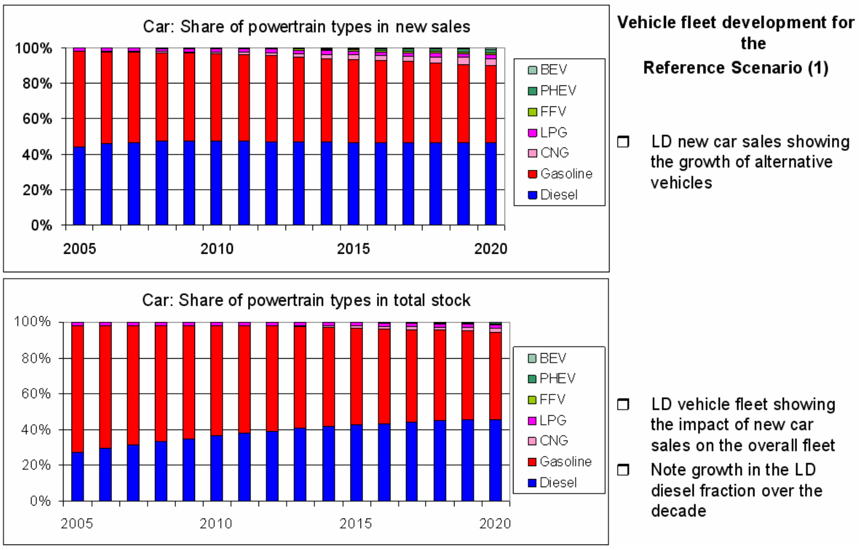

Figure 2. Example of F&F Model Output: Vehicle Fleet Development

The F&F model includes a set of adjustable parameters that can be changed individually for each vehicle type and fuel option. Adjustable parameters include:
– Sales and stock annual growth rate per vehicle class and fuel type
– Vehicle activity, that is the annual mileage (km driven for passenger cars, vans and bus&coach) and annual tonne-km for heavy duty vehicles
– Vehicle fuel efficiency and prospective development year-on-year
– Alternative vehicle sales share in projected vehicle fleet in the year 2020

The only concession made to this assumption is a minus 0.1% by volume of blending tolerance for each blending grade.

The F&F model allows up to 3 different gasoline grades ("protection grade", main grade, and E85) and up to 2 different diesel grades ("protection grade", and main grade). Additionally, for the main diesel grade, market uptake by Heavy Duty (HD) fleet, Light-Commercial Vehicles. Light-Duty vehicles and vehicle vintage compatibility can be independently set.

The F&F model allows setting vehicle vintage (model year) compatibility with fuel grade. It is worth noting though that HVO or BtL are included in the diesel pool assuming backward compatibility. Advanced ethanol (lignocellulose-based) is replacing/added to gasoline and therefore equally not subject to the blending

[11] xEV stands for PHEV or BEV.
[12] CNG and LPG vehicles are options to replace diesel vehicles in the respective class. It is not assumed to use LPG or CNG in a diesel engine.

grades of conventional ethanol. Other oxygenates (e.g. ETBE) are not modelled separately but would be allowed up to the maximum oxygen specification allowed.

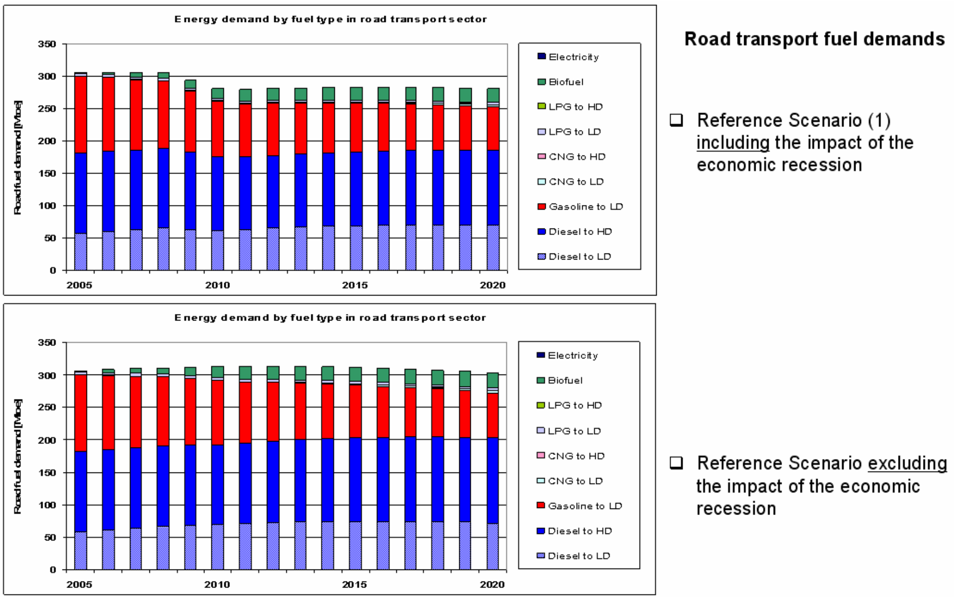

Figure 3. Example of F&F Model Output: Road Transport Fuel Demand

The F&F model includes energy demand by non-road transport modes using historic data series [13] and projections in reference sources by European Commission (iTREN2030 2010 and EC 2008), as sketched in Figure 4. Data have been verified by actively seeking the expert advice of key European stakeholders of non-road transport modes.

Aviation
- Projections range from 56[2] - 73[1] Mtoe consumption by 2020
- Jet fuel specification likely to allow only HVO or BTL in this decade
- HVO/BTL or ETS certificates are options to offset GHG emissions
- Aviation fuel consumption excluded from FQD but included in RED

Rail
- ~10 Mtoe consumption by 2020 [1] [2]
- Fuel by 2020: ~70% electricity, ~30% Diesel (DG TREN[1])
- Rail Diesel: likely shifts to road diesel quality fuel by 2020
- Diesel will likely contain FAME, HVO, BTL, the same as road diesel (i.e. B7 = reference blend)

Inland navigation
- ~6 Mtoe consumption by 2020 [1] [2]
- Likely shifts to road diesel quality fuel by 2020
- Diesel will likely contain FAME, HVO, BTL, the same as road diesel (i.e. B7 = reference blend)

Other off-road diesel
- ~20 Mtoe consumption by 2020 (JEC estimate)
- Diesel will likely contain FAME, HVO, BTL, the same as road diesel (i.e. B7 = reference blend)
- Other off-road fuel consumption excluded from RED but included in FQD

1) DG TREN: "European Energy and transport trends to 2030, Update 2007"
2) iTREN 2030, 2009

Figure 4. Non-road transport modes: Outlook

When considering RED targets extra-credits provided for in that legislative act are implemented in the F&F model for advanced biofuels and renewable electricity.

3.2 Non-road transport modes

The F&F model is mainly devoted to the analysis of road transport energy and fleet demand. Nonetheless it is not realistic to consider and analyse road transport in isolation. This is true for three reasons at least:

– non-road transport modes are accounted for towards meeting the targets of the RED and FQD EU Directives;
– non-road transport mode demand for alternative transport fuels, including (but not limited to) biofuels may represent a competing demand limiting the uptake opportunity of such fuel options in the road transport sector;
– other modes' demand may provide opportunities for investment in new biofuel plants and/or funding for advanced research and development activities (this seems to be realistic with a longer term perspective).

Rail contribution towards meeting the RED target has been split into its electricity and diesel components assuming 35% average renewable electricity in the grid by 2020 (EREC 2008, JRC 2009), accounting for slightly less than 1% of the RED target from this mode. Inland navigation assuming the uptake of B7 by the sector accounts for less than 0.1% towards the RED target while

13 http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database

aviation is assumed to make no contribution by 2020.

4 Scenario analysis

With the support of the F&F model, a reference scenario has been defined, which represents the energy demand development commonly agreed by the European automotive industry, the fuel producers active in Europe and fully in line with the EU energy and transport regulatory and policy framework. Considering diverging starting points and expectations, the identification and characterisation of a commonly agreed reference scenario can already be considered a success.

Following this fundamental step, eight further scenarios have been developed and analysed, which are feasible to approach the RED 10% target in 2020.

4.1 Reference case scenario 2020

Fleet parameters in the reference scenario have been assumed to be the following:

- Sales and stock in 2020 for all vehicle classes as in TREMOVE except for sales of Heavy Duty vehicle classes expected to be lower due to economic recession;
- Economic recession impacts fleet activity (vkm and tkm), using input from the iTREN2030 project;
- Efficiency improvements are specific per vehicle class;
- Alternative fuel vehicles enter the market assuming a start year for market introduction and a target sales share by 2020.

Fleet parameters in the 2020 reference scenario (as sketched in Table 2) therefore result in:

- Passenger cars
  - New car average CO2 target is 95g/km[14];
  - Diesel/gasoline sales share at 50%/50%;
  - Sales reach 20 million vehicles per year.
  - Total fleet is 270 million vehicles
  - Alternative fuel vehicles enter the market;
  - Although the financial crisis impacts miles travelled, total fleet mileage still increases.

- Vans
  - New van average CO2 target is 175 g/km[15];
  - Sales reach 1.5 million vehicles per year. Total fleet is 28 million vehicles;
  - Alternative fuel vehicles enter the market;
  - Although the financial crisis impacts miles travelled, total fleet mileage still increases.

- Heavy Duty vehicles
  - New truck average year-on-year energy efficiency improvement is 1.5% (the model defines different efficiency gains per heavy duty vehicle class);
  - Sales reach 0.8 million vehicles per year. Total fleet is 15 million vehicles;
  - Alternative fuel vehicles enter the market in specific heavy duty classes (and therefore Member States markets);
  - Although the financial crisis impacts heavily on both activity (tkm) and sales, dynamic growth is still expected.

[14] Value is used for calculation purposes; so far the figure is a proposal at regulatory level and still subject to review
[15] Value is used for calculation purposes; so far relevant legislation is at negotiation stage.

Alternative Fuel Passenger Cars	In 2020 New Sales		In 2020 Vehicle Fleet	
Flex-Fuel Vehicles (FFV)	1%		0.5%	
Compressed Natural Gas Vehicles (CNGV)	4% 0.8 Million		2% ~5 Million	
Liquefied Propane Gas Vehicles (LPGV)	2% 0.4 Million		2% ~5 Million	
Electric Vehicles Battery Electric (BEV) & Plug-in Hybrid (PHEV)	3% 0.6 Million		1% 2.7 Million	
Alternative Fuel Vans	**In 2020 New Sales**		**In 2020 Vehicle Fleet**	
Compressed Natural Gas Vehicles (CNGV)	4%		1.7%	
Liquefied Propane Gas Vehicles (LPGV)	1%		0.4%	
Flex Fuel Vehicles (FFV)	1%		0.3%	
Electric Vehicles Battery Electric (BEV) & Plug-in Hybrid (PHEV)	2% 24 Thousand		0.4% 90 Thousand	
	In 2020 New Sales			
Alternative Fuel Heavy Duty Vehicles	3.5t to 7.5t	7.5t to 16t	16t to 32t	Bus-Coach
Compressed Natural Gas Vehicles (CNGV)	2%	1%	1%	5%
Di-Methyl Ether Vehicles (DMEV)	==	==	0.5%	==
95% Ethanol (E95) Vehicles	==	==	1%	2%

Table 2. Alternative Fleet Parameters in the Reference Scenario

The resulting biofuel parameters used in the reference scenario are as follows:

– Conventional biofuels: blending grades
  - Ramping up to E5 by 2011 with no vehicle compatibility restriction (protection grade);
  - New E10 (main) grade from 2011 with vehicle compatibility with E10 from 2005+ model year;
  - Ramping up to B7 by 2010 with no vehicle compatibility restriction (protection grade);
  - Assumption of 1 Mtoe FAME/HVO coming from waste oils, which are accounted double towards meeting the 10% RED target. Quality of produced FAME or HVO is expected not to be impacted.

– Non-conventional biofuels
  - Ramping up of HVO, BtL and advanced ethanol according to assumptions outlined in Table 3.

	Biomass-to-Liquid (BTL)	Hydrogenated Vegetable Oil (HVO)	Advanced Ethanol
Start year	2012	2009	2012
Production simulation	Linear ramp-up to 2020	+1.6 Mtoe to 2012 +1.4 Mtoe and linear ramp from 2012 to 2020	Linear ramp-up to 2020
Availability in 2020	0.25 Mtoe	3 Mtoe	0.64 Mtoe

Table 3. Advanced biofuels as fuel parameters in the reference scenario

Results in terms of energy demand in the 2020 reference scenario when compared to start year 2010 can be summarised as follows:

- Fossil energy demand changes
  - Gasoline demand decreases by 24%
  - Diesel demand increases by 6%
  - Diesel demand increases 13% for light duty and 3% for heavy duty vehicles
  - Diesel/ gasoline ration increases from 2.0 to 2.8
- Large biofuel volumes are needed, with increasing demand for CNG and CBG
- The RED 10% target is not met, but reaches 9.7% including 1.0% contribution from non-road transport modes;
- FQD target of -6% GHG emissions is not met, with 4.4% savings from all relevant transport modes included.

Road fuel (Mtoe)	2005	2010	2020
Fossil Gasoline to car	118	87	66
Fossil Diesel to car	58	61	69
Fossil Diesel to HD	123	114	117
Sum fossil Diesel	181	175	186
Diesel to Gasoline ratio (road only)	1,5	2,0	2,8
CNG	0,42	0,85	3,26
CBG			0,82
LPG	4,17	3,32	3,24
FAME	1,50	11,90	12,80
HVO	0,00	1,00	3,00
BTL	0,00	0,00	0,25
DME	0,00	0,00	0,09
Total Ethanol	0,72	2,47	5,32
EtOH conv.	0,72	2,47	4,68
EtOH Adv.	0,00	0,00	0,64
"Fossil" Electricity	0,00	0,00	0,28
Renewable Electricity			0,15
Sum road fuel demand	**306**	**281**	**281**
RED Contributions			
Non-road			1,0%
Road			8,6%
Sum RED-%			**9,7%**
FQD GHG saving			**-4,4%**

Table 4. Energy demand in the reference case and EU Directives targets

Results in terms of alternative fuel demand for the transport sector are:

- FAME dominates the biofuel market: the steep demand increase in 2010 is driven by B7 blending specification
- The steep demand increase for ethanol in 2010 is driven by E5 blending specification while increase beyond 2010 is due to E10 blending specification
- HVO and BtL demand follow availability assumptions (backward compatible vehicles imply no grade dependency)
- CNG and CBG demand is driven by the introduction of CNG vehicles in Light Duty fleet segment but also Heavy Duty segment.

In absolute terms, FAME demand in all transport sectors in 2020 will be approximately 15 Mtoe per year, increasing from 1.5 Mtoe per year in 2005 and 7.9 Mtoe in 2008. Ethanol demand is expected to be in the range of 5Mtoe per year, increasing from 0.7 Mtoe in 2005 and 1.8 Mtoe in 2008.

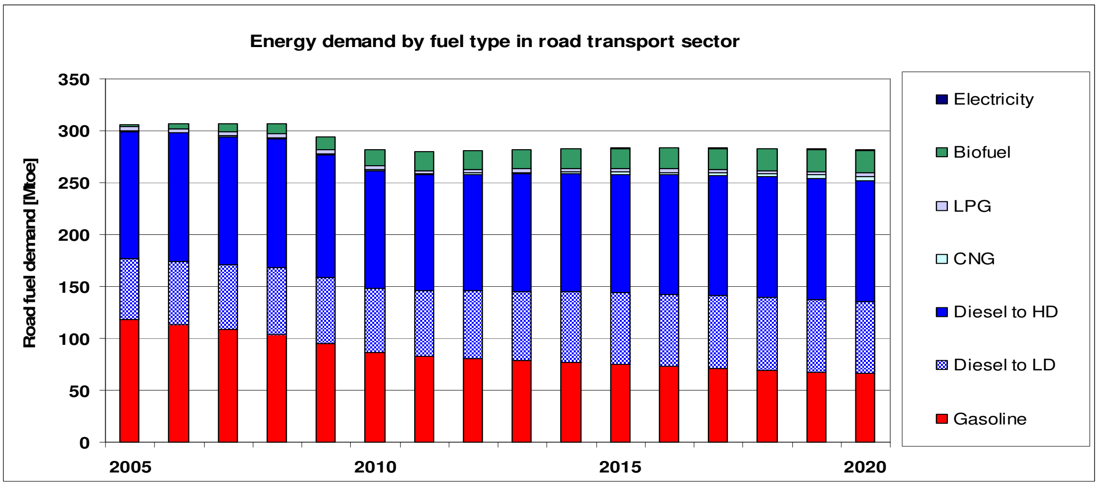

Figure 5. Energy demand by fuel type in road transport sector in the reference scenario

4.2 Biofuels scenarios using the Fleet and Fuels model

The eight further scenarios analysed with the F&F model imply a specific development of the vehicle fleet with given years of introduction of fuel grades and given model years of vehicle compatibility, resulting in a given energy demand and fuel diversification per fleet vintage.

The rationale for defining the scenarios is based on the following criteria:

– Respect the constraints identified in the definition of the reference scenario;
– Reflect differences in current situations and – therefore – likely future priorities, which are present across EU Member States;
– Maintain the number of scenarios to a reasonable number allowing a detailed analysis, including their pros and cons as well as a sound sensitivity analysis.

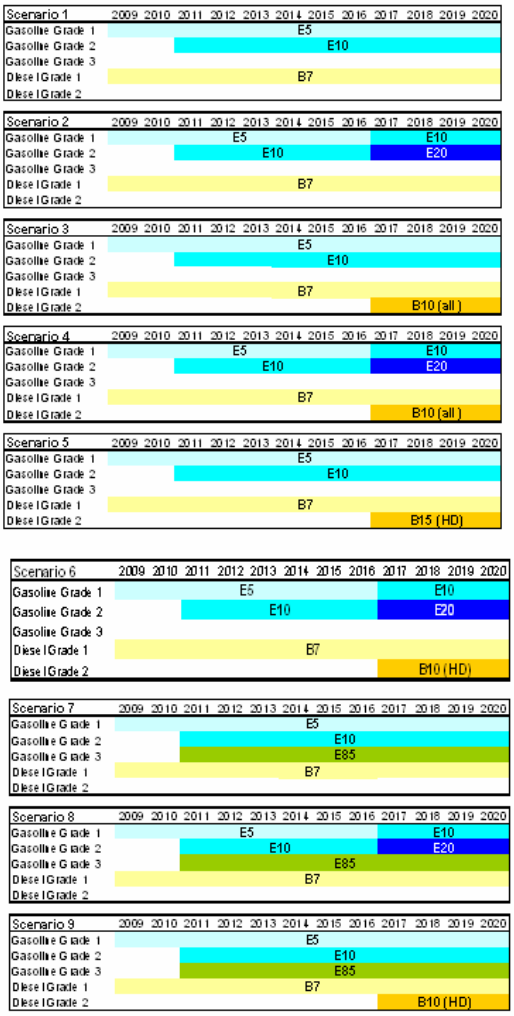

Figure 6. Visual representation of analysed scenarios

Scenario 1 is the reference case described in detail in Section 4.1.

Scenarios 2-9 can be characterised as follows:

– Scenarios 2-4: "high biofuel grades for all vehicle classes";
– Scenarios 5-6: "high biodiesel grades for heavy duty vehicles only";
– Scenarios 7-9: "additional Flex-Fuel vehicles (FFV)"

The FFV scenarios feature a sales share of 4.5% resulting in a 2.5% FFV stock (6.5 million) vehicles in 2020.

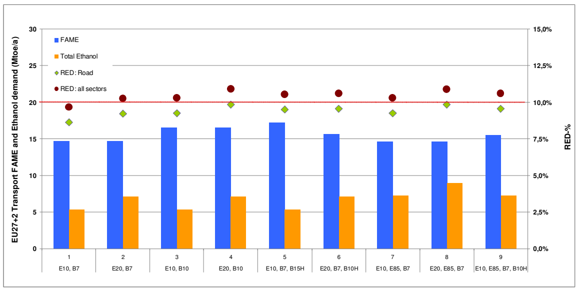

Figure 7. Summary of scenario results

4.3 Sensitivity analysis

The F&F model has several adjustable parameters that influence projections to the year 2020. They can be grouped in three categories and the main outcomes of the sensitivity analysis are presented.

– Passenger Cars

Sales assumptions for alternative fuel vehicles, namely Flex-Fuel Vehicles (FFV) impact the capacity to reach the RED % target.

Passenger Cars Parameter		reference	min	max
Sales	M cars/a in 2020	20,20	16,2	24,2
Total fleet	M cars in 2020	270	216	324
Total Mileage	% yoy growth (2011+)	2,25%	1,8%	2,7%
CO2 sales avg 2020	g/km	95	95	120
Diesel reg. 2020	% of G+D	50%	30%	70%
CNGV	sales sales start year	4,0% 2006	2,0%	6,0%
LPGV	sales	0,40%	0,0%	2,6%
FFV	sales sales start year	1,00% 2005	0,0%	4,0%
Electric vehicle	sales sales start year	3,00% 2011	1,5%	10,0%

Table 5. Sensitivity analysis for passenger cars

– Vans and Heavy Duty

Sensitivity assumptions for both vans and heavy duty vehicles do not make a significant difference in terms of reaching the RED % target.

Vans Parameters		reference	min	max
CO2 sales avg 2020	g/km	175	160	175
vkm YoY growth 2011-2020		1,00%	0,8%	1,2%
CNGV sales share 2020		4,0%	2,0%	6,0%
FFV sales share 2020		1,0%	0,0%	4,0%
HD Parameters				
Efficiency 2011+ ALL HD classes YOY improvement 2011 - 2020		-1,45%	-1,00%	-1,45%
Load factor ALL HD classes w/o bus&coach Load YOY growth 2005-2020		0,080%	0,06%	0,10%
Transport demand ALL HD classes w/o bus&coach tkm YoY growth 2011-2020		2,250%	1,8%	2,70%
HDV Vehicles 3.5-7.5 Tonnes				
CNGV sales share 2020		2,0%	0,00%	4,00%
HDV Vehicles 7.5-16 Tonnes				
CNGV sales share 2020		1,0%	0,00%	2,00%
HDV Vehicles 16-32 Tonnes				
DME sales share 2020		0,50%	0,00%	1,00%
E95 sales share 2020		1,00%	0,00%	2,00%
CNGV sales share 2020		1,00%	0,00%	2,00%
HDV Vehicles bus&coach				
E95 sales share 2020		2,00%	1,00%	4,00%
CNGV sales share 2020		5,0%	0,00%	10,00%

Table 6. Sensitivity analysis for vans and heavy duty vehicles

– Fuels

The pace of development of advanced biofuels (BtL and advanced ethanol) and HVO significantly impacts the capacity to reach the RED % target.

Biofuels availability 2020		reference	min	max
HVO	[Mtoe/a]	3,0	1,5	4,5
BTL	[Mtoe/a]	0,25	0,0	0,5
Adv. Ethanol	[Mtoe/a]	0,64	0,00	1,28

Table 7. Sensitivity analysis for fuels in all scenarios.

Sensitivity was tested on scenario-specific additional parameters, chosen based on expert advice.

Additional		Reference	min	max
HVO availability in 2020	[Mtoe/a]	3,0	1,5	4,5
FFV	sales% 2020	1,0%	0%	4,0%
E20 MY 2015+	first model year	2017		2015
B10 MY2015+	first model year	2017		2015
B10 MY2015+ (cars) & all (HD)	first model year	2017		2015/all
B15 HD MY2015+	first model year	2017		2015
B15 HD all	first model year	2017		all
Biogas in CNG	Share e/e [%]	20%	0%	40%
Renewable electricity in road trans.	Share e/e [%]	35%		100%
B30 for Inland Navigation	FAME blend	B7		B30
Renewable electricity in rail trans.	Share e/e [%]	35%		100%

Table 8. Additional parameters' sensitivities.

As a conclusion of the sensitivity analysis and of Section 4, the following statements are highlighted as mostly relevant:

- Timely implementation and uptake of higher biofuel levels significantly impacts RED % target. For instance, the 50% reduction in uptake of E10 grade in the reference scenario would decrease the RED% from 9.7% to 9.3%.
- Implementing higher biodiesel levels in non-road sectors significantly impacts RED % target;
- Renewable electricity in rail transport mode can contribute significantly to RED % target.

5 Biofuel Supply Outlook

Inevitably, the question that accompanies the projected biofuel demand per type of fuels based on the assumptions and analysis of the F&F is whether these quantities of biofuels will be available not only and possibly more interestingly for the objectives of the study – whether they will be available for European use through 2020 and, if so: from domestic production and from imports? From sustainable sources meeting GHG reduction targets?

The biofuel supply part of the analysis is considerably less detailed than the modelling and analytical work performed for the demand side and its primary focus has been on availability and not on costs and investments although they are indirectly factored in the main reference source[16] (WMac 2009) used for this section of the study.

5.1 How this complements the demand analysis modelled with Fleet and Fuels

Using scenarios presented in Section 4, biofuels demand, including sensitivity testing on selected parameters, is summarised in Table 9.

[16] Data from European Biodiesel Board (http://www.ebb-eu.org) and European Bioethanol Fuels Association (http://www.ebio.org) have been considered for the analysis.

	Biofuel Type	Demand Outlook (Scenarios)	Demand Outlook (Scenarios & parameter variation)
Conventional Biofuels	Bio-ethanol from fermentation	Up to 8.5 Mtoe	Up to 12 Mtoe
	FAME (and FAEE)	Up to 17.5 Mtoe	Up to 19 Mtoe
Advanced Biofuels	Bio-ethanol from lignocellulose	0.6 Mtoe	1.3 Mtoe
	Hydrogenated Natural Oils (HVO)	3.0 Mtoe	4.5 Mtoe
	Biomass to Liquids (BTL)	0.25 Mtoe	0.5 Mtoe
Other Renewables	Biogas	Up to 0.7 Mtoe	Up to 1.0 Mtoe
	Electric from renewables	Up to 0.5 Mtoe	Up to 1.0 Mtoe

Table 9. Biofuel demand from modelled scenarios

Today's European production capacity[17] installed in Europe (GBC 2010) is in the range of 3.4 Mtoe bioethanol functioning at 43% of its potential and therefore producing approximately 1.5 Mtoe bioethanol per year and an additional 13 plants currently under construction to produce 0.9 Mtoe when operational. European biodiesel production capacity installed in 2009 reaches 18.4 Mtoe per year, with 6.9 Mtoe actually produced in 2008 at a utilisation rate of 37% of installed capacity.

Furthermore, HVO production needs to be taken into account with an expected production capacity in Europe slightly below 2 Mtoe per year as of 2015 and in the range of 3Mtoe per year worldwide. These assumptions are therefore in line with those used for the 2020 reference case. Yet, it is important to remember that the demand for HVO from other world regions may change over the next decade.

The supply of both FAME and HVO is limited by the total availability of natural and waste oils. Imports are therefore essential to fully utilised higher biodiesel blends to the volume levels suggested by the demand scenarios. The same statement is valid for ethanol where both imports and the development of advanced ethanol are key to meeting projected demand volumes.

5.2 *Key messages comparing biofuel supply and projected demand*

Although there are many uncertainties, the results of our demand and supply analysis allows reaching these preliminary conclusions:

- Ethanol is likely to be available in volumes needed to cover EU demand given lower gasoline volumes and availability of imported ethanol;
- FAME may possibly be available in needed volumes with open questions regarding domestic development, global demand, and competition for natural and waste oils for HVO production;
- Advanced ethanol: despite growing global supply uncertainties remain about European production through 2020;
- HVO may be possibly competing with demand from global aviation sector and, and competition for natural and waste oils for FAME production;
- BTL scaling up to world-class plant size seems difficult within the given time horizon due to technical issues.

[17] JEC analysis for conventional and advanced biofuels, based on data provided in referenced source.

Other related issues that could affect supply include:

- Sustainability and certification criteria not yet fully defined;
- Impact of Indirect Land Use Change (ILUC) on GHG targets is far from being a settled issue;
- Impact of taxation and tariffs on imports/exports.

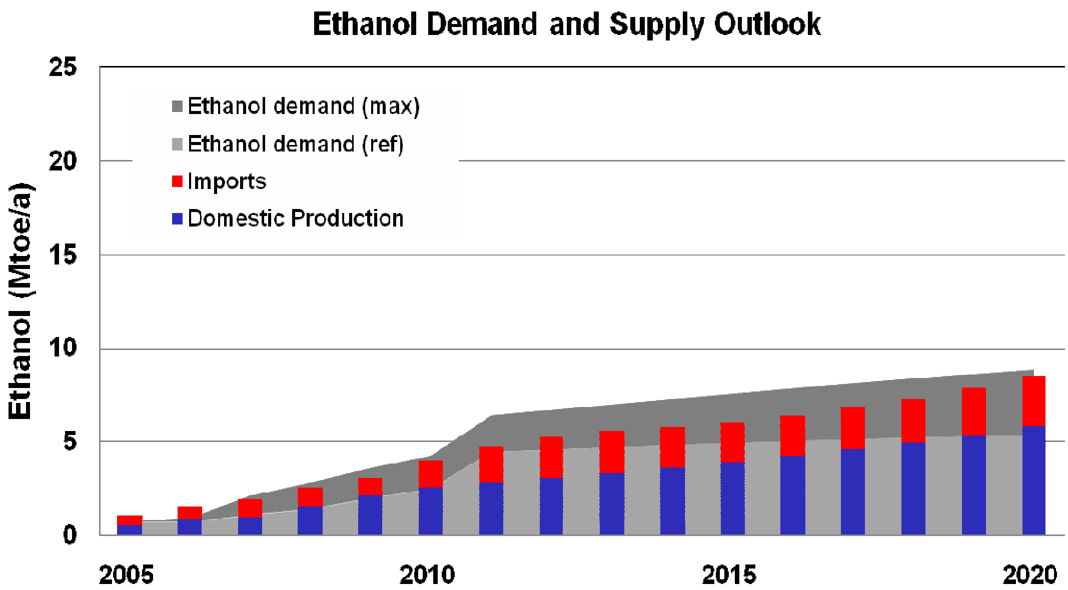

Figure 8. Demand and supply: FAME and HVO

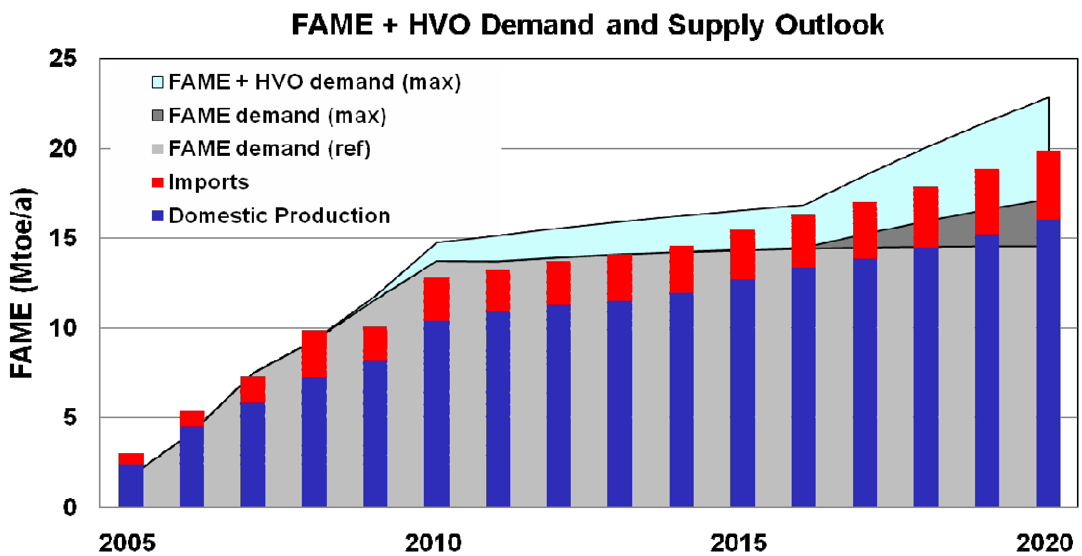

Figure 9. Demand and supply: Ethanol

6 Conclusions

The coming decade for European road transport can be characterised by focusing on three components and on the basis of such characterisation, the outcomes of the JEC Biofuels Programme via its F&F model as main analytical tool can be valued.

The first component is that of vehicles. Vehicles in the coming decade are expected to be characterised by more advanced engines and after-treatment systems, while at the same time we will see an increasing diversification in engines and fleet. Fuel consumption of light-duty vehicles is expected to fall with heavy duty diesel demand slightly increasing. Increasing pressure from the regulator on limiting CO2 emissions is expected to lead to higher associated costs. Customer preferences may potentially be in conflict with transport and energy policies.

Certainly, today's vehicles are already E10 (from model year 2005 onwards) and B7 compatible. On the other hand, compatibility with higher biofuel blends is still to be proven and this will take time, testing and investment.

The second component is that of fuels. Fuel production at refineries will continue the current trend characterised by an increasing diesel/gasoline demand ratio. This means that higher CO2 emissions can be expected due to diesel demand and product specifications. Similarly to the "vehicles" component, an increasing pressure from the regulator on limiting CO2 emissions is expected and likely to push up associated costs.

It is uncertain whether existing logistics infrastructure may be compatible with higher blending grades. A coordinated development of CEN specifications is needed for higher grades to match the needs and/or payback investments needed to have that infrastructure adapted. The scenario analysis shows that potential higher blends need to be fully utilised in order to approach regulatory EU targets set in the RED and the FQD Directives, even more so when considering that in the chosen scenarios the FQD Article 7a GHG emissions' reduction target was not achieved.

The third component is that of biofuels and other renewable energy sources for transport. In the first place, the 10% (energy basis) mandatory target by 2020 is a given assumption. Conventional biofuels are widely available but are accompanied by sustainability concerns in the face of increasing demand. This concern is strengthened when noticing the slower than expected pace of development of some advanced biofuels. It is also worth noticing and keeping in mind the different pace of development and the different priorities across EU Member States, potentially leading to a proliferation of fuel varieties and specifications. As a counter side to that, the standardisation process (CEN specifications) is somehow struggling to keep pace with the regulatory targets, which are relatively more swiftly adopted.

Significant questions therefore remain regarding sustainability, pace of development, and imports. Given these uncertainties, ethanol and FAME are in the range needed to achieve the RED 10% target, yet the most important factors – and open questions – are the pace of development of non-conventional biofuels on the one hand, and the uptake of HVO/BTL by the aviation sector.

To conclude, other key messages to be learned from the study are schematically exposed as follows:

- The attractiveness of different scenarios will vary by Member State;
- Contribution of non-road transport modes to achieving the RED 10% target is important;
- Potential exists for higher biodiesel blends to be used in non-road targets to meet targets but will require time, testing and investment;
- Higher biodiesel blends could also be used in non-road transport modes to meet targets;
- Costs and investments could be significant and were not evaluated in this study;
- Maintaining consumer and citizen confidence in European fuel and biofuel strategy is critical to achieve objectives.

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Mitigation vs Adaptation.
Conflicting policy arenas and the post-Kyoto negotiations

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Key words: climate policy, problem definition, decision making
Abstract: The UN Convention for Climate Change is the result of two international organizations initiative, the UNEP and the WMO, which define climate change (C.C.) as an environmental degradation problem and encourage industrialized countries to adopt measures in order to mitigate theirs GHG emissions. This "mitigation oriented" rationality is also respected by the Kyoto Protocol which commits signatory countries to reduce GHG emissions.

Until the adoption of the UNFCCC and the Kyoto Protocol, the climate change discussions were considerably evolved while its definition was enlarged. The environmental dimension of the issue weakened and other competing aspects occupied the public debate thus legitimizing new institutions in the field. Since the rising temperature is expected to impact less developed countries, the UNDP points primarily to the 'development problem' related to C.C. C.C is also discussed as a "security problem" evolving the NATO or the UNHCR. Further the migration sectors look at climate change as a potential 'migration crisis'.

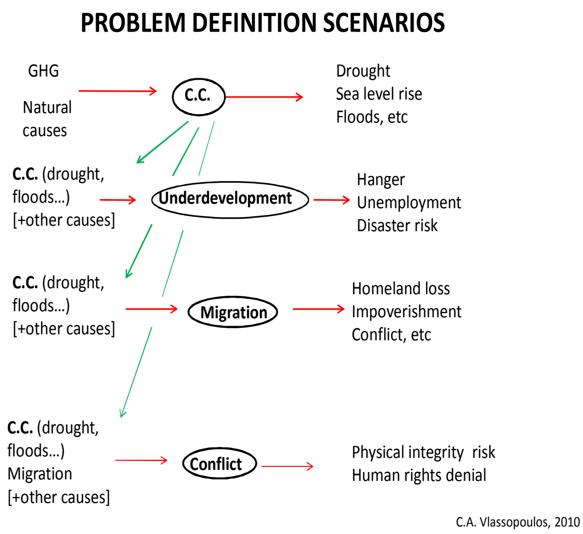
These interactive definitions consider C.C. as the cause of other major problems (development, security, migration) rather than an autonomous environmental problem and they imply the intervention of institutions with no background in environmental policy making. This evolution put forward more "adaptation" than "mitigation" oriented measures. While this polyphonic discourse persists the problem definition process remains unaccomplished and consequently policymaking cannot be established.

Introduction:
This proposal intends to focus on the different definitional debates linked to C.C. and their impact to the post-Kyoto negotiations process. The analysis is based on the 'definition approach' suggested by Spector and Kitsuse who propose to consider public problems as a discursive interactive process driven by the policy actors.
Most of the analysis referring to international agreements explain their success or failure by pointing either to the presence or lack of governmental compliance or to the institutional complexity and need for coordination between enforcement agencies. Less attention is paid to the way public problems are perceived by different policy agencies and the fact that, under the same definitions, not all the actors refer to the same problem. This paper proposes focusing on the different definitional debates linked to Climate change and their impact for the post-Kyoto negotiations process.
The UN Convention for Climate Change defines climate change as an environmental degradation problem and encourages industrialized countries to adopt measures in order to mitigate theirs GHG emissions. The same mitigation rationality is respected by the Kyoto Protocol. Gradually the climate change discussions considerably evolved. The environmental definition initially promoted by the UNEP and the WMO weakened and other competing images entered the public debate, legitimizing new policy actors in the field. Through more or less parallel debate forums climate change has been defined as a development problem, a migration problem and a security problem. These interactive definitions consider climate change as the cause of other major problems to be dealt with (security, development, migration) and less as a consequence of human induced air pollution. They reflect an anthropocentric approach of climate change pointing more to adaptation oriented measures than to mitigation as suggested in the UNFCCC and the Kyoto Protocol.
The first paragraph discusses the importance of problem definition for the policy making process. The second paragraph presents the former definition of climate change as an environmental problem. The third paragraph examines the expansion of the climate's change definitional arenas which converge toward an anthropocentric vision of the problem.

1/ The policy relevance of problem definition process

Public problems are like Russian dolls that are enclosed within one another. Let's take the example of climate change: Greenhouse gas emissions cause global warming. Global warming causes drought. Drought can subsequently lead to underdevelopment, malnutrition or forced migration. Forced migration can generate conflict. Climate change can be defined as an autonomous public problem produced by certain causes and causing certain consequences like ecological and social vulnerability, migration conflict, etc. But it can

also be perceived as one of the causes of another public problem.
Greenhouse gases emissions → Global warming (Drought, sea level rise, etc) → Underdevelopment → Migration → Conflict…
The definition of a situation as a public problem and its official registration on the political agenda are purely political actions that involve the search for a compromise between multiple actors supporting different positions. The official recognition of a problem means allocation of a budget, distribution of authority and designation of persons to blame and protect. To put it another way, problem definition is an issue of power, since it divides the social and public actors into winners (who profit from the recognition of the problem) and losers (who will lose material or symbolic resources) (Stone, 1997). For example, the recognition of climate change as an autonomous problem will strengthen the positions of the agency asked to manage this problem, which will probably in turn have its budget and its personnel increased. It will also help people affected by the deterioration of the environment who will benefit from positive measures. On the other hand, this same recognition can prove harmful for industrialist that must assume the cost of CO2 reduction measures and for the agencies that lose control of the issue. If no compromise is found between policy actors to converge towards a common definition of the problem policy making to address the problem becomes impossible.
When a situation becomes a public problem, which must be dealt by the public authorities, it passes through a double definitional debate (Vlassopoulos, 2007). The first determines the causes of the problem and answers the question "what is the problem?". The second determines the consequences of the problem and answers the question "why does this situation constitute a problem?". The causes define the responsible that must pay for solving the problem. The consequences define the **victims** to whom the policy must be addressed. Each problem contains its own rationale of victimization and responsibility attribution and this influences the recognition of authority to one or another policy sector. Thus each sequence of 'cause-problem-consequence' do not refer to the same policy sector. Different scenarios are possible:



In the sequence 'GHG emission – climate change – environmental degradation (Drought, sea level rise, extreme weather events, etc) climate change is considered as an autonomous environmental problem whose origins must be combated by the adoption of pollution abatement measures guaranteeing ecological equilibriums. The environmental sector appears to be the most relevant to tackle these causes by adopting traditional ex post 'polluter pays principle' measures, to mitigate the problem.
In the sequence 'C.C. – underdevelopment – hanger, unemployment, etc.' The main problem is underdevelopment that, among other causes, can be enhanced by climate change. In this case the development sector has competence to propose development and adaptation measure to protect against the negative effect of global warming but has no authority to address environmental measures.
In the sequence 'climate change – migration – impoverishment, loss of traditional habitat, etc.', migration is the autonomous problem. Climate change is one of the potential migration causes (others can be conflict, economic crisis, or deliberate choice). In this case, the migration sector is most relevant to deal with migration flows but it has no competence to tackle the environmental causes of migration. Policies in that case protect vulnerable populations by the adoption of adaptation measures and if necessary of relief responses.
In the sequence 'climate change – security – physical integrity, human rights, etc. Security is the autonomous problem. Climate change is one of the potential security causes (others can be war, forced migration, political regression, etc. Here the security sector appears as most relevant to deal with the problem but it lacks the competence to tackle the environmental causes of security. Policies in that case are most oriented toward conflict preventive measures and if necessary urgent responses to human crisis situations.
The variety of the definitional frames through which climate change is actually debated places it at the

intersection of different policy arenas, each one with its one rationality, objectives and functioning and its one policy actors. Important incompatibilities separate these policy arenas, making their collaboration difficult. More specifically, the environmental sector was built in the 1970s on an ecocentric approach to reality against the anthropocentric approach dominant until then (Theys, 2007). The environment constitutes a new autonomous social value that must be protected in itself and not, as in the past, through reference to human health. The new environmental policies are based on the responsibility concept operationilized by the "polluter-payer" principle. The development, the migration and the security sectors are built on an anthropocentric approach to reality. This involves giving priority to human well-being. Migration and security policies are responses to human crisis situations, and as such, they cannot be based on the individual responsibility concept. Costs are shared by the community.
Neither the objectives (environmental protection vs human protection) nor the means (constraint and sanction trough pollution mitigation, help and inducement through community adaptation) are common to these policy arenas whose discourses aliment a dissonant problem definition process.

2/ Setting the agenda of climate change: the construction of an environmental policy issue

The climate change issue is not new. First the French mathematician and physician J. Fourier described the green house effect in his article published at the *Annales de la Chimie et de Physique* in 1824. The Swedish (Arrenius, 1896) half century later put the accent on CO2 and the effects of burning coal to the earth's temperature but ignored its negative impacts. Many years of scientific debate followed until the consideration of C.C. as a global public problem requiring the intervention the international community and national gorvernemnts.

Until 1970 the climate debate was mostly confined to the scientific community of climatologists. Climatic variations were perceived as a scientific issue and climate research was fragmented into diverse university ventures. In 1971 a first international study group of experts was created at Wijk Lidingö (Sweden) in order to define the state of knowledge in climate research and make propositions for further research. Based on this first international cooperation a broader group of experts was organized three years later by the World Meteorological Organization (WMO) and the International Council of Science (ICSU) within the frame of the Global Atmospheric Research Program (GARP) to examine the highly complex problem of the physical basis of climate (Flohn, 1977). This is the first United Nations' initiative on the climate issue followed by the first World Climate Conference organized by the WMO in 1979. This was an entirely scientific meeting of some 400 experts from more than 40 countries but participants were asked to recommend whether a conference at the ministerial level should be convened to take necessary international policy actions.

While the participants were climate scientists and researchers on energy, land use or water resources, the topics discussed in this Conference were not merely scientific. The debate on climate models and predictability went together with environmental concerns pointing to the interdependence between climate and society. More specifically, the effects of climatic hazards for developing countries and the potential of greenhouse effects to question the sustainability of the industrial civilization received particular attention during the meeting (Ausubel, 1987). The Declaration of the World Climate Conference, unanimously adopted by the participants, gave for the first time a clear definition of human induced climate change as a major environmental problem necessitating *ad hoc* measures in order to prevent the degradation of the world's environment:

> *The long term survival of mankind depends on achieving a harmony between society and nature. The climate is but one characteristic of our environment that needs to be wisely utilized. All elements of the environment interact, both locally and remotely. Degradation of the environment in any national or geographical area must be a major concern of society because it may influence climate elsewhere. The nations of the world must work together to preserve the fertility of le soils; to avoid misuse of the world's water resources, forests and rangelands; to arrest desertification; and to lessen pollution at the atmosphere and the oceans. These actions by nations will require great determination and adequate material resources, and they will be meaningful only in a world at peace.*

Through the1979's Conference and Declaration, climate change has been identified as an autonomous public problem to be addressed by the establishment of environmental policies to combat desertification, deforestation and pollution. Further the participants of the Conference founded the World Climate Program, under the joint responsibility of the World Meteorological Organization (WMO), the International Council of Scientific Unions (ICSU) and the United Nations Environment Program (UNEP), to address needs in research, data collection, climate services and impact assessment. By defining climate change as an environmental problem the UNEP appeared as the most suitable international institution to propose specific policy measures.

The WMO, insuring the scientific expertise, and the UNEP, insuring the policy expertise, became the main institutional actors on the domain. Their environmental perception of climate change gave to the U.N. policy approach a double orientation. *First*, the importance is given to the causes of the problem and more insistently to greenhouse gases and CO2 emissions, one of the most studied issues for the scientific community of climatologist. Jointly, the WMO, UNEP and IUSC organized in 1980 a meeting on "CO2-induced climate change" followed by the 1985's "International Conference on Assessment of the Role of Carbon Dioxide and of Other Greenhouse Gases in Climate Variations and Associated Impacts". Since, CO2 and GHG emissions have been defined as the main cause of global warming. *Second,* mitigation measures are considered as the most suitable response for combating the causes of climate change. This is the dominant approach not only of the Intergovernmental Panel on Climate Change (IPCC), created by the UNEP and the WMO, but also of the United Nations Framework Convention on Climate Change (UNFCCC) directly influenced from the IPCC's reports. The ultimate objective of the Convention and its related legal instruments announced at the article 1 is "to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". In reference to the Kyoto Protocol, its main official objective is to "sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas emissions". Although some work on adaptation has been made by UNFCCC and the Kyoto Protocol established the adaptation fund, mitigation remained the priority for climate policy.

The dominant environmental perception of the 70s and 80s, giving priority to the causes of climate change and to mitigation strategies started declining during the 90 and the beginning of the new century confirmed the trend. This is not only due to the lack of engagement by certain big GHG-emitter countries and in relation to the inappropriate application of the emissions trading system. It is also, and probably most, due to the diversity of the policy actors who at present support competing definitions of the climate change issue.

3/ Alternative definitions: climate change as a challenger for the humanity's wellbeing

Stripple notes that global climate governance is marked by a multiplication of functional interlinkages and communication channels, apparent in the observation that the future of global climate governance is currently negotiated in different and often non-synchronized discussion fora (Stripple, 2008). The authors put the accent to the institutional complexity of climate governance and presume that under the designation "climate change" all the actors at presence discuss about the same policy issue. Yet, while discussing about 'climate change' different policy communities perceive different problems. This makes the convergence towards a common policy scenario very uncertain.

Mee remarks that the post World Summit on Sustainable Development (WSSD) agenda has moved strongly towards a debate on how to deliver sustainable development rather than how to protect the environment *per se* (Mee, 2005). Indeed, from the 90s' global warming knows a slow definitional shift at the international agenda: from an autonomous environmental problem whose causes (particularly CO2) must be combated, it starts be discussed as the cause of other international public problems threatening the humanity's wellbeing (mostly poverty, migration, security).

Different UN agencies and other international organizations, with no environmental competency, enter the debate. Their concern is not how to mitigate air pollution but how to adapt to a changing climate in order not to aggravate under-development, to administer population's displacement and prevent the emergence of conflict over scarce resources. International organizations are not alone participating to this process. At the same time new scientific communities of social scientists) get interested at the climate topic and produce new research that defy the dominant climate surveys and put the accent on risk assessment and adaptation.

a) The diversification of scientific knowledge

Climatologists are the main scientific community for the study of climate change until the 80s' and are still dominant inside the IPCC working groups. If climate science is the only relevant to make assertions about the evolution of the earth's climate it is not the best suited to analyze human behavior in relation to the changing environment. However, in order to politically establish the urgency of the climate issue, the IPCC reports not only proceed to the scientific assessment of Climate Change but also consider the social and economic impacts of global warming for developed and developing countries and the policy options available. These analysis served as a starting point for the development of many researches in social sciences dealing with the human dimension of climate change. As (Yearley, 2009) remarks, the IPCC was clear that global climate change could not be studied in the absence of social science analyses, particularly economics. The last two decades economists but also, geographers, policy scientists and sociologists showed growing interest for research on climate impacts, social vulnerability and policy making.

If at the post-WSSD period the international community, NGOs' and local governments directed their interest towards the impact-adaptation scenarios, the progressive availability of social science studies focusing on the human dimension of climate change reinforced, that tendency. Simultaneously, IPCC's fourth assessment report "Climate Change 2007" (WG I) concluding that "warming of the climate system is unequivocal" and that "impacts can't any longer be seen as hypothetical outcomes", pushed in the same direction. At the opening meeting of the International Human Dimension Programme on Global Environmental Change in 2009, a physicist of the Potsdam Institute for Climate Impacts Research suggested that 90% of research [on global change] should be done by the social scientists.

The considerable growth of social science studies the last ten years did not constitute a unified domain of 'social climate studies'. Instead, deferent preexisting research communities adapted the climate topic to their traditional research inquiry. Consequently, each one serves as an intellectual background nourishing different alternative definitional frames of the climate change.

b) The development perception

During the Second World Climate Conference in Geneva, in 1990, it became clear that there was a 'North-South' divide on how developed and developing countries viewed climate change. For the former it was primarily a scientific and environmental issue, while the latter emphasized the implications for poverty and development of any future regime. Developing countries considered that the new legal instrument should not obstruct their economic development (Boisson-de-Chazournes, 2008).
Indeed the declarations of the Group of 77 (and particularly the least developed countries) call for efforts to address climate change not as an environmental issue but as a development issue: climate policy must enhance and ensure the sustainable development, promote economic growth of the developing countries and the eradication of poverty, hunger and disease. As far as the international community continues to adhere to the Principle of Common but Differentiated Responsibility, mitigation is not absent from the G 77 discourse. However its principal claim concerns the obligation of developed counties to support adaptation of developing countries by warranting financial and technological assistance.

Contesting the dominant environmental perception, the G 77 succeed for the first time to marginalize the WMO and the UNEP by imposing an International Negotiating Committee (INC), working under the auspices of the UN General Assembly, to lead adoption process of the UNFCCC. Even if, as Levy and Downie (LevyD.L. & Downie & M.A., 2000) argue, the UNEP is heavily involved in the climate change regime, the fact that the negotiations were not under the responsibility of an environmental agency served a window of opportunity for the UNDP which have played until then a marginal role to climate negotiations.

L.D. Mee remarks that until the 90s' and although involved in several high profile relief efforts, "UNDP's work had little environmental emphasis – so little that it only received a single passing mention in the 1987 Brundtland report" (Mee, 2005). The development-oriented discourse of developing countries legitimized the UNDP as a new UN partner to climate policy making. Simultaneously, the agreement with the World Bank in April 1991 to become a partner in the newly created Global Environment Facility (GEF) and the active participation in the UN Conference on Environment and Development confirmed the entrance of the UNDP to the environmental agenda. The nomination of the environmentalist James Gustave Speth from 1993 to 1999 as Administrator of UNDP has also contributed to the UNDP's environmental turn. Mee points out that Speth was a strong advocate of the concept of 'mainstreaming' the environment into all aspects of UNDP's work rather than through separate streams of finance or operational units.
If the environment was no longer seen as an enemy but as a partner for 'sustainable' development, particularly since the Rio Conference, the concept of sustainable development reflects, however, the integration of the environment into the need for development and not vice versa. The participation of the developing countries to the global environmental governance has also contributed to this evolution in, most significantly by turning the global environmental discourse from what 'global environmental politics' into 'global politics of sustainable development' (Najam, 2005). The reinforcement of the UNDP's role and the pressure exercised by the G77 considerably strengthened the perception of climate change as a development problem and put the emphasis on adaptation measures.

The 2007-2008 Human Development Report entitled "Fighting climate change: Human solidarity in a divided world" represents the new definition of climate change at the international arena. From an ecocentric approach, climate change is considered through an anthropocentric approach that puts the accent most to the impacts of global warming than to its causes, most to human vulnerability than to ecosystem equilibrium: "*The battle against dangerous climate change is part of the fight for humanity*". The redefinition in based on the assumption that "*The world is already committed to further warming because of the inertia built into climate systems and the delay between mitigation and outcome*". Thus, adaptation appears as the most relevant climate policy strategy "*For the first half of the 21st Century there is no alternative to adaptation to climate change"*. It is therefore suggested to *"Put* *climate change adaptation at the centre of the post-2012 Kyoto framework*" (UNDP Human Development Report, 2007-2008). For Y. Zhang (2009) the notions of climate adaptation and development are hard to distinguish. If the term adaptation is used, this is because of funding purposes as developing countries require adaptation financing to be new and additional to the traditional Official Development Assistance. On the contrary mitigation is seen for developing countries as irrelevant and dangerous if not sustained financially by developed countries.

This conceptual shift is also reflected in the changing titles of the three IPCC Working Group II assessment reports completed between 1990 and 2001 : 1990: *Impacts Assessment of Climate Change* ; 1995: *Impacts, Adaptation and Mitigation of Climate Change* ; 2001 and 2007: *Impacts, Adaptation and Vulnerability*.[18] The emphasis is consequently put on the most vulnerable regions, which generally coincide with the poorest regions lacking the necessary infrastructures to cope with the effects of global warming (droughts, floods, extreme weather events). In other words, the environmental policies no longer appear as the principal response to the problem. Development projects offering improved resilience to vulnerable regions start to be seen as the principle instrument for climate policy (Vlassopoulos, 2010).

The climate discourse of developing countries and the UNDP mutually reinforce each other and both profit from the growing social sciences bibliography on social vulnerability and development that is focussing on the links between the human condition and the changing environment. The development-vulnerability discourse is not however the only one defying the environmental perception promoted by the UNEP, the WMO and the UNFCCC secretariat. Other policy communities give alternative definitions that further legitimize the anthropocentric view of climate change.

c) The migration perception

Environmental migration constitutes a research issue for Migration specialists since the 80. The UN report of El-Hinnawi in 1985 has identified different causes of environmental migration as dam construction, industrial accidents, natural disasters, etc. Only recently the scientific community, NGO's and international agencies have put more precisely the accent to what they call a 'climate migrant" (Felli, 2008). European Greens has also concentrates their discourse on climate migration[19]. This growing attention must be linked to the Summary for policymakers of the IPCC's Working group II that mentions 'the potential migration' in the areas affected by climate change (IOM, n° 2008).

Migration studies and debates perceive climate change as a cause for people's displacement. Forced displacement is thus considered as the main problem to deal with and the environmental dimension is marginalized. The main questions treated by social scientists in that field are in relation to the number of environmental refugees, their distinction to other refugees and their legal protection. N. Myers was one of the first scientists estimating the number of people that will be forced to migrate because on environmental reasons and his writings considerably influences the public debate.

The 2007/2008 UNDP report on 'Fighting climate change' contains only one reference to migration. The argument is that if development and adaptation are not seriously considered migration will become a threat for human development across the developing world: "*Losses of productivity linked to climate change will increase inequalities between rainfed and commercial producers, undermine livelihoods and add to pressures that are leading to forced migration*". The climate-migration debate is more actively engaged by the International Organization for Migration (IOM) and more recently by the United Nations Refugee Agency (UNHCR). Both put the accent to the human impact of global warming.

The IOM, based on the latest IPCC reports (that predict temperature increases throughout the globe), directing its approach on people's livelihoods, especially in poor and vulnerable areas. It accepts that the linkage between climate change and migration is not yet clearly established and promotes further researches and public debate. The IOM promote itself as the most suitable international institution to prevent, organize and manage environmental migration in general and climate migration in particular (IOM, 2009). One of the approaches is to consider migration not only as a negative climate impact to combat but also as a proactive adaptation strategy that helps prevent human suffering in vulnerable areas.

The UNHCR responsible for asylum policy around the world left itself out of the 'environmental refugee' debate until the climate-migration nexus was formulated. Since, it defines climate change as a humanitarian problem that must be dealt as such by the U.N: "*climate change is likely to pose humanitarian problems and challenges.* […] *UNHCR would encourage more reflection on the humanitarian and displacement challenges that climate change will generate* […]. *As such it is of direct interest to humanitarian agencies, including the Office of the United Nations High Commissioner for Refugees*" (Guterres, 2008). Alike the IOM, the High Commissioner of the UNHCR claims a leading role in

[18] http://www.adaptation.nrcan.gc.ca
[19] See Conference on Climate Refugees at the European Parliament, the 11 June 2008 and subsequent Declaration.

climate-migration policymaking. As it has jurisdiction not only for internally displaced persons (IDP) but also for forced migration beyond the national frontiers, it appears like the most appropriate organization to deal with climate migrants in the field: "*UNHCR is a leading agency of the United Nations responsible for and possessing the expertise in the area of forced displacement. It is projected that climate change will over time trigger larger and more complex movements of population, both within and across borders, and has the potential to render some people stateless. Since climate change is certain to have a major impact on future patterns of human mobility, approaches which address environmental issues in isolation from other variables and processes will not be sufficient to solve the problem* […] *It is clear…that some movements likely to be prompted by climate change could indeed fall...within UNHCR's mandate*" (Guterres, 2008). Therefore, a "UNHCR's climate change strategy" is announced by its High Commissioner.

d) The securitization of climate change

The definition of climate change as a migration issue has generated further interest on the behalf of security specialists who propose an alternative definition of climate change as a security problem. The dominant argument is that if climate change generates large scale human displacements, these migration flows are expected to cause conflict and insecurity for displaced people as well as for hosting communities. In that sense, N. Myers argues in 1984 that "*Migration flow will become an important source of insecurity around the world*".

This additional framing strengthens the anthropocentric approach of CC for at least two reasons. *First*, security discourse puts the accent to people's conditions of living and not to the quality of the environment per se. Human and environmental security are not two different issues. Like economic development, food availability, health conditions, political conditions, the environment is a component of "human security" (UNDP, 1994, 22-25). In order to avoid that vulnerability becomes a threat for human security, the majority of measures that have been advocated are development measures, typically those that are associated with the international development agencies (Christie, 2007). In that sense, the securitization of the humanitarian and development organizations should not be a surprise. Indeed, the UNDP's report on Human security is one of the first in 1994 to connect global warming to security by defining 'human security' as the need to shift attention from state centered to people centered security issues and by presenting environmental change as one of the major stressor for human security. In the same direction, the UNHCR recognizes that: "*Climate change is already undermining the livelihoods and security of many people*" (Guterres, 2008). In 2009 during the Global Environment Forum in Korea the Secretary General of the U.N. warned that "*If we fail to act, climate change will intensify droughts, floods and other natural disasters… Tensions will worsen. Social unrest – even violence – could follow*"[20]. Under these conditions, the environmental specialists and NGOs, originally attracted by the idea of "environmental security" thinking that it could make obvious the urgency for more efficient environmental measures, have denounced the militarization of the issue (P.H. Liotta, 2007).

Second, new institutions are added at the list of non environment-relevant organizations seeking for participation in climate framing and policymaking. Since 2004, NATO joined five other international agencies to form the Environment and Security (ENVSEC)[21] Initiative and from 2009 is challenging a leading role in climate security. Having lost much of its importance after the end of the cold war, NATO has found in climate issue a new 'raison d'être'. Its Secretary General, in his speech at Lloyd's Conference in 2009, recognized that the changing climate have potentially huge security implications and called for a change in the dominant approach. He further invited the organization's allies to discuss on "*how NATO could do better to address the security aspects of climate change*" (NATO-News, /2009)[22].

4. In lieu of conclusion: United Nations delivering as one?

Under the leadership of the Secretary-General of the United Nations, the United Nations System Chief Executives Board for Coordination (CEB) has initiated a process, known as the "UN system delivering as one", to achieve a coordinated action-oriented approach to the global and multifaceted challenge of climate change (UN-CEB, 2008)[23], Ban Ki-moon reminded during the Copenhagen side event "The U.N. delivers as one" that: "*no one has monopoly to deal*

[20] http://www.un.org/apps/news/infocus/sgspeeches/search_full.asp?statID=557

[21] The five other agencies are: the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP), the Organization for Security and Co-operation in Europe (OSCE), the United Nations Economic Commission for Europe (UNECE) and the Regional Environment Center for Central and Eastern Europe (REC). NATO collaborates mostly with the UNDP as both organizations have agencies to the local level.

[22] http://www.nato.int/cps/en/SID-47090647-599A4E35/natolive/news_57793.htm?selectedLocale=en

[23] http://www.un.org/climatechange/pdfs/Acting%20on%20Climate%20Change.pdf

with climate change". However the expected unity does not seem to be shared by the different international agencies .

Before the Copenhagen meeting, the humanitarian and development UN agencies (UNDP, UNHCR, FAO, OCHA, WFP, WHO, UNFPA, UNICEF, UNHABITAT) with the IOM, the World Bank, and humanitarian NGO (ICRC, ICVA, IFRC, InterAction), as parts of the Inter-Agency Standing Committee (IASC), addressed in April 2009 a letter to the Yvo de Boer, Executive Secretary of the UNFCCC, asking for "*the humanitarian implications of the climate change to be duly acknowledged and addressed in successor agreement to the Kyoto Protocol*". They also claimed the establishment of "*a joint action considered as the only way forward*" and affirmed their determination to *"continue to engage with climate change community and all other relevant stakeholders to identify and implement solution that climate change presents to humanity*".

The growing influence of the anthropocentic perception of climate change is visible since 2007 with the adoption at the COP 13 of the Bali Action Plan which can be considered as the first consensus document identifying adaptation "as one of the key building blocks required for a strengthened future response to climate change"[24]. The representation of climate mitigation and adaptation as parallel processes is also observable in the IPCC's fourth assessment report (K. Bäckstrand & E. Lövbrand, 2007). The Copenhagen Accord gives as well equal importance to climate impacts and adaptation and to climate origins and mitigation. However the institutional frame responsible for the negotiation of the post Kyoto protocol remains the same. As said in the 2008 CEB publication at "*the high-level event on climate change, convened by the United Nations Secretary-General on 24 September 2007 to galvanize political consensus, … world leaders … concurred that the United Nations provides the appropriate multilateral framework for action and that the United Nations Framework Convention on Climate Change is the only forum in which agreement can be crafted on the objectives and scope of international action*". This position does not meet the new balance of power between policy actors. Kasa and co-authors note that developing countries refuse to discuss new commitments under the UNFCCC and the Kyoto protocol (S. Kasa, 2008). As a UNDP representative put it: "*If environmentalists continue to pilot the post-Post Kyoto negotiations no agreement can be achieved. Climate change today is something much larger and goes beyond environmental degradation*" (personal interview, 2010). While governments, international institutions and the scientific community continue their dissonant discourse the problem definition process remains unaccomplished and consequently policymaking cannot be established.

[24] http://unfccc.int/adaptation/items/4159.php

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THE ROLE OF THE GREEN QUOTA AND REVENUE RECYCLING SCHEMES IN THE CLIMATE CHANGE OPTIONS: A DYNAMIC GENERAL EQUILIBRIUM ANALYSIS FOR AUSTRIA

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ABSTRACT
Through simulations with dynamic equilibrium model the long term impacts of two alternative policy instruments for responses to climate change were assessed, namely, the green quota and double dividend hypothesis. Electricity demand growth was de-coupled from the economic growth. 3 economic sectors, 5 existing and three new vintage electricity production technologies were considered.

By 2050 the share of renewables in the electricity production could be reaching 0,289 and there are sufficient potential renewable resources. The economic burden is bearable and the welfare is growing.

The double dividend hypothesis check (trade-off b/n environmental benefits and gross economic costs): reduction in the labor tax is increasing consumption; reduction of consumption tax is doing to a lesser extent so but the reduction in the lump-sum refund to the representative household is detrimental to consumption.

Hence, only for the case of labor tax recycling, the existence of a strong double dividend could be assumed.
Keywords: climate change, CO_2 taxation, abatement strategies, general equilibrium models
JEL Classifications: D58, Q32, Q43, Q56

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Introduction

The aim of the paper is to quantitatively assess the macroeconomic and sectoral impacts of possible responses to climate change in Austria.

At first place this is done by evaluating mitigation options for increased market penetration of electricity produced from renewable energy sources.

In addition some aspects of the **adaptation** strategies related to energy and resources conservation in the sense of sustainable development have been explored and particularly the de-coupling of electricity demand from the economic growth.

In the long-term **mitigation** options for the electric power sector will focus on CO_2 reduction by the mean of a set of the technological options with strong CO_2 reduction potentials.

To grasp synergies in climate change policies the adaptation and mitigation options must be analyzed within a consistent, dynamic framework allowing for carrying out of integrated analyses of alternative scenarios for adaptation and mitigation.

Mitigation and adaptation policies should be assessed on their full effects and their quantification calls for the use of the newly developed Top/Down -BU for Bottom-up E3 (energy, environment, economy) dynamic general equilibrium model (TD-BU-E3 DGEM) allowing for systematic trade-off analysis of environmental quality, economic performance and welfare (consumption).

As to policy measures related to mitigation by promotion of renewable energies there had been a shift - as more generally in environmental policy design - from command-and-control policies to market-based instruments such as taxes, subsidies, and tradable quotas. A recent impact assessment by the European Commission, 2008, shows that feed-in tariffs in Austria are the preferred promotion measure. In addition, direct subsidies for renewable energy have been enacted – typically differentiated by the type of green energy, i.e., wind, biomass, solar cells, etc.

A relatively new regulation policy is the use of tradable green quotas where energy supplies are required to produce a certain share of energy services from renewable energy but are flexible to trade these shares between each other in order to exploit potential difference in specific compliance costs.

This paper focuses on two alternative policy instruments that may be quite relevant to the Austrian strategy for promotion of renewable energy sources namely

1. Quota obligation systems and
2. Carbon Taxation (double dividend) instruments.

Methodologically the focus is set on novel CGE (Computational General Equilibrium) modeling approach, frequently quoted as Top-Down part of the model. The objective is to describe in a consistent way within a overall analytical economic modeling framework the Bottom-Up part of the model, namely the role of the specific energy technologies.

CGE is used as an analytical Top-Down part that is enhanced by representation of specific technology descriptions in the Bottom-Up part of the model.

The paper is structured as follows: Section 2 provides a background to the TD-BU-E3 DGEM and its algebraic representation in the MCP framework, followed by the required adjustment to the study's specifics and then an application to the particular case studies in Section 3 that is dealing with Scenario definition and policy analysis starting with benchmark assumptions, then the description and analysis of the Baseline Scenario followed by the Green quota scenario and respective analysis and ending with the Carbon Taxation (double dividend) Scenario. Section 4 concludes.

The TD-BU-E3 DGEM

Our modeling and programming work was motivated by recent theoretical and practical developments in algorithms for nonlinear complementarity problems and variational inequalities based on the GAMS/MCP modeling format (Rutherford, 2002).

The TD-BU-E3 DGEM (here TD stands for Top/Down, BU for Bottom-up, E3 for energy, environment, economy and DGEM for dynamic general equilibrium model) provides a basis for evaluating economic impacts of the chosen energy policies both at macroeconomic (sectoral) and technological level. The modeling period is between 2005 (year of calibration) till 2050.

The hybrid approach permits an energy-economy model to combine technological details of an energy system (bottom-up) with a characterization of the overall economy market equilibrium (top-down).

: The TD-BU-E3 DGEM model as a representation of the economy

In our formulation of an integrated top-down / bottom-up model we consider a competitive (Arrow-Debreu) economy with n commodities (including economic goods, energy goods and primary factors) indexed by i, each attached with a price, m production activities (sectors) indexed by j, attached with an activity level, and one infinitely lived representative agent, or household. We also include the notion of perfect foresight, meaning that agents in the model know as much about the future as the modeler. This concept is put into a dynamic intertemporal setting, using the standard Ramsey model of savings and investments.

The household, or representative agent, maximizes intertemporal welfare (utility), which is a composite of goods consumed and leisure, subject to the budget constraint. Income is determined by labor and capital income. Economic sectors (macroeconomic and energy sectors) are cost minimizing activities, which produce output according to consumption demand, using primary factors, electricity and other energy goods as inputs. The Market clearance conditions imply that no good with a positive price is in excess demand, and all consumer demands are met, hence all markets are cleared. Each of the sectors produces a different good, therefore, in order to ensure perfect competition we assume that no sector makes a positive profit, by the so called zero profit condition (costs equal revenues).

: Notion on the algebraic representation of the TD-BU-E3 DGEM in the MCP framework

We are using the Mixed Complementarity Programing framework suggested by Boehringer (2007) formulation of market equilibrium problems as mixed complementarity problems (MCP) thus permitting integration of bottom-up programming models of the energy system into top-down general equilibrium models of the overall economy.

Competitive market equilibrium for the economy is represented by the following set of decision variables together with their complementarity conditions:

y is a non-negative m-vector for activity levels of constant-returns-to-scale (CRTS) production sectors,

p denotes a non-negative n-vector in prices for all goods and factors,

M is a scalar, denoting consumer income level,

- **Zero-profit condition**: No production activity makes a positive profit.

$$-\Pi_j(p) \geq 0 \qquad (1)$$

Where $\Pi_j(p)$ denotes the unit profit function (unit revenue minus unit cost) for constant returns to scale production activity j, y is the associated complementarity variable.

- **Market clearance conditions:** Excess supply is non-negative for all goods and factors.

$$\sum_j \nabla\Pi_j(p)\cdot y_j + \omega \geq d(p,M) \qquad (2)$$

Here ω indicates the initial endowment vector and $d(p,M)$ is the utility-maximizing demand vector, of the representative agent. The associated complementarity variable is p.

- **Income balance**: Household expenditure does not exceed income.

$$M = p^T \cdot \omega \qquad (3)$$

The equation which defines consumer income level is conceptually distinct from the zero profit and market clearing conditions in that there is no explicit complementarity at work in this part of the model. The income variable is added to the equilibrium system solely as a means of simplifying the expression of household demand.

The concept of complementarity is crucial here. A decision variable (an activity level or a price) can only be strictly positive if the associated complementarity condition (zero profit or market clearance respectively) is zero and vice versa. Hence in equilibrium a good in excess supply has a zero price, and any activity earning a negative profit is idle.

For calibration of the TD-BU-E3 DGEM we make use of the three sectoral social accounting matrix for 2005, which is derived from Austria's input-output table of Statistic Austria:

Households as a representative agent (+ **government** for redistribution) three non-energy sectors:

X1 - Agriculture,

X2 - Energy intensive goods,

X3 - Other goods

Some additional assumptions:

Intertemporal elasticity of substitution	0,5
Baseline interest rate	2 %/year
Baseline growth rate	0.9 %/year
Depreciation rate	7 %/year

The top-down nesting structure of the production functions is exemplified in Annex 1.

Specified data on the energy sector, used in the bottom-up part of the model, is derived from the Austrian input output table as well as the energy balances of Statistic Austria, which are both given in Annex 2.

scenario definition and policy analysis

Some technological considerations

For electricity production in the TD-BU-E3 DGEM we have eight different technologies, divided into existing and new vintage technologies, and also categorized as renewable (or green) or not renewable.
Three conventional primary energy sources:

Oil, Gas, Coal (COL)

The renewable energy forms are represented by

(1) **Hydro power**

(2) Wind engines: existing and new types

(3) Fuel Wood for space heating and power production

(4) Advanced technologies for biomass use, e.g. liquefaction

(5) Advanced photovoltaic devices

The relative prices per unit of electricity produced have been ranked from the cheapest, hydro power, to the most expensive, new solar photovoltaic - assumed to be 2.2 more expensive

At the Figure 1 the benchmark production shares of the existing technologies for the year 2005 are shown.

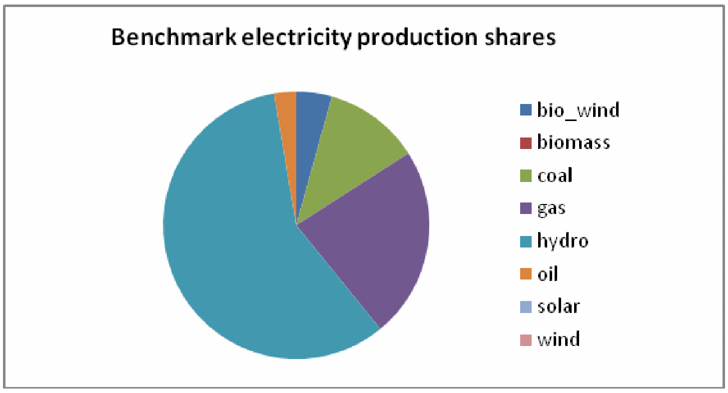

Figure 1: Benchmark electricity production shares

We made assumption that the existing power plants will be functioning in the future till the end of their useful life and the new technologies will be entering the market after the old have exhausted the limit of their resource allocation.

For the existing Bio-Wind technology we have imposed a limit at a level of 2.5 times the value of its benchmark electricity production.

Similarly, based on the limiter resource availability, the Hydro Power production was limited to 1.4 times its benchmark production level.

According to the trend analysis the production of the coal power plants does not change much and oil power plants are going out of market.

For the period up to 2040-2050 the new renewable technologies have an imposed potential of their maximal contribution to the total electricity production, namely, the new Wind - 7%, new biomass - 15%, and the new solar - 20%.

The relative prices per unit of electricity produced for the technologies have been ranked from the cheapest, hydro power, to the most expensive, new solar which is assumed to be 2.2 more expensive than the hydro. The other technologies are lying in between this range.

The advanced renewables are assumed to be not active at the beginning of the period mainly because they are supposed to be technologically available at a later stage and because they are relatively quite expensive.

Baseline Scenario

Scenario assumption related to the **adaptation** is the de-coupling of electricity demand from the economic growth. This is assumed to be done by energy and resources conservation in the sense of sustainable development, by changing consumption pattern and habits, etc. – all that are long term measures related to socio economic changes.

The growth of total electricity production, shown at Figure 3, is assumed to be 0.7% per year, hence decoupled from the assumed economic growth of 0.9%/year. Just for comparison – till 2008 electricity demand in Austria were growing with 1% per year.

The Scenario assumptions for the main fuel inputs in the power production till the year 2050 are based on energy supply analysis by Kratena and Wrüger (2005) (Figure 2).

The main features of this scenario are:

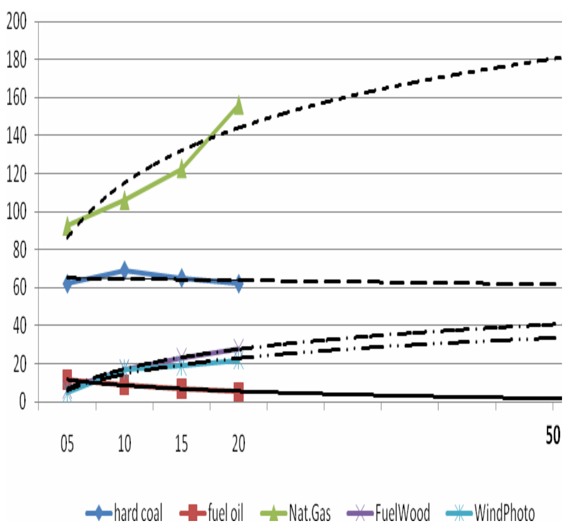

Figure 2: Assumptions for the main fuel inputs till the year 2050 (in PJ)

As said the growth of total electricity production, at Figure 3, is assumed to be decoupled from the economic growth of 0.9%/year so that we are coming to a growth index of 1.64 for electricity production over the 50 year period.

In the baseline scenario renewables will increasing their part of the production but at the historical growth rate – reaching approximately 9% by 2050.

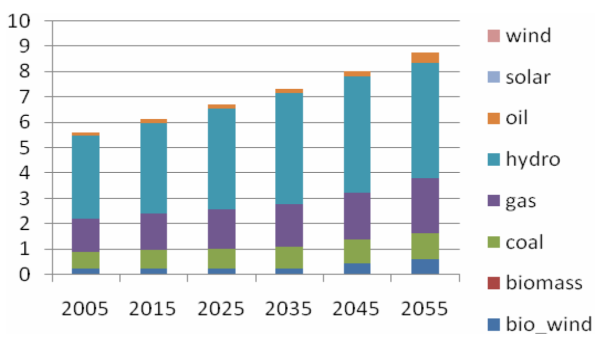

Figure 3: Structure of the power production

- doubling the natural gas input for power production,
- hard coal use - almost constant,
- quadrupling the wind and biomass use and
- gradual extinction on fuel oil use in the power plants.

The quadrupling of fuel wood and wind electricity seem to be realizable because the available wind energy potential has been evaluated at 14 - 50 PJ and the fuel wood availability at 30 Mio m3 or 232 PJ (Hantsch and Moidl, 2007; Balabanov, 2008).

Green quota scenario

A part of the integrated energy and climate change policy guidelines, as adopted by the EU in December 2008 (DG for Energy and Transport 2008), is the obligation by the member states for covering an average of 20% of their total energy needs from renewable sources. Therefore each country agreed to fulfill a different renewable energy quota by 2020.

The target for Austria by 2020 is 34% whilst for the year 2005 it was 23.3% of the total energy use. In so far as this target is recognizing the hydro power as green energy and the *Hydro share for 2020 is projected to be 14.73%* in fulfilling the quota obligation an accelerated growth rate of other renewables would be need in order to reach around 20% by 2020 which is seen by WKOE (2008) as difficult.

The **green quota scenario** is simulating the structural change in power producing technology mix needed to achieve a 30% share of renewables (without hydro) in the electricity production by 2050

By running the TD-BU-E3 DGEM under the above assumption we have as an output the changes in the main indicators as shown at Figure 4.

The growth of the power production indexed with 1.66 is following quite closely the scenario assumption and around 2030 there is a small bump.

This is result of the exhaustion of the conventional hydro and bio-wind resources and the slum is due to the significant subsidies needed for the start up of the new wind and biomass technologies.

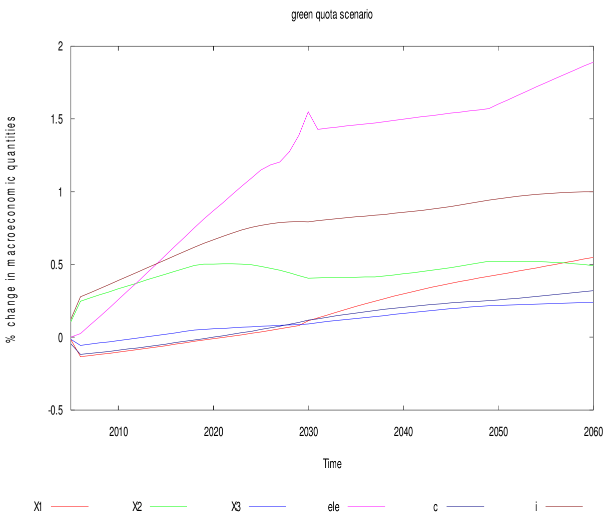

Figure 4: Model output for the main indexes

The accelerated development of the agricultural sector (X1) is a result of the demands of agricultural inputs by the biomass technologies while heavy industry´s production (X2) is slightly declining due the general trend in exporting/downsizing the energy intensive industries.

The growth of investment is following closely the growth of the electricity output and this is due to the high capital intensity of the power sector. It is quite indicative that the consumption is growing, albeit at a lower rate, despite the significant investment demand.

Here is to be said that by 2030 the share of renewables (without hydro) in electricity production is reaching 0,184 and by 2050 - 0,289.

To summarize: Achieving the quota of close to 30% by 2050 is feasible and there are sufficient quantities of potential renewable resources for that purpose.

It also seems that the economic burden is bearable and the welfare is growing.

The next figure shows the electricity production structure by the different technologies in TWh for graphical reasons the dominating Hydro power production is not shown at Figure 5, since it would be depressing the view. The scenario run resulted in steady increase of hydro power production of up to 50 TWh by 2020 when in it reaches its imposed production limit.

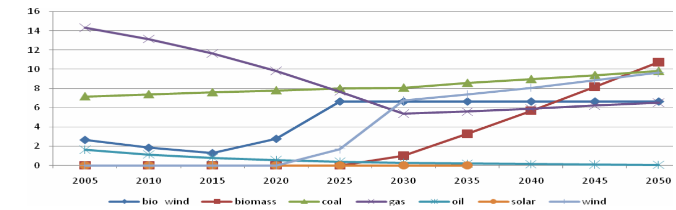

Figure 5: Production (in TWh) of the conventional and renewable energy technologies

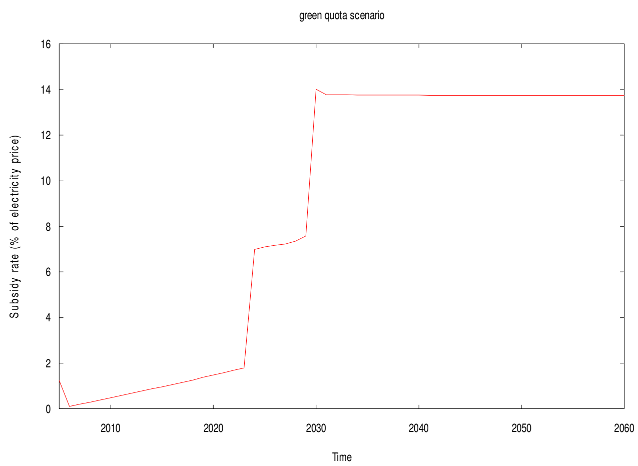

Figure 6: The subsidy rates for the green technologies

Few years later – by 2025 - the bio-wind is also reaching its production limit which results in the output rise by the conventional bio-wind technologies and that is opening the way to entering the market for the new wind and new biomass – the so called backstop technologies.

This start up of the new and expensive technologies result in a jump of the subsidy rate for green technologies, see Figure 6, first in 2025 at the level of 8% from the electricity production cost. When new Vintage reaches its potential, in 2030 there is another jump in subsidy rates reaching to 14%, so that new biomass technologies could start producing electricity.

As a result of these developments by 2030 the share of renewables in the electricity production (including hydro) is reaching **0,825** or without hydro **0,184** and by 2050 the same share without hydro is **0,289,** while the share (including hydro) remains at 0,825.

Carbon Taxation (double dividend) Scenario

The **greenhouse gases** are measured in megatons of Carbon dioxide equivalency (MCO_2eq) and there are a number of alternative tax instruments for reducing its emissions.

Carbon dioxide equivalency is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (**GWP**), when measured over a specified timescale (generally, 100 years). Carbon dioxide equivalency thus reflects the time-integrated radioactive forcing, rather than the instantaneous value described by **CO_2e**.

For example, the GWP for methane over 100 years is 25 and for nitrous oxide 298. This means that emissions of 1 million metric tons of methane and nitrous oxide respectively are equivalent to emissions of 25 and 298 million metric tons of carbon dioxide.

Over the last decade, several EU Member States have levied some type of carbon tax in order to reduce greenhouse gas emissions from fossil fuel combustion contributing to anthropogenic global warming (OECD 2001). In this context, the debate on the **double dividend** hypothesis has addressed the question of whether the usual trade-off between environmental benefits and gross economic costs (i.e. the costs disregarding environmental benefits) of emission taxes prevails in economies where distortionary taxes finance public spending. Emission taxes raise public revenues which can be used to reduce existing tax distortions. Revenue recycling may then provide prospects for a double dividend from emission taxation (Goulder 1995):

The **double dividend** of CO2 taxation is:

1st dividend: the improvement **in environmental quality**, and

2nd dividend: finding the best, in terms of welfare gains, of the alternative ways of recycling the additional tax revenues for a revenue-neutral cut of existing taxes. The additional carbon tax revenues can be allocated in three different ways: 1. Labor tax reduction; (labeled as "**TL**"); 2. Cuts in the consumption tax; (labeled as "**TC**"); 3. Lump-sum refund to the low income part of the households (labeled in the Figure as "**LS**")

If – at the margin – the excess burden of the environmental tax is smaller than that of the replaced (decreased) existing tax, public financing becomes more efficient and welfare gains will occur.

The setting of TD-BU-E3 DGEM for simulating Carbon Taxation Scenario differs slightly from the original setting for the Baseline Scenario, e.g., final consumption is being split into public (governmental) and private (household) consumption, where public consumption is estimated at a level of 25% of total consumption.

Therefore a new production activity is defined, indicating a public good (e.g. infrastructure, healthcare, etc.), which is then consumed by the Private households or firms in the economy.

In our dynamic policy simulations, we investigate the economic effects of carbon taxes that are set sufficiently high to reduce carbon emissions by 20% compared to the base year emission level.

The Figure 7 bellow is showing the rate of decarburization of the produced electricity, namely the reduction of CO2 emissions per TWh of produced electricity.

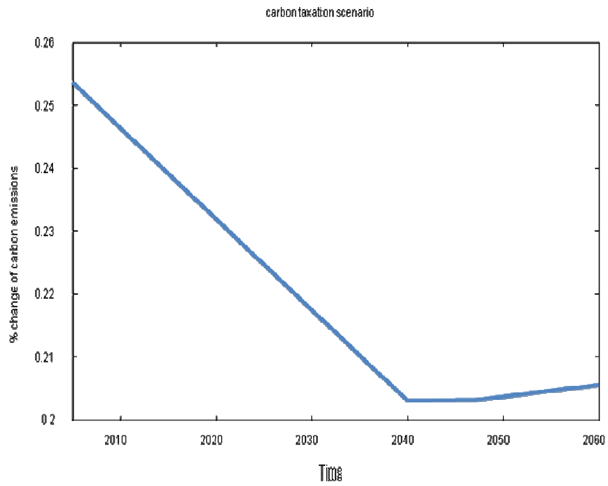

Figure 7: Trajectory of CO2 emissions per unit electricity produced

The main outcomes of our dynamic simulation, Figure 8, are:

- In the case of reduction in the distortionary labor tax (**TL**) the consumption levels are increasing over a long period of time.
- To a lesser extend the same applies to the case of a cut in the distortionary consumption tax (labeled as "TC")
- The reduction in the distortionary lump-sum refund to the representative household (labeled as "LS") tends to reducing consumption and respectively the welfare.

In line with the undisputed weak double dividend hypothesis (Goulder 1995) - the reduction of the distortionary consumption or labor taxes (TL) is superior in efficiency terms to both the consumption tax (TC) and to the lump-sum recycling of carbon tax revenues (LS).

Hence, only for the case of labor tax recycling (**TL**), we could assume the existence of a strong double dividend.

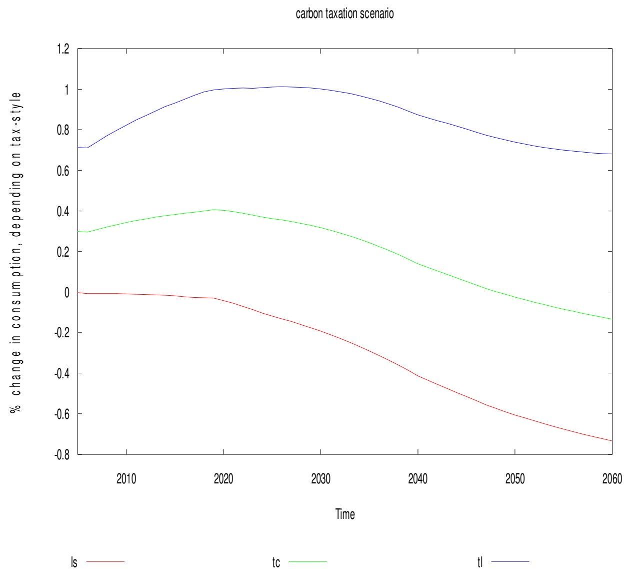

Figure 8: Carbon Taxation Scenarios

Figure 9 shows the associated carbon tax rates, or the marginal abatement cost (MAC), to achieve the target emission reductions.

The computed maximum MAC of bellow EUR 100 that correlates very well with other multi country studies for the EU region, e.g. the Marginal Abatement Costs (MAC) levels have been estimated by the EU´s "Impact Assessment of the EU's objectives on climate change and renewable energy for 2020" (EC 2008) to be around € 90/t CO2.

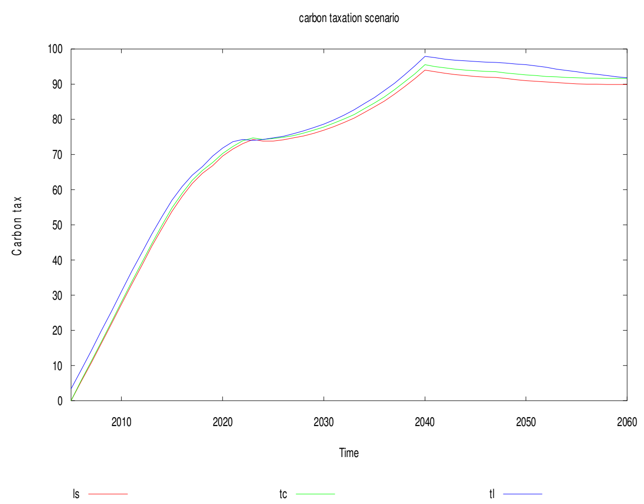

Figure 9: Dynamics of the carbon tax rates/MAC

MAC – as the direct incentive for emission mitigation in production and consumption – increase with the stringency of the emission constraint but hardly differ across recycling variants.

In the dynamic analysis of environmental tax reforms, we impose a linear reduction of carbon emissions compared to baseline emission levels by 20% between 2005 and 2040, holding the percentage reduction vis–à–vis the Baseline and keeping it constant thereafter.

CONCLUSIONS

By adapting and extensively validating the newly developed Top/Down -BU for Bottom-up E3 (energy, environment, economy) dynamic general equilibrium model (TD-BU-E3 DGEM) we assessed the long term impacts on the macroeconomic and sectoral structural components of two alternative policy instruments for responses to climate change and for promotion of renewable energy sources:

- Green quota, and
- Carbon Taxation (double dividend)

In our baseline Scenario, as a part of the adaptation strategy, we assumed de-coupling of electricity demand growth from the economic growth.

In the model we have introduced 5 existing electricity production technologies, namely: Gas Power Plants, Oil Power Plants, Coal Power Plants, Hydro Power Plants, Biomass and Wind electricity production power units.

The new vintage technologies, namely, new wind, new biomass and solar/photovoltaic – are tentative names and should be better seen as the end-of-the pipe technologies that are assumed to be more efficient than the existing but also much more costly.

The model runs for the Green quota scenario have shown that as a result of the rising demands for agricultural inputs by the biomass technologies there is accelerated development of the agricultural sector while heavy industry´s production is slightly declining due the general trend in exporting/downsizing the energy intensive industries.

The growth of investment is following closely the growth of the electricity output and this is due to the high capital intensity of the power sector.

It is quite indicative that the consumption is growing, albeit at a lower rate, despite the significant investment demand.

Here is to be said that by 2030 the share of renewables in the electricity production (without hydro) is reaching 0,184 and **by 2050 - 0,289** and the renewables share (including hydro) is 0,825.

Our results are pointing out that achieving the green quota of close to 30% by 2050 is feasible and there are sufficient quantities of potential renewable resources available for electricity production. It also seems that the economic burden is bearable and the welfare is growing.

The **double dividend** hypothesis has addressed the question of whether the usual trade-off between environmental benefits and gross economic costs (i.e. the costs disregarding environmental benefits) of emission taxes prevails in economies where distortionary taxes finance public spending.

Emission taxes raise public revenues which can be used to reduce existing tax distortions. Revenue recycling may then provide prospects for a double dividend from emission taxation.

While keeping public good consumption at the base-year level, the additional carbon tax revenues can be recycled in three different ways:

(i) a reduction in the distortionary labor tax
(ii) a cut in the distortionary consumption tax
(iii) a lump-sum refund to the representative household

The results of the simulations are showing that the reduction in the distortionary labor tax is leading to increases over a long period of time of the consumption levels. To a lesser extend the consumption increases in the case of a cut in the distortionary consumption tax. From the other side the reduction in the distortionary lump-sum refund to the representative household tends to reducing consumption and respectively the welfare.

Hence, only for the case of labor tax recycling, we could assume the existence of a strong double dividend.

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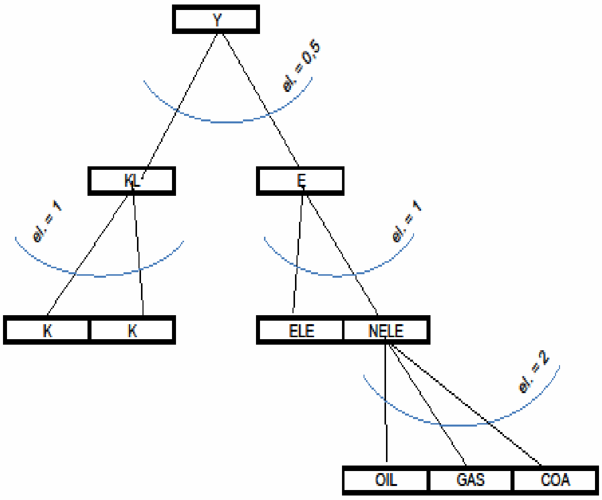
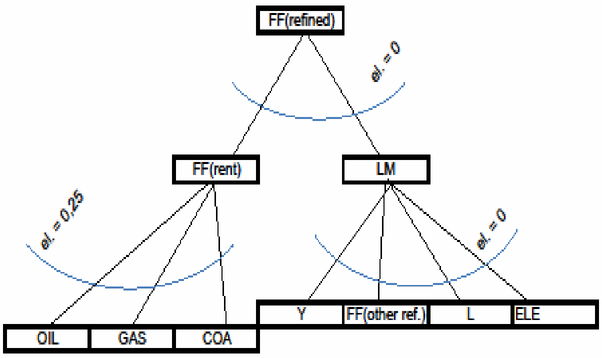
ANNEX.1: TD-BU-E3 DGEM: NESTING STRUCTURE OF THE PRODUCTION FUNCTIONS

TOP DOWN NESTING STRUCTURE.

STRUCTURE FOR SECTORAL PRODUCTION:



STRUCTURE FOR FOSSIL FUEL PRODUCTION



ANNEX2: TD-BU-E3 DGEM: BENCHMARK DATASET

Social Accounting Matrix for Austria 2005:

	X1	X2	X3	e	ra
X1	4911	0	0	-1	-4910
X2	0	62328	0	-3333	-58995
X3	0	0	152314	-1023	-151291
oil	-71	-685	-802	2442	-884
coa	-5	-55	-33	97	-4
ele	-88	-1320	-1818	5595	-2369
gas	-14	-839	-526	2230	-851
Labor	-898	-20559	-70440	-456	92353
Capital	-3835	-38870	-78695	-4484	125884
Rent	0	0	0	-1067	1067

Disaggregation of energy sector netputs :

	oil	coa	ele	gas	e
X1	0	0	-1	0	-1
X2	-942	-1	-598	-1792	-3333
X3	-207	-2	-573	-241	-1023
oil	2499	0	-56	-1	2442
coa	-169	427	-161	0	97
ele	-1	0	5603	-7	5595
gas	0	0	-471	2701	2230
Labor	-76	-4	-307	-69	-456
Capital	-231	-315	-3436	-502	-4484
Rent	-873	-105	0	-89	-1067

X1 agricultural sector
X2 production sector
X3 service sector
e energy composite

Emission scenarios for Bulgaria using the integrated model GAINS

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Abstract: The model GAINS is an integrated model for assessment of air pollution, developed by the International Institute for System Analysis (IIASA), Austria, as a tool to identify emission control strategies that achieve given targets on air quality and greenhouse gas emissions at least costs. It considers the following air pollutants - SO2, NOX, VOC, PM, NH3 and Greenhouse Gases (GHG) - CO2, CH4, N2O and the F-gases HFC, PFC, SF6, emitted from different economic sectors. In "scenario" mode GAINS focuses on individual abatement measures and considers the "multi-pollutant multi-effect" of a given measure simultaneously on air pollution and GHG. Thus, exploring synergies between measures for emissions reduction and GHG mitigation cost benefit results could be achieved. In "optimization" mode the model can be used to search for cost-minimal balances of controls of the pollutants considered that simultaneously achieve user-specified targets for human health and ecosystems impacts.

The model GAINS (Annex I version) is used in this work to realize some emission scenarios for Bulgaria till 2030 concerning the national emissions for the most of the above pollutants and GHG. For each scenario are calculated the costs for emissions reduction of some pollutants. Sensitivity analyses are carried out applying different control strategies. The results presented are compared and discussed. The use of this model approach in Bulgaria is at an early stage.

Key words: integrated model, emission scenario, control strategy

1. INTRODUCTION

The Regional Air Pollution Information and Simulation (RAINS) model has been developed at the International Institute for Applied System Analysis (IIASA) as a tool for the integrated assessment of emission control strategies for reducing impacts of air pollution from the following pollutants: SO2, NOx, VOC, NH3, PM, O3. Since 2007 it has been replaced by the model GAINS (Greenhouse Gas Air Pollution Interactions and Synergies), which is used by the European Commission (EC) to develop, apprise, modify and set emission level ceilings for a range of transboundary air pollution under the National Emission Ceiling Directive (NECD) 2010. GAINS affords not only air quality modeling as does RAINS, but explores Greenhouse Gas (GHG) emissions of CO2,CH4, N2O and the F-gases CFCs, HFC, SF6, as well as additional abatement options. Thus, except impact on ecosystems, GAINS is used also for assessment of climate change options. Another innovative possibility of the model is focusing on the individual abatement measure for the level of associated economic activity and emissions and its impact on different pollutants and GHG simultaneously (multi-pollutant multi-effect approach). This allows identifying synergic effects of the control measures application, i.e. simultaneous change of emissions and GHG as a result of application of a single measure. More information about the model could be found at the web site of IIASA – www.iiasa.ac.at.

GAINS is an integrated model operating with a large number of input data for the different economic sectors, but at the same time it is simplified in a sufficient extent for easy use with sufficient accuracy. Nevertheless, it is recognized that many aspects that are presently not hard-wired into GAINS are important. That is why, instead of incorporating all complex relations that are relevant to these aspects into one super-model, a network of specialized models that address these aspects in more details has been created through the EC4MACS (European Consortium for the Modelling of Air pollution and Climate Strategies) project - www.ec4macs.eu. The EC4MACS model suite includes the GAINS integrated assessment model for air pollution, the PRIMES energy model, the TREMOVE transport model, the CAPRI agriculture model, the EMEP atmospheric dispersion model, the GAINS-Europe model for greenhouse gas mitigation, models for health and ecosystems impacts, the GEM-E3 macro-economic general equilibrium model and the Beta and ExternE benefit assessment approaches.

The Network for Integrated Assessment Modelling (NIAM - http://www.niam.scarp.se/) is established under the UNECE Convention on Long-Range Transboundary Air Pollution. The aims of the NIAM network is to encourage collaboration between national activities and with IIASA in integrated assessment modelling, to provide a forum for discussion, to facilitate communication and to enhance development of integrated assessment modelling complementing the work of IIASA as well as providing additional contributions to the work of the Task Force on Integrated Assessment Modelling. NIAM supports national activities in the use of GAINS and keeps close contacts with the working groups involved in the project EC4MACS. As a result of NIAM, national versions of the model GAINS are created, for example in Italy, the Netherlands, Ireland and some other countries.

The author of this work has experience with integrated modelling as a result of participation in the project DECADES of the International Atomic Energy Agency (IAEA) on case study for sustainable development of the Bulgarian power sector (using WASP model), participation in the FP5 project MERLIN (Multi-pollutant multi-effect assessment of European air quality – an integrated approach) and keeping contacts with IIASA and some of the NIAM members.

In the present work are considered 3 emission scenarios, concerning the national emissions and abatement costs for most of the above mentioned pollutants and GHG. The emissions from the power sector of Bulgaria are presented separately. The results are compared and discussed.

2. GAINS METHODOLOGY

GAINS considers the following traditional air pollutants: SO2, NOx, VOC, NH3, PM and the 6 Kyoto GHG: CO2,CH4, N2O and the F-gases CFCs, HFC, SF6. The main important innovations in the model methodology, in comparison with RAINS, except addition of the GHG, are following.

The recent scientific insights open new opportunities for an integrated assessment that could potentially lead to a more systematic and cost-effective approach for managing traditional air pollutants simultaneously with greenhouse gases as they have common sources. That is why it is possible to carry out comprehensive and combined analysis of the common pollutants and GHGs, responsible for pollution and climate change and respectively, to combine measures for their reduction and mitigation (multi-pollutant, multi-effect approach). Important synergies of emission control measures, which could be of high policy relevance, reveal during this process. The synergic effects are based on the connections between measures for emissions reduction and mitigation of the GHG potential. This means that the application, for example, of one control measure (abatement measure) to reduce emission of one pollutant or GHG could reduces the emission also of one or more another pollutants or GHG and this leads to economic benefits. The model GAINS treats the multi-pollutant technologies (abatement measures) in a different way than RAINS. Costs of such measures are related to one pollutant in RAINS and to several pollutants in GAINS. This could lead to a different choice of technologies: measures that were not cost-effective in the single pollutant approach may become cost-effective in the multi-pollutant approach. Thus GAINS allows simulation of variety of flexible mechanisms for controlling GHG and air pollution emissions. The GAINS model operates with approximately 1500 end-of-pipe technologies to reduce emissions of SO2, NOx, NH3, VOC and PM and several hundred options to reduce emissions of greenhouse gases.

The GAINS model quantifies the full DPSIR (demand-pressure-state-impact-response) chain for the emissions of air pollutants and greenhouse gases. It incorporates data and information on all different elements in the DPSIR chain and specifies connections between these different aspects. In particular, GAINS quantifies the DPSIR chain of air pollution from the driving forces (economic activities, energy combustion, agricultural production, etc.) to health and ecosystems effects, which procedure is similar to this of RAINS.

The GAINS model framework makes it possible to estimate, for a given energy- and agricultural scenario, the costs and environmental effects of user-specified emission control policies (the “scenario analysis” mode). Furthermore, an optimisation mode can be used to identify the cost minimal combination of emission controls meeting user-supplied targets on air quality and/or greenhouse gas emissions, taking into account regional differences in emission control costs and atmospheric dispersion characteristics. The optimisation capability of GAINS enables the development of multi-pollutant, multi-effect pollution control strategies.

To summarise, in order to model the synergic effects of measures aimed at greenhouse gas emissions and air pollution, the RAINS model was extended and its optimization methodology was refined accordingly. The original RAINS model used single pollutant cost curves to find cost-effective emission reductions to attain environmental targets. The new GAINS model is based on individual measures that can reduce one or more pollutants, e.g. fuel substitution and structural changes in energy production as well as add-on control techniques that have an impact on one or several pollutants.

Methodology and theoretical basis of the model GAINS are well described by Amann M. et al., 2008, Klaassen G. et al., (2005). Information about the optimisation could be found in Wagner, F. et al., (2007).

3. EMISSION SCENARIOS

3.1. General principles

At this stage the GAINS model could be used only on line at the web site of IIASA after registration. Thus, the users obtain a possibility to interact directly with the GAINS database, to modify, create and/or update data and create their own scenarios. The basic principles for use of the database for calculating emissions and emission control costs in the model are following.

Emission = Activity * Emission factor * Technology implementation

Costs = Activity * Unit cost * Technology implementation

The exact formulae are given in Amman M. (2008). Components on the right side are organised into three data categories. Emission-generating economic **activities** are organised into **activity pathways**. Activity data are divided into five groups: Energy (ENE), Mobile sources (MOB), Agriculture (AGR), Process (PROC) and VOC-specific (VOC). **Emission factors and unit costs** of control technologies, together with all background information, form the so-called **emission vector**. Finally, **technology implementation** for each activity is specified in **control strategies**.

Each **emission scenario** is created through a combination of the following three data categories: **activity pathway, emission vectors and control strategies**. Activity pathway refers to the time-dependent evolution of economic activities and show the way how the activities (energy consumption, agriculture livestock, production of energy-intensive products, wastes etc.) will evolve in the future**. At this stage changes in emission vector, using GAINS on-line, are possible only with permission of the data administrator. Control strategy** is a data set that contains assumptions on the penetration of emission control technologies in a given emission scenario and includes information on controls applied in all sectors for all pollutants for the period considered. In general, this period is up to 2030 with a five years time interval. Additional input data, as macroeconomic parameters for example, also could be viewed as an element of the database. **In online use of GAINS the user has a permission to create/change only activity pathway and control strategy.**

GAINS energy database includes the following components of energy system:

- Electricity and district heat generation in the power plants and district heating sector (PP);
- Energy use for primary fuel production, conversion of primary to secondary energy other than conversion to electricity and heat in the power and district heating plants, and for delivery of energy to final consumers (CON);
- Final energy use in: industry (IN), domestic sector (DOM), transport (TRA) and non-energy use of fuels (NONEN). The domestic sector covers residential and commercial sectors, as well as agriculture, forestry, fishing and services.

GAINS contains alternative pathways of energy use from national and international energy projections, e.g., scenarios developed for Europe by the PRIMES model, projections of the international Energy Agency (IEA) scenarios, based on national studies. Total energy consumption in a given country can be derived by summing up the fuel use in the conversion sector (CON), power sector (PP) and final demand sectors, i.e., IN, DOM, TRA and NONEN. Although this total is a sum of primary and secondary energy, it is equal to the total primary energy demand at a country level. Gains model includes rather detailed specifications of energy carriers. This is because emission factors for air pollutants and GHG heavily depend on the type and quality of fuel used. Consumptions of fuel in a given economic sector determine the level of energy-related activity used in emissions calculations. This consumption is measured in PJ.

3.2 Emission scenarios considered

The model GAINS exists in different versions: GAINS on Annex I countries, GAINS Europe, GAINS Souse Asia, GAINS China (GAINS Russia and GAINS Rest of World are not yet publicly available). The user's rights to manage (modify scenario or create a new one) could be given by the model administrator only for the version Annex I. **At this stage this means working only in scenario mode but not in optimisation one.** Each version contains a set of different emission scenarios. As it was mentioned above, each scenario consists of **activity pathway, emission vectors and control strategies** (emission vectors could be managed under special permission). It should be mentioned, that the model is being constantly improved. IIASA, as well as different users, also constantly increase the number of scenarios, stored in the database. This is the reason for the only possibility at present for on-line use of the model.

Three scenarios are considered in this work. They are as follows.

- Scenario 1: Scenario called "IEA WEO 2008; current policies" is created by IIASA and is recommended to be used as a source scenario. The reason is that this scenario was recently updated and used as a baseline (target) for Annex I countries. Energy activities for Annex I non-EU countries originate from the IEA World Energy Outlook 2008. For EU-27 PRIMES Baseline 2007 scenario has been used. Sources for agricultural activities are: for EU - CAPRI model scenarios; for other countries - FAO projections. The scenario includes "current policy" air pollution control measures in each country.

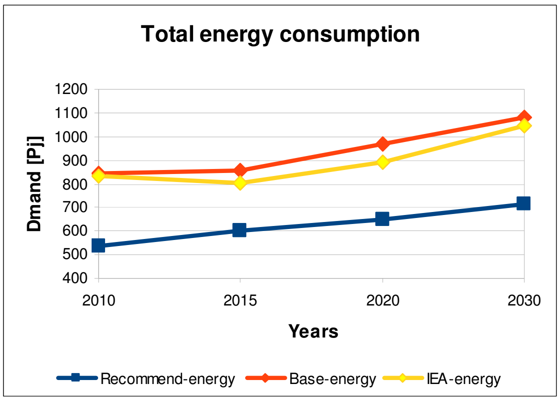
One new created emission scenario and supporting pathway and control strategy is possible to be blank, i.e., all necessary input data to be introduced in them. But it is advisable the new scenario, pathway and control strategy to be existing ones, which further to be modified in order to create a unique scenario. The reason is that most of the existing data is relevant and the user should change only the rest according to his own projections.

Using this approach and scenario "IEA WEO 2008; current policies" and respective pathway and control strategy as sources two additional scenarios are created. They are as follows.

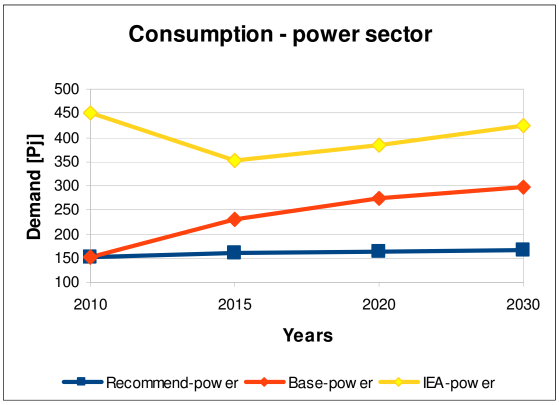
- Scenario 2: This scenario is called "baseline". The results from the project CASES for Bulgaria (Tzetanov P. et al., (2008)) are used as input data. These results concern the energy sector with preliminary accent of the power one. The scenario, presented in this work is a reasonable and actualised revision of all existing scenarios in Bulgaria about this sector. One further improvement of this scenario is presented by the same participants in the project CASES (Tzvetanov. P. (2009)) and practically this data is used for realisation of the above mentioned baseline scenario. The rest data are the same as these stored in IEA 2008, used as a source scenario. The control strategy used is the same as for scenario IEA 2008. Different sensitivity analyses are carried out in this control strategy, modifying some parameters, concerning emissions reduction of some pollutants. Finally, the results presented here are connected with the original control strategy for scenario IEA 2008.

- Scenario 3: This scenario is called "recommended". Practically, it is an extension of the work of the Bulgarian group participating in the project CASES, done after the project closing, and is described in Tzvetanov P., et al., (2009). It is actually one purifying vision for development of the Bulgarian energy sector, with a strong accent on the power sector. This scenario was proposed for implementation to the decision-making group of the Bulgarian Parliament. That is why it is considered here as one recent, actual and interesting national concept.

On Fig. 1a are presented the total country energy consumptions (demand) according to the above three scenarios and on Fig. 1b - this for the power sector.



1a



1b

Fig.1 Projections of the total energy consumption (1a) and consumption in power sector (1b) for Bulgaria in Pj

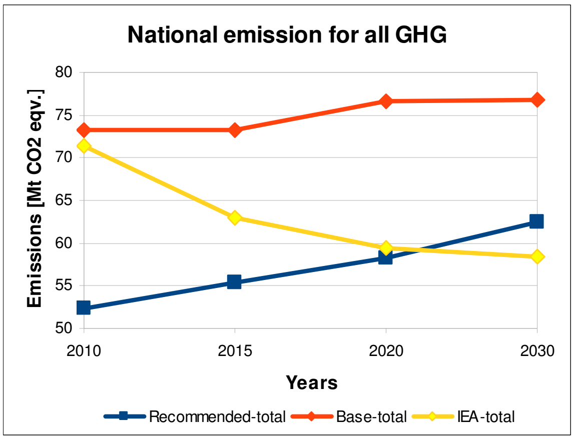
3. Results

Emissions of the following pollutants are considered below: Total GHG, CO2, NH3, NOx, PM2.5, PM10, PMtsp (total suspended particles), SO2 and VOC. The control costs are presented for: total for the country control costs, NOx, PMtsp, SO2.

4.1. Emissions

Model GAINS allows obtaining the emissions of each GHG considered: CO2, CH4, N2O and the F-gases. Here are presented only the total GHG emissions and CO2 emissions.

On Fig. 2 are shown the total national emissions of all GHG (fig. 2a) and the total GHG emissions from the power sector only (Fig. 2b) (in CO2 eq./yr.). As it could be seen, the latter are 60-70% of the total GHG emissions. Lowest emissions are connected with the recommended scenario, where is stressed on the renewable energy sources.



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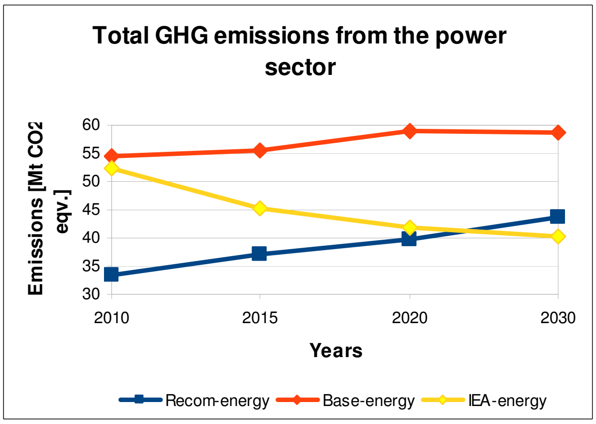
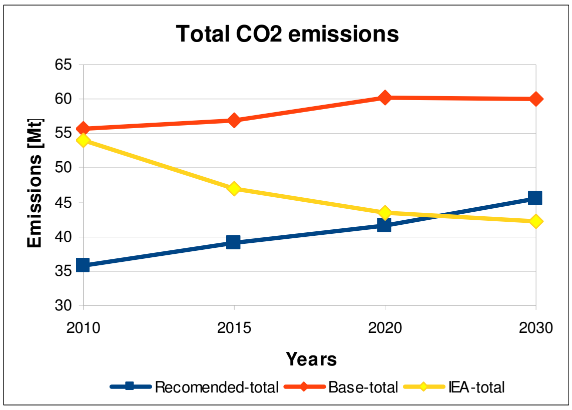


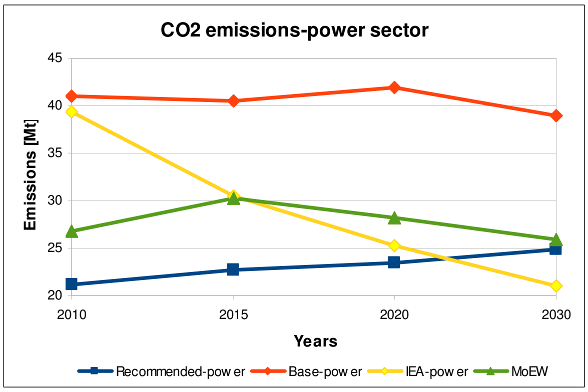
2b

Fig. 2 Total GHG emissions (fig 2a) and emissions from the power sector (Fig. 2b) (in Mt CO2 eqv.)

The CO2 emissions are presented on Fig. 3. On Fig. 3a are shown the total CO2 emissions and on Fig. 3b – these from the power sector only. As it could be seen, in comparison with the results on Fig. 2, the CO2 emissions are significant part of the total GHG emissions and respectively the CO2 emissions from the power sector are significant part of the total CO2 emissions. On Fig. 3b are presented also results of the Ministry of Environment and Waters in Bulgaria (MoEW), presented in (Tzvetanov P., et al. (2009)).



3a



3b

Fig. 3 Total CO2 emissions [Mt] (3a) and CO2 emissions [Mt] from the Bulgarian power sector (3b)

The total NH3 emissions are presented on Fig. 4 and on Fig. 5 – the national NOx emissions. As it could be seen, NH3 emissions are very similar for all scenarios and keep a rising trend. The reason is that these emissions are mainly due to the agriculture sector where not many measures for reduction are foreseen.

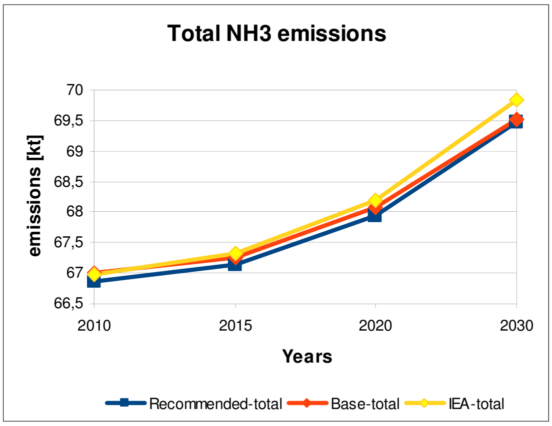


Fig. 4 National NH3 emissions [kt].

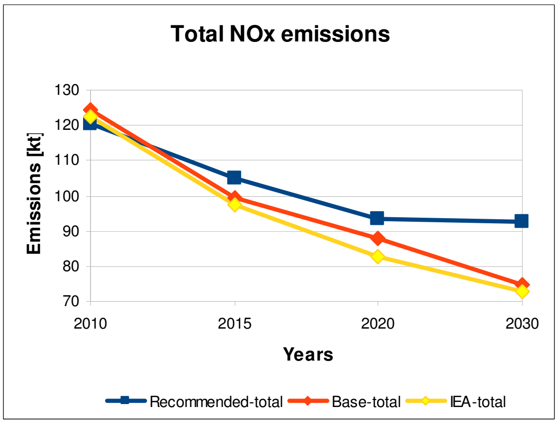


Fig. 5 National NOx emissions [kt].

GAINS model divides the particular matter (PM) into 3 categories: fine particles PM2.5, bigger ones – PM10 and PMtsp – total suspended matter. Their total emissions for Bulgaria are down presented on Figs 6, 7 and 8.

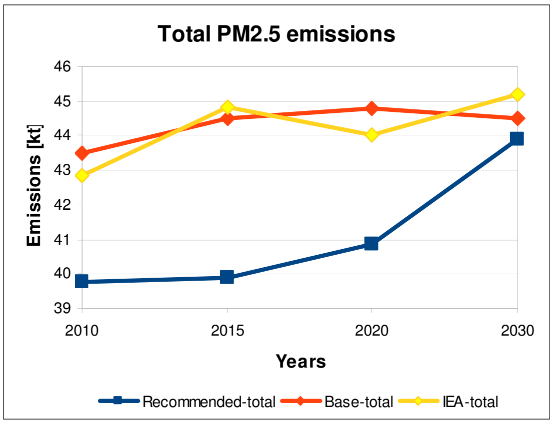


Fig. 6. Total PM2.5 emissions [kt].

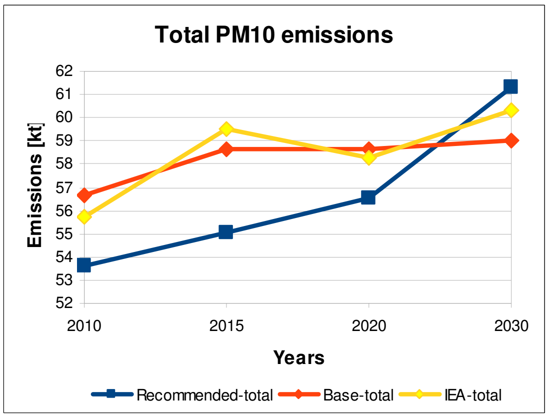


Fig.7. PM10 emissions [kt]

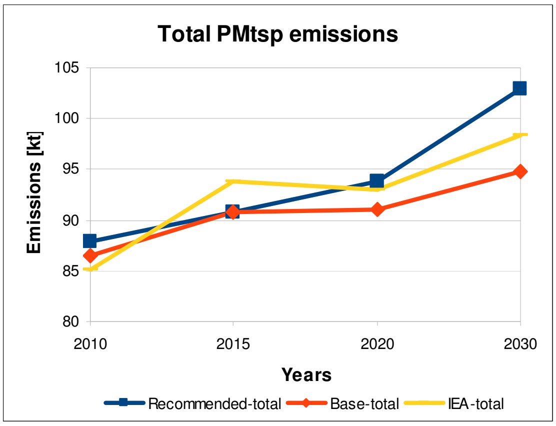


Fig. 8 Total PMtsp emissions [kt]

On Figs 9 and 10 are presented (in kt) the SO2 and VOC emissions, respectively.

4.2. Costs of reducing emissions

This option displays emission control costs computed by the GAINS model for a selected emission scenario (= combination of energy pathway and emission control strategy), and provides details on the cost-relevant input data used for the calculations. Costs of reducing CO2 emissions through implementation of all costs of that measure are reported under NOx. Second priority is given to PM, i.e., if a measure reduces PM and other pollutants (but not NOx), all costs are reported under PM.

However, **these rules are only applied for the reporting of costs in the GAINS-online version. For the GAINS optimization, costs of multi-pollutant measures are not allocated to a single pollutant, but are associated with the particular measure, for which the simultaneous impacts on several pollutants are accounted (the "technology-based" approach of GAINS). GAINS optimisation is not available online at present.** For calculating emission control costs, GAINS relies on international operating experience of pollution control equipment and extrapolates it to country-specific conditions. The basic methodologies are described in model documentation for air pollutants and greenhouse gases.

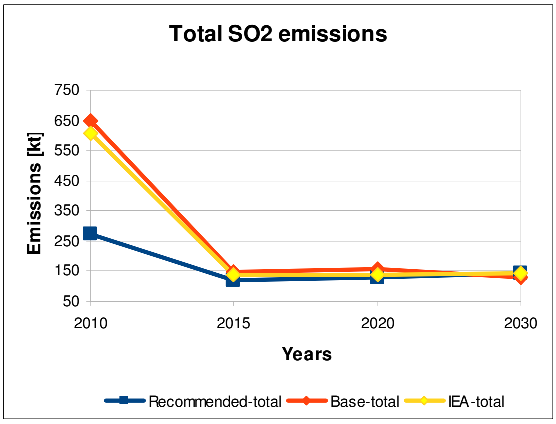


Fig. 9 Total SO2 emissions [kt]

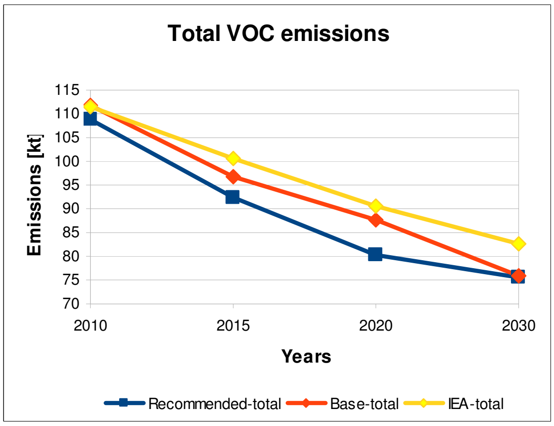


Fig. 10 Total VOC emissions [kt]

energy system measures could be analyzed using the GAINS Mitigation Effort Calculator and are not discussed here.

For measures that influence more than one pollutant at the same time, the tables presented on the GAINS web site report their total costs under the main pollutant. In particular, if a measure reduces (inter alia) NOx emissions,

Furthermore, recent information on emission control costs has been incorporated into GAINS on the basis of the reports prepared by the Expert Group on Techno-Economic Issues (EGTEI). Actual data that are used for the calculations can be extracted from the menus on this web site.

All input data for costs calculations are in Euro 2005. User can choose the cost level (Euro 2005 or Euro 2000) and the interest rate used for tables with calculation results. Here is used 10% interest rate. The results are presented in million euros per year.

On Fig. 11 are presented the control costs for all air pollutants (i.e., SO2, NOx, PM, NH3 and VOC) for different scenarios. The values for the selected years do not double-count costs of measures that affect more than one pollutant at the same time. On Figs 12, 13 and 14 are presented the control costs for NOx, PMtsp and SO2, respectively.

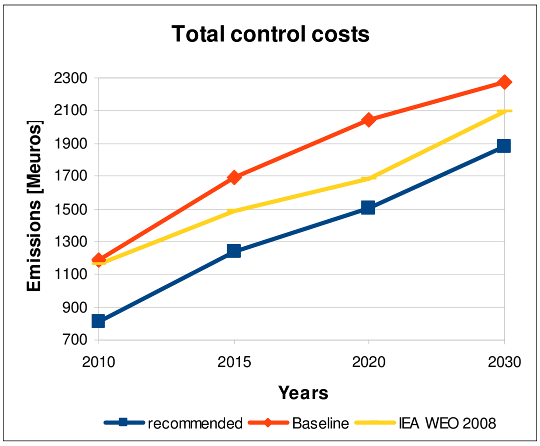


Fig. 11 Control costs for all air pollutants [Meuros]

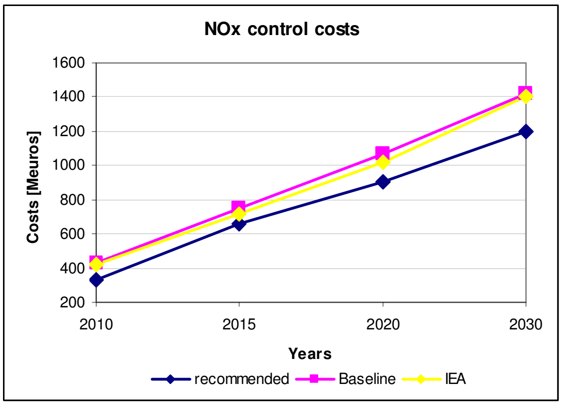


Fig. 12 Control costs for NOx [Meuros]

4. Conclusions

The present investigation should be considered as preliminary for Bulgaria, as the use of the model GAINS is at its beginning. The new scenarios – baseline and recommended are based on contemporary data and results, obtained by the Bulgarian participants in the project CASES. But they concern preliminary the power sector of Bulgaria. For more detailed description of the energy consumption from all economy additional data should be collected and their projections should be obtained for the selected scenarios.

Nevertheless, the results are interesting. Their comparison shows that the base scenario, which is a compilation and revision of the existing scenarios in Bulgaria, is not quite realistic. It is based on a too high demand forecast and commissioning of energy supply options that are not relevant very much. The respective emissions and reduction costs are biggest in

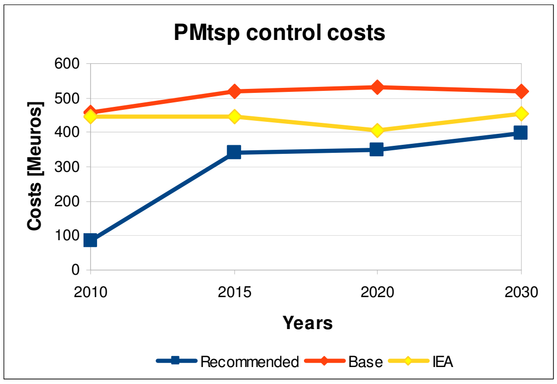


Fig. 13 Control costs for Total suspended particular matter [Meuros]

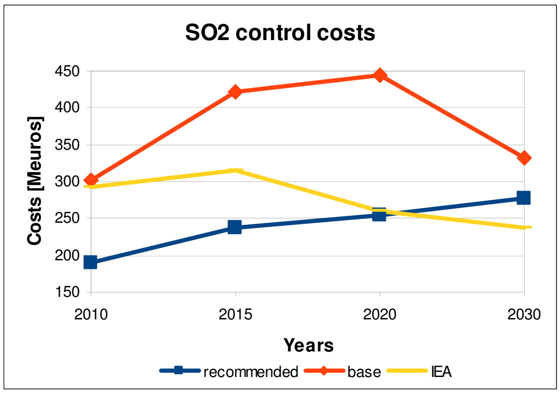


Fig. 14 Control costs for SO2 [Meuros]

comparison with the other scenarios. At the same time, the recommended scenario sounds more realistic. It is based on extended use of renewable energy sources, but excludes development of new nuclear options. The latter appears to be preliminary political decision, which in this case foresees building of such capacities. The emissions and reduction costs are lowest for this scenario. The referent scenario IEA WEO 2008, created by IIASA, is based on national and international input data. It is realistic, but some input options in it should be bring up-to-date.

Besides, it will be very interesting to compare the scenario considered, using the optimization module. This is not possible at present on-line. Such opportunity will give optimized results because in this case is used the "technology-based" (synergic) approach of GAINS – one measure is applied to more pollutants. This way allows achieving emission and impact targets at lowest costs. Impact assessment on human health and ecosystems is also not available on line at present.

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Critique of the Regulatory Limitations of Exhaust CO_2 Emissions from Passenger Cars in European Union

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Abstract: Transport is the second emitter of CO_2 in European Union, after the energy production sector, with constantly increased trend. If that trend continues in the future, the benefit of CO_2 emissions decrease from other sectors will be canceled. To avoid such an evolution, European Union proposed a new regulation (443/2009) to control the CO_2 emissions from new passenger cars. This regulation is also due to the failure of the volunteered agreement for the reduction of CO_2 emissions between European Commission and car manufacturers associations (ACEA, JAMA and KAMA). According to the regulation 443/2009, the average, for each car manufacturer, CO_2 emissions of the new passenger cars registered in 2020 in European Union should not exceed the value of 95 g CO_2/km on the New European Driving Cycle. In the present work the regulation 443/2009 is analyzed and a critique is dressed to three points of this text. The first point concerns the average upper limit of CO_2 emissions of each car manufacturer. The second point concerns the possible derogation for the low volume manufacturers and the third to the penalties for the extra CO_2 emissions. A change to the above points is proposed. The maximum decrease of CO_2 emissions and the principle of equity of citizens are the two principles of our propositions for the CO_2 regulations.

Keywords: CO_2 emissions, passenger cars, European Union regulations

1. Introduction

Since some years, the European Union (EU) started some actions to control the CO_2 emitted from the transport sector. Special attention was given to CO_2 emissions of new passenger cars (PCs), as they are responsible for the 12% of the total CO_2 emissions (Zervas 2010a). Based on the Community Strategy which was founded on 1995 by the EU, the aim was to reach 120 g CO_2/km from the new PCs till 2012 (European Commission, 1995a).

In the framework of this effort, some accords were made with automobile manufacturers in order to reduce emissions by the new models of PCs. In 1998, The Association of European Car Manufacturers (ACEA) committed with the target of 140 g CO_2/km for new PCs till 2008. In 1999, JAMA & KAMA (Japanese and Korean Associations of Car Manufacturers) committed with the target of 140 g CO_2/km for new PCs till 2009 (Commission Recommendation 1999/125/EC). Even though there was a reduction of CO_2 emissions of new PCs during those years, the target was not reached.

The European Commission announced in 2007 the intention to set a special series of laws, as the rhythm of CO_2 reduction was lower than the desired one (EU Regulation (EC) No 715/2007). In April 2009, appeared the EU regulation 443/2009 setting an upper limit to the CO_2 emitted from new PCs (EU Regulation (EC) No 443/2009). According to this regulation the emissions from new PCs registered in the EU must not exceed, on 2020 and afterwards, 95g CO_2/km on average for each car manufacturer.

The target of the current study is to analyze the regulation 443/2009 on three critical points that are, according to the authors, against the general idea of CO_2 reduction. The first one is the average upper limit of CO_2 emissions of each car manufacturer and not of each passenger car, the second one the possible derogation for the low volume manufacturers and the third one the penalties for the extra CO_2 emissions. At the end of this study, a suggestion to overcome those three points is presented.

2. Methodology

Exhaust CO_2 emissions of new passenger cars (PCs) are measured on the New European Driving Cycle (NEDC), which is the official regulatory driving cycle in EU, according to European directive 70/220/EEC (Directive 70/220/EEC). Its total distance is 11 km (figure 1), from which 4 km simulate urban driving conditions (UDC) and 7 km extra urban ones (EUDC). The total time is about 20 minutes; the highest speed is 120 km/h, while the average speed is 33.6 km/h. It must be noticed that NEDC is just a regulatory driving cycle and real CO_2 emissions can be completely

different. Real exhaust CO_2 emissions depend on the driving profile, annual mileage etc.
The European PCs fleet can be dived into eleven different segments, mainly based on their size. Table 1 shows these segments and some representative models of each segment (Zervas E., 2010b).
In the first part of this work, a critique is dressed to three points of the Regulation 443/2009. In the second part we propose an adaptation for the above points.

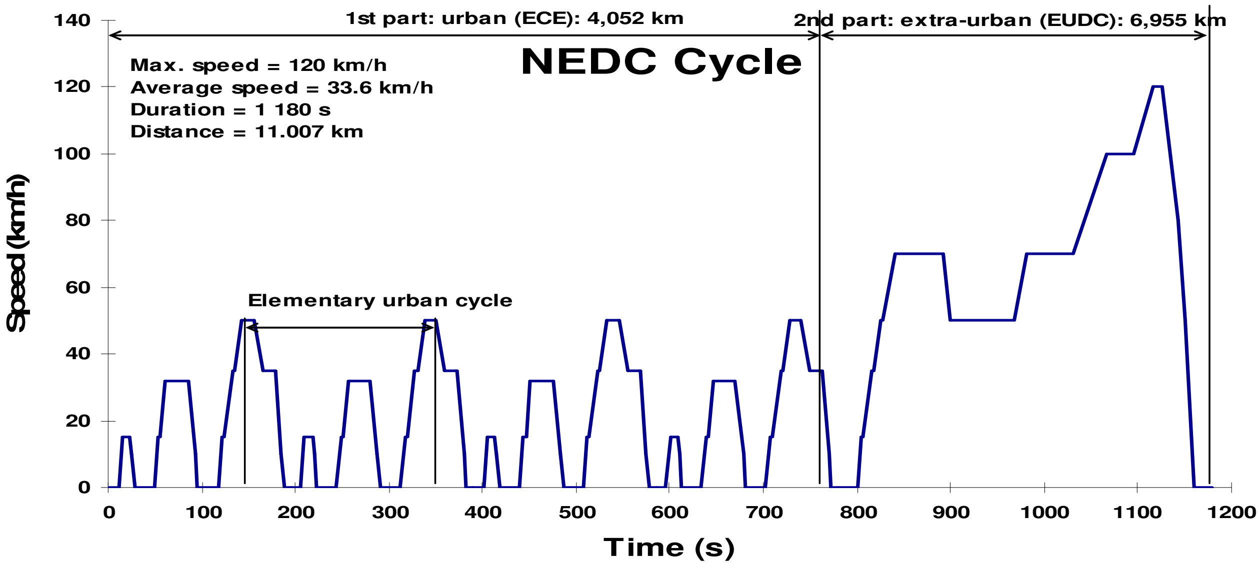

Figure 1. The New European Driving Cycle (NEDC)

Segments	**Gasoline (kg)**	**Diesel (kg)**	**Models**
Economic	839	900	Citroen Saxo, Peugeot 106, VW Lupo
Small Car	947	1021	Fiat Uno, Ford Fiesta, Peugeot 206, Renault Clio, Seat Ibiza, VW Polo
Lower Medium	1138	1217	Audi A3, Ford Focus, Peugeot 306, Renault Megane, Toyota Corolla, VW Golf
Upper Medium	1340	1396	Audi A4, BMW 320, Ford Mondeo, Peugeot 406, Renault Laguna, VW Passat
Superior	1510	1568	Audi A6, BMW 525, Mercedes Class E, Opel Omega, Peugeot 607, Volvo V70
Compact	1697	1716	Ford Galaxy, Mercedes Class V, Renault Espace, VW Sharan
Prestige	1712	1779	Audi A8, BMW 728, Mercedes Class C
SUV (< 4,5 m)	1345	1631	Ford Maverick, Land Rover Freelander, KIA Sportage
SUV (> 4,5 m)	2004	1970	BMW X5, Jeep Grand Cherokee, Mercedes Class M, VW Touareg
4x4 (< 4,5 m)	1406	1749	Jeep Cherokee, Nissan Partol, Opel Frontera, Suzuki Vitara, Toyota Land Cruiser
4x4 (> 4,5 m)	1982	1969	Hyundai Terracan, Land Rover Discovery

Table 1. The 11 segments of the EU PC market, their average weight in 2003 and some representative models of each segment during the years 1995-2003.

3. Critique of the Regulation 443/2009

3.1. Average value of CO_2 emissions of each manufacturer

The first critique is that the regulation 443/2009 proposes a limit on exhaust CO_2 emissions based on the average emissions of each manufacturer sales and not a limit for each passenger car. The principal idea is that if a car manufacturer sells a number of PCs with CO_2 emissions higher than the limit, it has to sell a number of PCs with CO_2 emissions lower than the limit to compensate the difference. Moreover, this regulation allows the manufactures to create groups of manufactures and in that last case the average value of CO_2 emissions is applied in the case of the entire group.
We believe that that point has a number of issues. First is that specific CO_2 emissions are estimated on the NEDC for all PCs, but all PCs do not have the same annual travelling distance.
Figures 2 and 3 show, for gasoline and Diesel PCs, the average annual mileage of new PCs as a function of segment. The data come from the analysis of 822 different passenger cars in France from 1995 to 2005. Some segments are grouped as they have very similar

values.

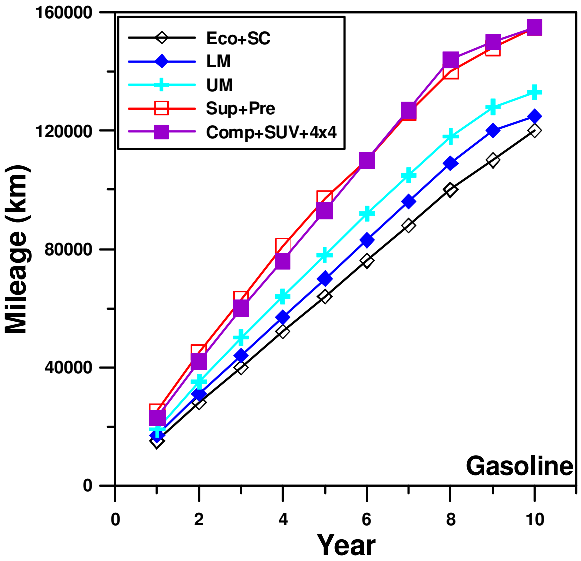

Figure 2. Annual average mileage of gasoline as a function of the segment.

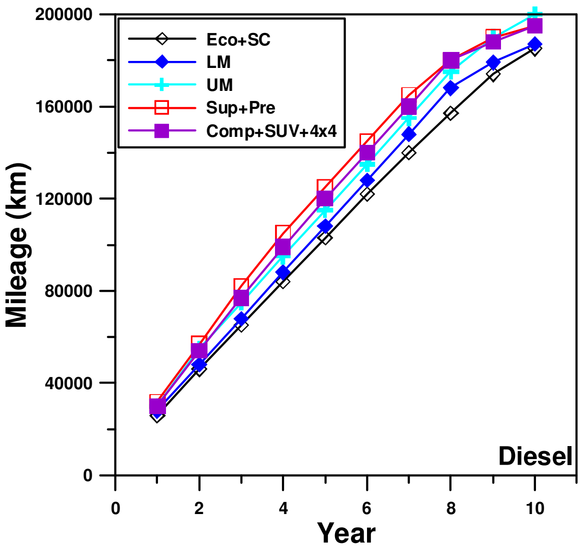

Figure 3. Annual average mileage of diesel PCs as a function of the segment.

Figures 2 and 3 show that there is a significant difference on annual mileage between each segment, especially in the case of gasoline PCs, with bigger cars, and thus higher CO_2 emitters, to run higher mileages than the smaller ones. That statement indicates that real CO_2 emissions will be higher in the case of the use of an average CO_2 emissions limit than the same limit for each PC, because higher CO_2 emitters have higher mileages.

This difference will be higher in the case of a bigger PC fleet. Figure 4 shows the evolution of total new PCs in EU15 and also the sales of gasoline and diesel new PCs (Internet site of ACEA). This figure shows clearly that new PC sales show a significant increase during last years. A simple extrapolation of this curve leads to a number of about 16,000,000 new PC sales in 2020. This figure also shows the significant increase of Diesel share. Even if Figures 2 and 3 shows that the difference between average annual mileage of bigger and smaller cars is lower than in the case of gasoline PCs and the part of gasoline PCs generally decreases, Figure 4 shows that the part of gasoline new PCs, will remain significant, even in the worst case. It must be noticed that the last few years there is a decrease in the total sales of diesel PCs and a slight increase in the case of gasoline ones.

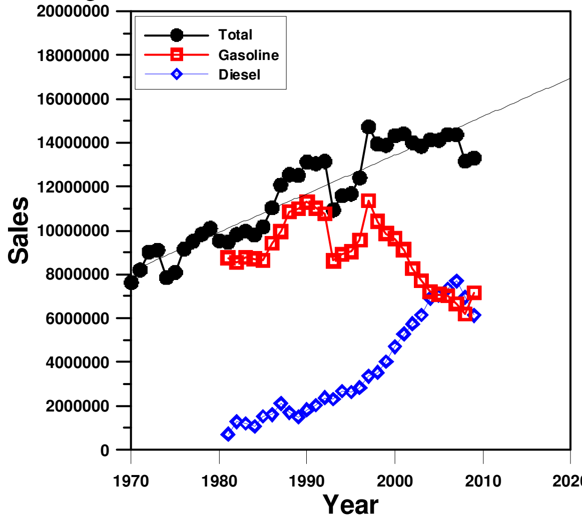

Figure 4. Total sales of new PCs and sales of diesel and gasoline new PCs in EU15 from 1970 to 2003 and projection to 2020.

To estimate more precisely the impact of the difference of average mileage of the different segments, figures 5 and 6 show the evolution of the gasoline and diesel segments from 1995 to 2003.

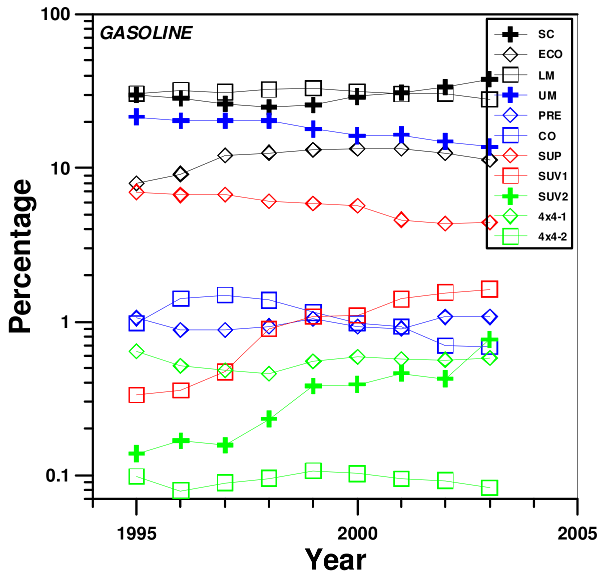

Figure 5. Gasoline segment penetration from 1995 to 2003.

Figure 4 shows that total Diesel sales increased 8.6 times in EU15 from 1981 to 2009. From 1995 to 2003 Zervas (2010b) reports that the higher sales increases are observed in the case of expensive segments: SUV<4.5m by 27 times, SUV>4.5m by 5.8 times and Prestige by 4.4 times. Figure 6, using the data of that last study, shows that the three main segments are Lower Medium, which percentage, with some fluctuations, remains quite constant at about 40% of total Diesel sales, Upper Medium, with about 25% in 2003 and clear decreased tendency and Small Car, with about 20% in 2003 and clear increased tendency. Those three segments correspond to about 81% of total Diesel sales in 2003. Concerning the other segments, the Superior, Economic and 4x4>4.5m ones show a clear decreased tendency, while the two SUV ones a clear increased one. It must be noticed that the percentage of the SUV<4.5m increased about 12 times from 0.18% in 1995 to 2.18% in 2003.

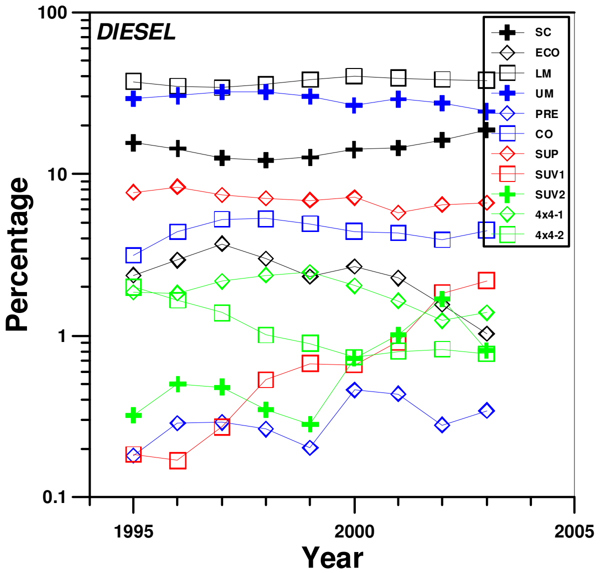

Figure 6. Diesel segment penetration from 1995 to 2003.

The sales of most gasoline segments decrease with time from 1995 to 2003 as total gasoline sales decrease. However, the sales of three segments increase from 1995 to 2003 (Zervas, 2010b): Small Cars by 6%, SUV<4.5m by 4 times and SUV>4.5m by 4.6 times, showing clearly the trend of gasoline PCs to two extremes, small and very big cars (Zervas 2010a, b, c). The three main segments are Small Car with constant increased percentage (38% in 2003), Lower Medium, with constant decrease tendency (28% in 2003) and Upper Medium, with about 14% in 2003 and clear decreased tendency. As in the case of Diesel new PCs, those three segments correspond to about 79% of total gasoline sales. Concerning the other segments, the percentage of Economic and the two SUV ones show a clear increased tendency, while the percentage of Compact and Superior decreases. As in the case of Diesel new PCs, the percentage of the two SUV segments increases by more than 5 times from 1995 to 2003.

Figures 5 and 6 show the general shift to bigger segments with a parallel increase of smaller cars.

At this point we have to compare the proposed regulation with the previous and current regulations of the other exhaust pollutants (CO, HC, NOX and particulate matter, PM) (Euro1-Euro4 for the past regulations (EU Directive 98/69/EC) and Euro5 and Euro6 for the current regulations (Regulation 715/2007). In those regulations there is the same limit for all passenger cars (which are divided in some categories as a function of their weight) and not an average value for each car manufacturer. It is obvious that the logic of an average value of the regulation about CO_2 emissions is in clear conflict with the logic of the regulation concerning the other pollutant without a justified reason.

3.2. Derogation of Manufacturers with low production

The second point of the European regulation 443/2009 is the possible derogation for a number of years to car manufactures that sell less than 10,000 vehicles per year. Even if this fleet is very small comparing to the total annual sales in EU, it is clear that the above derogation violates the principle of equality. In practice, only Ferrari and Maserati (of FIAT group) and Bentley, Bugatti and Lamborghini (of VW group) are concerned are concerned from that point. Figure 7 shows the annual registrations of the above manufactures (Internet site of ACEA).

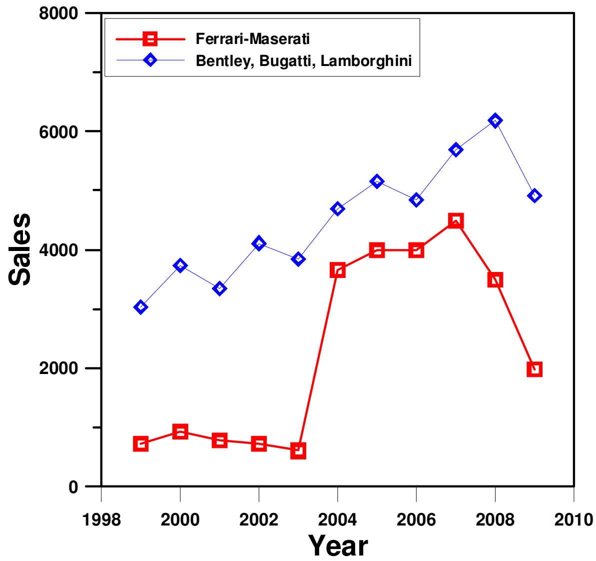

Figure 7. Annual registrations from 1999-2009 of low volume car manufacturers.

Table 2 shows the prices and the CO_2 emissions on the NEDC of some characteristic models of those manufacturers (Internet site of Carzine). It is clear that those models are not addressed to the great majority EU citizens, as their prices are extremely high. On the other hand, the CO_2 emissions are also extremely high. It is clear that, buying those cars, certain very rich EU citizens have the right to pollute more than the other EU citizens.

3.3. Penalties for the exceeding CO_2 emissions

The third critical point of the European regulation 443/2009 is the penalty proposed for the CO_2 emissions exceeding the limits. The penalty is 95 euro per exceeding gram of CO_2/km per vehicle. This penalty is paid from the car manufacturer, but in practice it will be included in the final price of the vehicle. Le idea is that this increased price will motivate the car buyers to buy cheaper cars and thus lower CO_2 emitters. Even this will probably be true in the case of cheaper cars, we don't believe that this will be an issue for the buyers of expensive cars. Once more the principle of equity is violated, giving the right to the richer citizens to pollute more than the poorest ones. To prove that statement, we need to demonstrate that there is a general increase of CO_2 emissions with vehicle price. As we couldn't find a file containing the prices and CO_2 emissions of all new PC models of EU, we extracted those data for the most common 2009 gasoline models of the Greek market (total of 106 values, Internet site of Carzine). Those data are shown in Figure 8 where is clear that CO_2 emissions increase with vehicle price. Figure 8 shows that the very expensive cars have very high CO_2 emissions.

Model	Price (Euros)	CO_2 (g/km)
Bentley Continental Flying Spur	257,600	396
Bentley Brooklands Coupe	473,000	465
Lamborghini Gallardo LP560	220,000	325
Lamborghini Reventon Roadster	1,100,000	495
Ferrari California	180,000	299
Ferrari 612 Scaglietti	232,100	470

Table 2. Prices (in Greece on 2009) and CO_2 emissions on the NEDC of some characteristic models of low volume car manufactures.

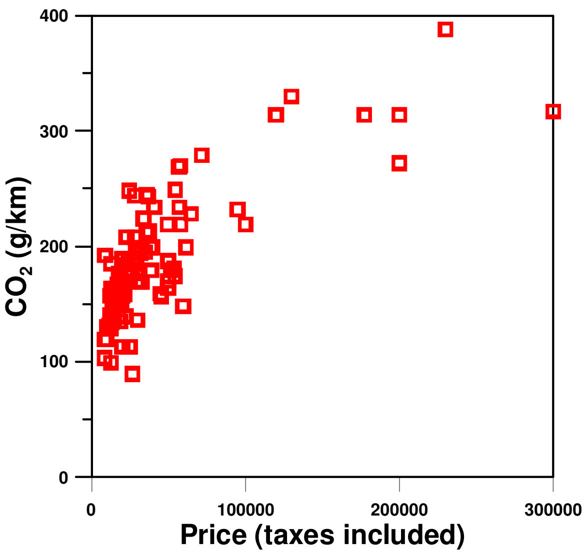

Figure 8. CO_2 on the NEDC for a number of 2009 gasoline models as a function of price in Greece.

Figure 8 shows that the penalty proposed can be very affordable for the buyers of vehicles of very expensive cars, as the extra price is a very low part of the total vehicle price. A penalty of even 1000 euros, which roughly correspond to a significant extra emission of 10 g CO_2/km is a very small part of a car of 100,000 euros.

From the other hand, we can take as example the Lamborghini Reventon Roadster (table 2). This vehicle emits today the extremely high value of 495 g of CO_2/km and costs the extraordinary price, for the extreme majority of EU citizens, of 1,100,000 euros. If that vehicle continues to emit 495 g CO_2/km, its price will be 1,500,000 euros. We believe that the potential buyers of that extremely expensive car will pay even that extra price. Once again the principle of equity of EU citizens is violated.

4. Propositions for the CO_2 Regulations in 2020

The propositions for the CO_2 regulations must be based on two principles: the maximum decrease of CO_2 emissions and the principle of equity of citizens. For that the proposed upper limit of CO_2 emissions must be applied to every PC, following the idea of the regulations for the other four regulated exhaust pollutants. The same limit at each passenger has several advantages.

1. The first issue was the higher mileage of heavier vehicles. Applying the same CO_2 limit, real world CO_2 emissions will decrease more.
2. The equity of all EU citizens is respected.
3. Car manufactures will increase their efforts to decrease CO_2 emissions.

From the second point of view, all derogations must be suspended and all car manufactures must have the same treatment. Also, the penalties for the exceeding of CO_2 emissions must be suspended. A passenger car of extra CO_2 emissions must be eliminated during the approval test as is the case of the other regulated exhaust pollutants.

5. Conclusions

The current work analyses and criticizes three point of the European Regulation 443/2009 for the control of exhaust CO_2 emissions of new passenger cars in EU in 2020. The first point concerns the limit on exhaust CO_2 emissions which is based on the average emissions of the sales of each manufacturer. Using this value, car manufacturers can produce cars which may emit both low and high levels of CO_2 emissions, as long as the average is up to 95 g CO_2/km. However, as cars with higher CO_2 emissions also have a higher mileage, the total CO_2 emissions will decrease less than the case of the same limit of all PCs. Furthermore, the new legislation allows a pooling arrangement between manufacturers, as long as the total emissions do not exceed its specific emissions target. So, car industries which manufacture extremely polluting cars (e.g. Ferrari and Maserati (of FIAT group) and Bentley, Bugatti and Lamborghini (of VW group) are allowed to pool together with others without limiting at all the emissions of their models. This fact in combination with the extremely high prices of these models legalizes the very rich EU citizens to pollute more than the other EU citizens and put into question the principle of equality. The second point is that the low volume manufacturers can receive a derogation for some years. However, as those car manufacturers are those producing very expensive models (and very high CO_2 emitters), the principle of equity is also violated.

The third point concerns the penalty of 95 euro per exceeding gram of CO_2/km per vehicle. In fact this penalty will be included in the final price of the vehicle, motivating the buyers to buy cars with lower CO_2 emissions. However, this measure is not applied in

the case of very expensive cars as price is not the first argument for their sale. Against, richer people will have the right to pollute more than the poorest ones.
Our proposition is based on the principle of the same CO_2 emissions of all new passenger cars without derogations and penalties. If a new car cannot satisfy that limit, it could not pass the approval test. This principle is also used in the case of the other exhaust pollutants.

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Calculation of Short-Term Greenhouse Gas Emission Using Fuzzy Neural Network

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Annotation - Because of the specific situation and considering the flexible mechanisms of the Kyoto Protocol Ukraine has the opportunity to use the greenhouse gas (GHG) emission reductions not only to improve the environmental situation, but also to strengthen its economic and political conditions. One way is to trade emissions of GHG on the carbon stock (international - now and internal - in future). Short-term and operational forecast of GHG emission is an integral part of planning, management and trade on the carbon stock. As a part of the input data is not quantitative but is ordinal or nominal, the decision in such situation using traditional methods is very complicated and in most cases an impossible task. To solve the problem of forecast we suggested fuzzy neural network as a method of forecasting.

Key words – energy saving, artificial intelligence, fuzzy-neural networks, fuzzy logic, Kyoto protocol, pollutant emissions, ecological forecast.

Efficient use of energy is one of the most important tasks of economic development. Energy is also the most important sphere of international business, significant object and mean of cooperation between countries. And due to the Kyoto Protocol this offers another way - financial and technical incentives energy saving and improving the environmental situation [1, 2].

Today Ukraine does not exceed their national quotas for greenhouse gas (GHG) emissions and, thus, may participate in the Kyoto Protocol established market mechanisms for the transfer of quotas (Articles 6 and 17 of the Kyoto Protocol). Due to its position and given the flexible mechanisms of the Kyoto Protocol, Ukraine has the opportunity to use the GHG emission reductions, not only to improve the environmental situation, but also to strengthen their economic and political situation [2 - 4].

Now following carbon exchange trading in financial instruments (futures, options and spot contracts) on the basis of European emission permits: the European Climate Exchange (ECX - 88% of total turnover), Energy Exchange Austria (Powernext), European Energy Exchange (EEX) Nord Pool. The volume of their operations are growing steadily, and some of them are already starting to trade futures on the secondary certified emission reductions (i.e. CERs already issued or guaranteed). Thus, the identity of the clean development mechanism became exchange goods [5 - 7].

Emissions trading can involve many sectors of the economy, but not all GHGs are taken into account the Kyoto Protocol (CO2, methane, nitrous oxide, hydro fluorocarbons, per fluorocarbons and sulfur hexafluoride). Emissions Trading Scheme takes into account only emissions of CO2 from large sources of heat power industry, as well as selected energy-intensive industrial sectors: from waste incinerators and oil refineries, coke ovens, steel mills, as well as enterprises producing cement, glass, ceramics, pulp and paper. But even this limited scope covers more than 12,000 installations in 27 member countries of the European Union (EU), which accounted for approximately 45% of all CO2 emissions in the EU or 30% of all GHG emissions [5 - 7].

It is planning the opportunity to enter the stock market not only at national level but also at the level of large enterprises, such as metallurgy, oil refining and cement in Ukraine [8 - 11].

Short-term and operational forecasting of GHG emissions is an integral part of planning, management and trade on the exchange.

As a method of forecasting we suggested fuzzy neural network (FNN) which was developed by a package Fuzzy Logic Toolbox Matlab software version 7.0.

Approach based on the use of computational intelligence, in particular artificial neural networks (NN) and fuzzy inference systems, is an effective alternative to standard mathematical methods. The effectiveness of these systems is related to their universal approximating capabilities and the ability to study directly in the forecasting process.

In recent years, systems with fuzzy logic (FL) and FNN have been widely used in Intellectual Systems of Decision-making (ISDM) in the tasks of pattern recognition and classification, cluster analysis, in the economy and the financial sector for forecasting and policy analysis, investment portfolio optimization and evaluation of the bankruptcy of the corporation. Now it is hard to find in decision-making sphere, where would not actively use the methods and models based on FL.

ISDM, especially artificial NN, have proven effective in solving a wide range of problems associated with forecasting and management in the energy sector.

Very often there are situations where a part of the input data is not quantitative, but set in ordinal or nominal scales, and decision making in such situations using traditional methods is very

complicated, time consuming and in most cases an impossible task. The only way of solving such problems is using fuzzy models and methods; in particular, with the help of FNN we can obtain maximum probable approximation and prediction.

For each task it is necessary to synthesize the most adapted specifically for this one NN. To date, this is not a problem because there are a sufficient number of software products and software packages, which allow creating NN with required architectures and for any field of use.

Necessary condition for obtaining an adequate prediction is the availability of reliable input data. Completeness and accuracy of the original data completely determines the success in making a decision using NN [12 - 15].

For short-term forecasting of GHG emission was designed fuzzy Mamdani-type system. Network architecture is depicted in Figure 1.

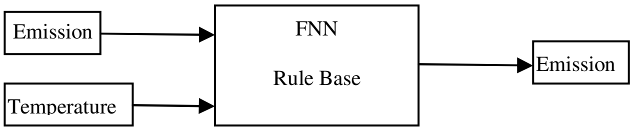


Fig.1. Architecture of Mamdani-type FNN

Consider in detail the theoretical foundations of fuzzy inference based on Mamdani mechanism.

This is one of the most common methods of inference in fuzzy sets. It is widely used in many expert systems and control systems. At its core it has the knowledge base, in which the values of input ($x \in X$) and output ($y \in Y$) variables are given by fuzzy sets [15, 16]:

$$\bigcup_{p=1}^{kj}\left(\bigcap_{i=1}^{n} x_i = a_{i,jp}, w_{jp}\right) \rightarrow y = b_j,\ j = \overline{1,m} \quad (1)$$

Where $a_{i,jp}$ – linguistic term, variable x is assessed in a line with the $jp\ (p = \overline{1,k_j})$ number; k_j - number of rows in which the yield is estimated by term b_j; m – number of terms that are used to assess the linguistic output variable.

In general, the system of Mamdani fuzzy inference can be drawn by diagram - Figure 2.

This mechanism involves the following steps:

1) Inclusion of vagueness (fuzzification). Membership functions (MF) defined on the input variables are applied to their actual value to determine the degree of truth for each premise of each rule ($A_1(x_0), A_2(x_0), B_1(y_0), B_2(y_0)$).

2) Logical conclusion. "Cut off" levels are found for the prerequisites for each rule using the operations of minimum:

$$\alpha_1 = A_1(x_0) \wedge B_1(y_0), \quad \alpha_2 = A_2(x_0) \wedge B_2(y_0) \quad (2)$$

And the "cut off" MF which are determine:

$$C'_1 = (\alpha_1 \wedge C_1(z)), \quad C'_2 = (\alpha_2 \wedge C_2(z)) \quad (3)$$

3) Composition. The union of found "cut off" functions using the operation of maximum. This results in a fuzzy subset for the variable output with the MF:

$$\mu_\Sigma(z) = C(z) = C'_1(z) \vee C'_2(z) = (\alpha_1 \wedge C_1(z)) \vee (\alpha_2 \wedge C_2(z)) \quad (4)$$

4) The next step is transforming to clarity, or defuzzification. Defuzzification method is selected depending the particular task. The main methods of defuzzification are: centroid method, the first maximum, average maximum method, the criterion of maximum altitude defuzzification.

In the following calculation the most frequently centric method or the method of center of area was used, which is calculated as follows [13, 16]:

$$z_0 = \int_\Omega z \cdot C(z)dz \Big/ \int_\Omega C(z)dz \quad \text{- in general terms} \quad (5)$$

$$z_0 = \sum_{i-1}^{n} a_i z_i \Big/ \sum_{i-1}^{n} a_i \quad \text{– for the discrete terms}$$

We realize the work of an artificial FNN with fuzzy inference by indicative data of air temperature and current CO2 emissions, which were obtained at a metallurgical plant for a period of 40 days.

The input is the current value of CO2 emissions and the current air temperature. The output is the predicted value of CO2 emissions.

In the first layer fuzzification of data occurs. The current value of CO2 emissions is coded using nine terms with triangular membership function (MF). Name of the terms means: the lowest, low, below average, a little below average, average, a little above average, above average, high and the highest amount of CO2 emissions, shown in Figure 3.

All linguistic terms in the knowledge base are represented as fuzzy sets, given the relevant MF.

$\mu_{jp}(x_i)$ - MF input x_i of fuzzy term $a_{i,jp}$, where $i = \overline{1,n}$, $j = \overline{1,m}$, $p = \overline{1,k_j}$,

i.e. $a_{i,jp} = \int_{\underline{x_i}}^{\overline{x_i}} \mu_{jp}(x_i) \Big/ x_i$, **where** $x_i \in \left[\underline{x_i}, \overline{x_i}\right]$

(6)

$\mu_{dj}(y)$ – MF output to fuzzy term d_j,

i.e. $d_j = \int_{\underline{y}}^{\overline{y}} \mu_{dj}(y) \Big/ y$, **where** $y \in \left[\underline{y}, \overline{y}\right]$

(7)

Similarly there is fuzzification of air temperatures by seven terms with a triangular MF, the temperature, which goes beyond the interval [-30, 30] are simply projected onto the interval [0, 1].

However, if the intersection of the MF terms for current emission occurs at the level of 0.5, the intersection of the MF the temperature at the level of 0,2 (see Figure 4).

Estimation the linguistic function requires using seven terms with a triangular MF, similar to the incoming value of CO2 emissions (Figure 5).

The next step is to form a rule base. There were formulated 56 rules with the form: if the current value of emissions = A, and the current value of temperature = B, then the projected value of emissions = C. Where as A, B, C were taken an appropriate value of current

CO2 emissions, air temperatures and CO2 emissions.

Using the rule base the dependence between the projected value and input data is formed. The dependence of the prediction of CO2 emissions from air temperature and the current value of CO2 emissions can be represented in graphical form (Figure 6). Dependence represents a surface where the abscissa is given the current value of CO2 emissions, and the ordinate ask the air temperature, and on the z-axis - the value of the forecast CO2 emissions.

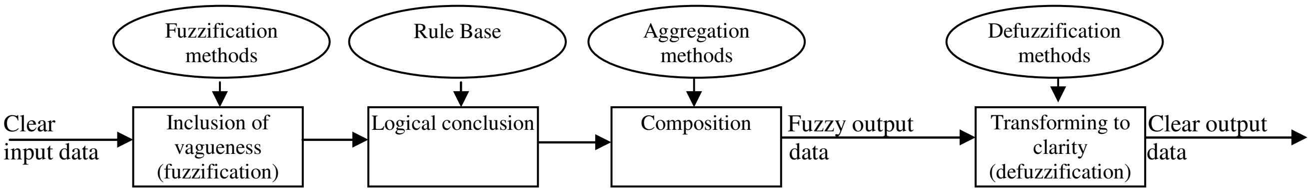


Fig. 2. Overall Mamdani-type FNN architecture

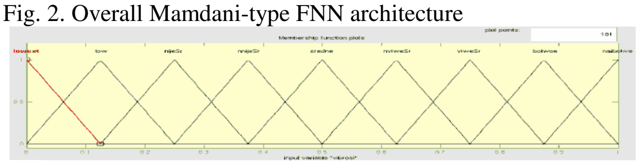


Fig. 3. Fuzzification of current value of GHG emission

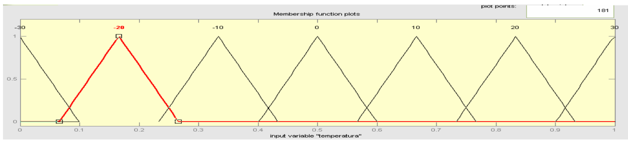


Fig. 4. Fuzzification of current value of air temperature

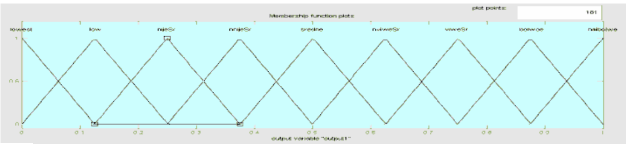


Fig. 5. Fuzzification of projected value of GHGs emission

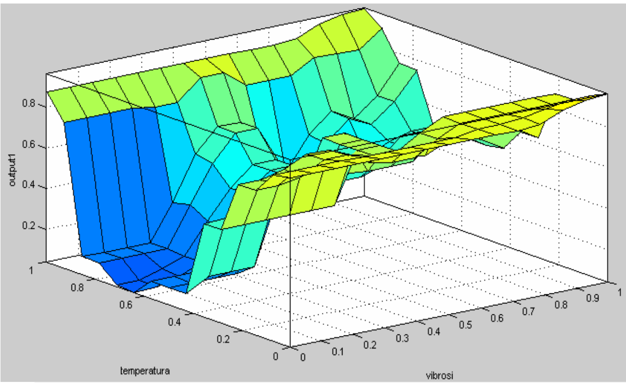


Fig. 6. Visualization of fuzzy logic conclusion in RuleViewer

As shown in Figure 6 there is a certain trend: the surface has the smallest value forecast CO2 emissions at an air temperature of about 18 and generally in the range (0, 20), the value of emissions is less than the range (-30, 0) and (20, 30), but with the increasing value of current CO2 emissions predicted value also increases.

In this case, the most interesting is the following mechanism, shown in Figure 7: establish the necessary level of the current value of CO2 emissions - the first column and the air temperature - the second column (the selected value shown in red) and obtain the prediction of CO2 emissions - the third column (shown in figure as a rectangle, for which there is no corresponding rule and the level shown in red).

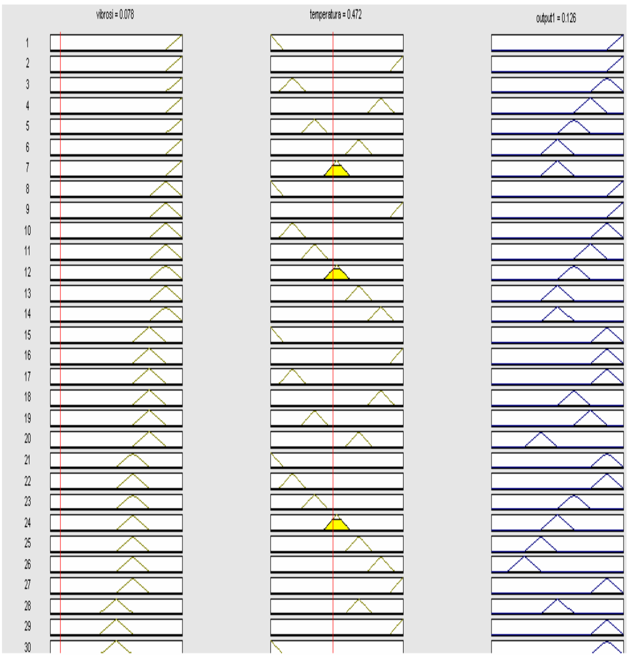
Degree of quality prediction is usually taken for the traditional tasks of short-term forecasting of MAPE (Mean Absolute Percentage Error - the average absolute error in percentage), which is calculated as follows:

$$MAPE = \frac{1}{N}\sum_{k=0}^{N}\frac{\hat{y}(k)-y(k)}{y(k)}100\ \%\,, \qquad (8)$$

where $y(k), \hat{y}(k)$ are respectively the real and projected values of the output value.

The result was obtained in a fuzzy way. The operations on the exchange are making with clear data. Thus, the prerequisite is to cast the result to a clear mind (defuzzification).

At the output layer the defuzzification of result by one of the methods of bringing to clarity: the centroid, the first maximum, average maximum, a criterion or a maximum height defuzzification method should occur.



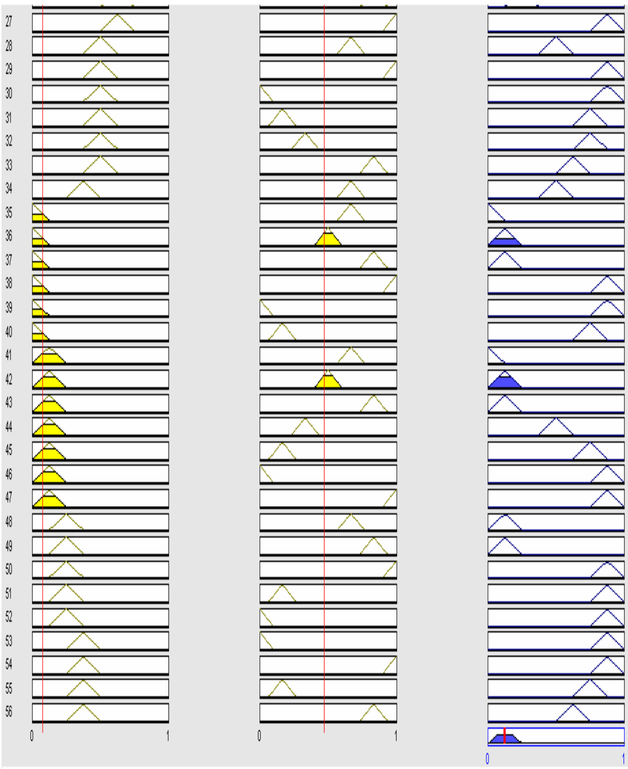


Fig. 7. GHG emission forecasting

There was obtained a result that differed from the actual. This discrepancy can be explained by imperfections in the original data, namely: the possibility of errors in measurement and insufficient number of measurements. The availability of reliable input data is the necessary condition for obtaining the adequate prediction. Completeness and accuracy of the original data completely determines the success in making a decision using FNN. It would also be advisable to conduct a similar experiment with other software and with a different configuration of NN.

Depending on the object for which the forecast is carried out there may be appropriate to record the day of week, time of day and season, as well as technology and volume production, but for predicting CO2 emissions in our case it is enough to the input data file having the greatest impact - namely, the current value CO2 and air temperature. Moreover, while the design of FNN was thought that for this steel plant there is a self-heating and rapidly adjusted to the needs of the enterprise. And also consider that the performance and capacity is taken into account in the value of current CO2 emissions. Separate records of these parameters will be made in the following calculation method.

There was also carried out the experiment with the Gaussian MF for the current and projected value of CO2 emissions and the forecast, which is almost identical to the above was obtained.

Consider the solution of this task using another method and software developed at the Department of Mathematical Methods of Systems Analysis, Institute of Applied Systems Analysis.

The program GMDH represents a Win32 application designed for solving prediction algorithms using a clear and fuzzy group method of data handling (GMDH and FGMDH) using different types of partial descriptions.

The main program window with opened the data file in the tab «Modeling Data» are shown in Figure 8.

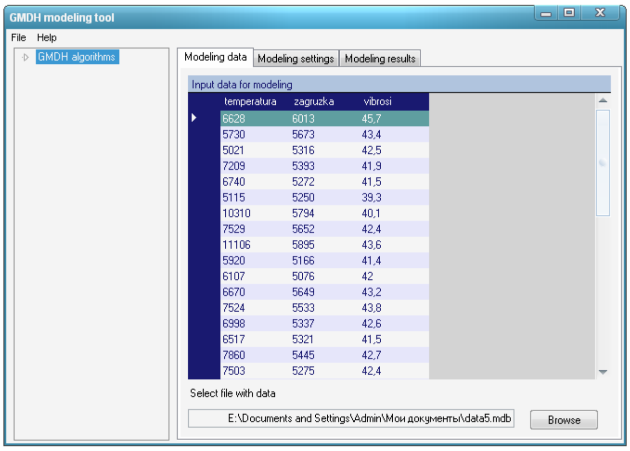


Fig. 8. Imput data

As the imput data other than temperature and current emission of GHGs separately taken into account capacity (was also carried out experiments with the performance and obtained a similar result), and there was also the technology of heat production taking into account, namely: the first technology - the old scenario where the blast furface gas was burned in a candle and at CHP enterprise nature gas is used as fuel gas, the second technology - is the base scenario after project implementation (JI), namely, - installation of a powerful turbo and use as fuel blast furnace and coke oven gas previously burned in a candle.

Setting the modeling and forecasting is carried out in the tab «Modeling settings», as well as through a multilevel list, located on the left side of the main window (see Figure 9).

Controls placed on the tab «Modeling settings» and have the following functions:

Learning / predictive sample ratio - determines the ratio of training and testing samples (in our case, we establish the ratio of 60 to 40, respectively).

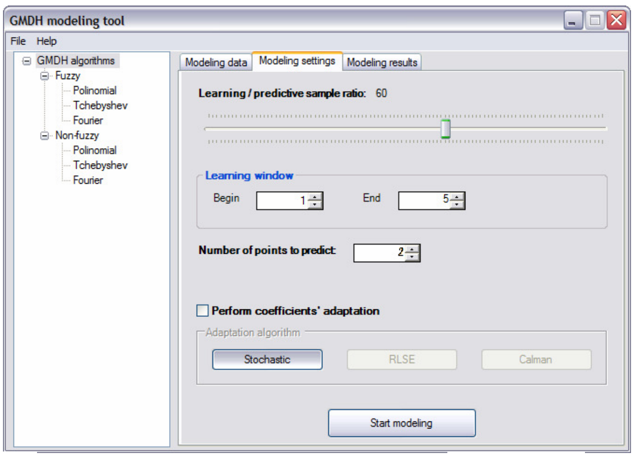


Fig. 9. Setting the modeling and forecasting parameters.

Learning window - specifies the starting and ending points of the trainee windows, i.e. the range of data on

which the construction of the model. Set the range (1, 5).

Number of points to predict - determines the number of forecast points. In our case, we establish five forecast points.

Perform coefficients' adaptation - determines whether the algorithm step by step adaptation of the predicted model is involved. Check the box and select the algorithm step by step adaptation.

Adaptation algorithm - determines the algorithm of the incremental adaptation of the predicted model. Choose from the following options:

1. **Stochastic - method of stochastic approximation.**
2. **RLSE - recursive least squares method.**
3. **Calman - Kalman filter.**

Choose the method of stochastic approximation.

Using a multilevel list in the main part of the window you can configure the following model:

Use clear or fuzzy GMDH algorithm (Fuzzy/Non-Fuzzy). After defining fuzzy GMDH algorithm opens the nested list that specifies the type of partial description.

Choose from these options:

Polynomial - quadratic polynomials.

Tchebyshev - orthogonal Tchebyshev polynomials.

Fourier - segments of Fourier series.

We choose the orthogonal Tchebyshev polynomials.

After pressing the «Start Modeling» will start the procedure of synthesis of the predicted model and when it is end there will be a tab «Modeling results» (Fig. 10).

GMDH program allows you to export the results for further analysis in the software package Microsoft Excel.

Results obtained using GMDH have the following meanings:

Left bound – left border of the interval predicted value.

Right bound – right border of the interval where the predicted value falls.

Center – center of the interval in which the predicted value falls.

Real – The actual value, which is projected.

This result differs from the actual by 10%, which shows greater efficiency than using the previous method, however, both methods of calculation have a fundamental difference in setting the initial data, so their comparison is not objective.

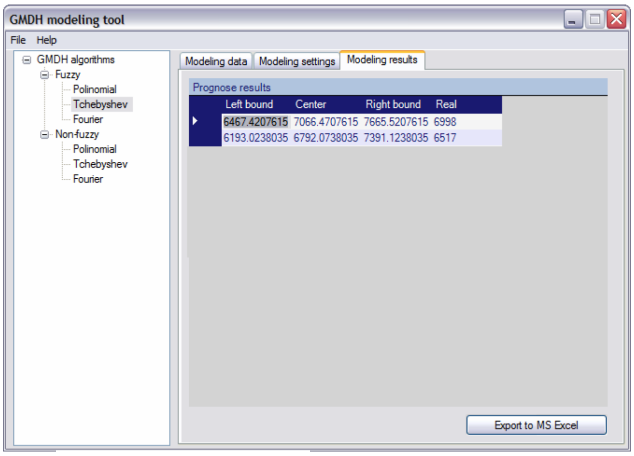


Fig.10. Result of forecast

The difference between the value of the real magnitude of GHG emissions and the projected can be explained by the fact that the original data may have an error, and that the program GMDH was designed to solve the problems of macroeconomic forecasting, and although we got an acceptable result, there is a probability of more truthful results using a specialized software.

To date, there are many applications that can help you to calculate and analyze the energy saving project, and obtain the comprehensive results with the financial, energy, environmental side. Most of them address a wide range of problems of energy conservation and energy efficiency, taking into account environmental and climatic factors. Therefore, if the desired result can be obtained in a standard way and there is an adequate mathematical model of an object, the use of systems with FL is not reasonable.

In general, the system with FL should be used in the following cases:

• For complicated processes, when there is no simple mathematical model;

• If expert knowledge about the object or process can be stated only in linguistic form.

Fuzzy systems are universal approximate functions and can produce accurate forecasts, but their design and configuration requires hard work and quality expert knowledge [13, 14].

For such projects - operational or short-term prognosis with the presence of fuzzy input information - properly designed fuzzy systems in conjunction with accurate and complete input information are the most convenient and accurate method.

The application of adequate predictive techniques, as FNN for solving the problem of short-term calculation of GHG emissions on a large industrial plant opens for it new opportunities and financial prospects for output on a carbon exchange.

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E4M-GAIA: Energy-Economy-Environment-Engineering Model of Gaia

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Abstract: This paper presents the structure and theory of a new Model, the Economy-Energy-Environment-Engineering Model of Gaia (E4M-GAIA) that has recently been developed. E4M-GAIA, adopts the same theoretical background with the "New Economics" school, mainly activated at the University of Cambridge, through –besides others- the highly-regarded macro-econometric MDM-E3 (for the UK), E3ME (for Europe) and E3MG (for the Global economy) models. It combines the features of an annual short- and medium-term sectoral model, estimated by formal econometric methods, with the detail and some of the methods of the Computable General Equilibrium (CGE) models that provide analysis of the movement of the long-term outcomes for key E4 indicators in response to policy changes. The E4M-GAIA combines a top-down approach for modeling the global economy and for estimating the aggregate and disaggregate energy demand and a bottom-up approach (Energy Technology subModel - ETM) for simulating the power sector, which then provides feedback to the energy demand equations and the whole economy. The ETM submodel uses a probabilistic approach and historical data for estimating the penetration levels of the different technologies, considering also their economic-technical and environmental characteristics. It can be used for dynamic policy simulation and for forecasting and projecting over the medium and long terms. As such, it is a valuable tool for E4 policy analysis.

Keywords: Economy-Energy-Environment-Engineering modelling, Climate Change Mitigation

7.1.1

1. Introduction

7.1.2

In recent years, climate change and the economic crisis have become the major challenges the modern society is facing. Towards tackling those challenges, decision makers have directed a number of fiscal, energy and environmental polices, implemented at regional, national or international extent. The most important development, in the thinking of many scientists and decision makers, was the adoption of the logic that the environmental challenge should be considered as a chance for economic growth. This more broad approach, namely the consideration of the interaction between different systems, has been applied to even more specific policies, e.g. energy policy has been shaped by the twin challenges of sustainability (in particular reducing emissions of greenhouse gases and other pollutants) and energy security. An important scientific outcome (IPCC, 2007), that has challenged the dominant neoclassical economic thinking, is that the economy should not be not a closed system, but it should be considered together with the energy system and the environment, when trying to estimate the consequences of climate change. Challenging theories, such the Gaia Hypothesis (Lovelock, 1972; 2009) have introduced that idea of considering the Earth as a self-controlling system, leading to the introduction of new branches such as the Gaian Economics, the Gaian Engineering etc. Moreover, alternative economic thinking, such as the "New Economics" thinking, introduced at the University of Cambridge (4CMR), challenges the dominant neoclassical theory. But, besides all this evolvement, in theoretical approaches, a clear outcome is that a more holistic approach, considering the interactions between the economy, the energy system, the environment and the engineering improvements, is needed in order to model properly the climate change mitigation and the economic crisis.

The need for integrated modelling has been further enhanced by those challenges, which revealed that the economic system should not be considered as a closed system, but it is crucial to examine its interaction with the energy system, the environment and the earth. Towards this integrated approach, most economic models have been readjusted to incorporate the dimensions of energy, environment and engineering (E4 integrated approach), while a number of alternative theoretical frameworks (Post-Keynesian, "New Economics", Economics of Climate Change, Economics of Gaia, Evolutionary economics, behavioral economics, complexity economics…) have been emerged as alternatives to the dominant neoclassical approach, in order to cover its inadequacies when facing those challenges. The E4M-GAIA model can be considered to adopt the "New Economics" theoretical background, which was introduced at the University of Cambridge, through the MDM-E3, E3ME and E3MG models, which have been evolved through time since the 1960s and the Cambridge Growth Project. Those models follow the same overall principles in their economics, construction and operation, namely: Post-Keynesian, structural, hybrid, macro-econometric and dynamic.

The E4M-GAIA model, where the G8 countries are individual regions within its 20 regions, has been used to implement this target through a portfolio of policies. The paper contributes by adopting a novel hybrid modeling approach of the energy system and the whole economy and therefore providing an alternative approach to the traditional economic equilibrium modeling. Moreover the paper aims to analyze the influence of crucial uncertainties, such as the carbon and energy pricing, in meeting deep reduction targets and to provide evidence that there exist pathways for meeting such targets and also helping the economy to grow, even when those targets are implemented among the developed countries only. The need for such evidence has been noted by the IPCC (2007) in its assessment of the literature on stringent mitigation targets. Such evidence can inform the international negotiations for a post-Kyoto global agreement.

2. Modeling Framework: E4M-GAIA Model Description

7.1.3

In projecting the future, the approach is first to consider the past. Looking back over the last 200 years, the socio-economic system seems to be characterized by ongoing fundamental change, rather than convergence to any equilibrium state. Maddison (2001) takes a long view of global economic growth over the last millennium. He finds growth rates to be very different across countries and over time, and ascribes the comparatively high rates of growth to technological progress and diffusion. He also finds that inequalities between nations in per capita GDP have increased (in particular since WW2), not diminished over time. These three features of growth (technological progress, diversity across nations and time periods, and increasing inequalities) are also characteristic to our modeling approach.

E4M-GAIA represents a novel approach to the modeling of technological change in the literature on the costs of climate stabilization. It is based upon a Post Keynesian economic view of the long-run. In other words, in modelling long-run economic growth and technological change, the "history" approach of cumulative causation and demand-led growth (Kaldor, 1957, 1972, 1985; Setterfield, 2002), focusing on gross investment (Scott, 1989) and trade (McCombie and Thirwall, 1994, 2004), and incorporating technological progress in gross investment enhanced by R&D expenditures, has been pursued. Other Post Keynesian features of the model include: varying returns to scale (that are derived from estimation), non-equilibrium, not assuming full employment, varying degrees of competition, the feature that industries act as social groups and not as a group of individual firms (i.e. no optimisation is assumed but bounded rationality is implied), and the grouping of countries and regions has been based on political criteria. The exception to the Post Keynesian approach is that at the global level various markets are closed, e.g. total exports equal total imports at a sectoral level allowing for imbalances in the data.

The model has been developed in the traditions of the Cambridge dynamic model of the UK economy MDM-E3 (Barker and Peterson, 1987) and the European model E3ME (Barker, 1999) (also see www.camecon.co.uk/e3me/intro.htm). In addition, the approach has been developed to include the bottom-up energy technology model, ETM (Anderson and Winne, 2004), within the top-down highly disaggregated macroeconomic model, E4M-GAIA. Thus, like the studies (Nakicenovic and Riahi, 2003; and McFarland, Reilly and Herzog, 2004) which are also based on the linkage of top-down and bottom-up models, our modelling approach avoids the typical optimistic bias often attributed to a bottom up engineering approach, and unduly pessimistic bias of typical macroeconomic approaches. The advantages of using this combined approach have been reviewed (Grubb, Köhler and Anderson (2002). Energy-economy-environment interactions within E4M-GAIA's hybrid (top-down/bottom-up) structure are presented in Figure 11, whereas the structure of E4M-GAIA's energy sub-model is displayed in Figure 12.

E4M-GAIA incorporates endogenous technological change in three ways:

- The sectoral energy and export demand equations include indicators of technological progress in the form of accumulated investment and R&D
- The ETM incorporates learning curves through regional investment in energy generation technologies that depend on global scale economies
- Extra investment in new technologies, in relation to baseline investment induces further output and therefore investment, trade, income, consumption and output in the rest of the world economy through a Keynesian multiplier effect.

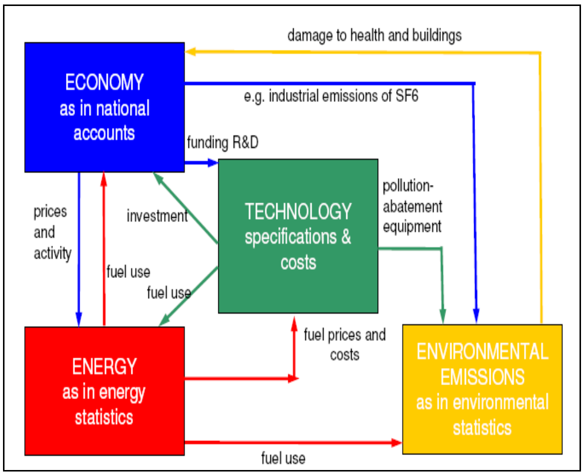

Figure 1: The hybrid (top-down/bottom-up) structure of the E4M-GAIA model

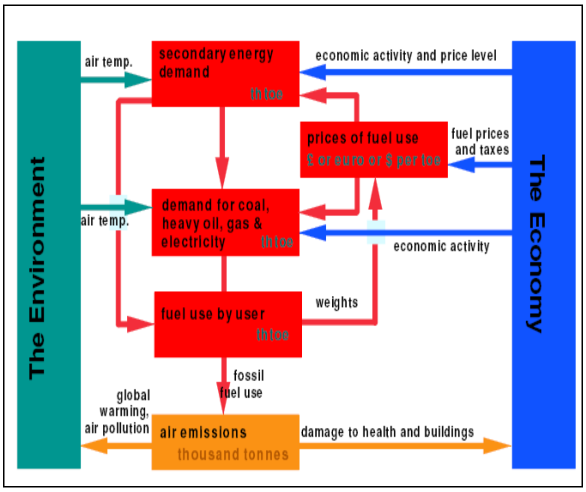

Figure 2: The structure of E4M-GAIA's energy sub-model

Mitigation and/or Policy Options and Instruments

The model is capable of explaining how low-carbon technologies are adopted as the real cost of carbon rises in the system, with learning by doing reducing capital costs as the scale of adoption increases. The model includes the economic instruments of CO2 emission allowances (auctioned or grandfathered), energy and carbon taxes, employment taxes, and other direct and indirect taxes. A rise in the costs of fossil fuels resulting from increases in CO2 permit prices and carbon taxes thus induces extra investment in low-carbon technologies, and this is larger and earlier than the investment in conventional fossil technologies in the baseline. The carbon tax revenues and part of the permit revenues are assumed to be recycled in the form of lower indirect taxes. The outcome is that the extra investment and implied accelerated technological change in the stabilization scenarios leads to extra exports and investment more generally, and higher economic growth.

The policy instruments that are explicitly in the model to promote GHG abatement are

- carbon taxes
- emission permit schemes are at regional and global levels by any mix of energy sectors
- revenue recycling
- R&D expenditures in total by sector and region.
- incentives
- regulation

These need to be supplemented by policy instruments associated with technological agreements between countries need to be included to allow for reductions in costs brought about by adoption of common standards and reduction of market barriers.

ETM - The Energy Technology Sub-model

A hybrid modelling approach has been implemented by linking with E4M-GAIA an annual, dynamic technology model, referred to here as the ETM model. The ETM sub-model has been built to generalize earlier work by Anderson and Winne (2004) to form the basis of a new energy technology component of E4M-GAIA. Although the ETM is not specifically regional and is not estimated by formal econometric techniques, it does model, the switch from carbon energy sources to non-carbon energy sources over time. It is mainly designed to model electricity supply technologies, but incorporates also technologies that cover other type of energy demand e.g heat.

The ETM model was designed to account for the fact that a large array of non-carbon options is emerging, though their costs are generally high relative to those of fossil fuels. However, costs are declining relatively with innovation, investment and learning-by-doing. The process of substitution is also argued to be highly non-linear, involving threshold effects. The ETM models the process of substitution, allowing for non-carbon energy sources to meet a larger part of global energy demand as the price of these sources decrease with investment, learning-by-doing, and innovation, learning –by-researching.

One component of the ETM is the learning curve. The importance of including a learning curve in the model cannot be underestimated, as the technology costs do not simply decline as a function of time, but decrease as experience is gained by using a particular technology. The learning curve in the ETM has the form

$$CC_t = CC_0 (X_t / X_0)^{-b} \quad (1)$$

where Ct are the capital costs at time t, C0 initial costs, Xt the cumulative investment (taken as an indicator of experience) in the technology by time t from the time of its first introduction and b is the 'learning-curve parameter'. This relationship is highly non-linear, especially in the early phases when Xt is small and experience accumulates rapidly. Figure 13 below shows the effect, in which market share is taken as a proxy for Xt.

To estimate the Unit cost, the fixed and variable maintenance costs, besides the capital cost, are considered, as following:

$$C_t = A(n,r) \cdot CC_t \cdot X + MC_t \cdot X + FUC_t \cdot Q / n \quad (2)$$

Where A(n,r) is the annuity rate for a plant life of n years and an interest rate of r, c is capital cost per kW installed, X the installed capacity, MC the fixed annual cost (mostly maintenance) per unit of capacity, FUC the cost of fuel, Q the annual kWh output and η the plant efficiency. A recent modelling update, is the incorporation of the carbon cost in the fuel cost.

As investment is made in 'new' technologies, learning takes place and the cost of the new technology lowers so that it becomes competitive with the 'old' technologies. For each type of energy demanded there is usually a technology or fuel 'of choice'—what might be termed a 'marker' technology—against which the alternatives will have to compete. In the ETM, the capital, operating and maintenance costs are being used to estimate the net present value of the different technologies, which is used for expressing the relative costs of the alternatives. Operating costs consider fuel and carbon prices. Those relative costs are readjusted based on the incentives or taxes that are applied to the different technologies. Even though the numeraire technology may comprise the majority of the market, there are always so-called niche markets and opportunities where the non-carbon technology is cheaper than then numeraire. Photovoltaics, although their relative costs were several times higher compared to a marker technology, took a small share in the market, even without the presence of a favorable policy e.g. feed-in tariff. This can be justified, concerning cost-effectiveness, in case of off-grid installations, but this is not always the case. Historical data show that several energy investments can not be justified by using cost optimization techniques, adopted by most energy system models. On the other hand, energy investments consider a number of critical issues, sometimes contradicting with each other. Such factors are political decisions (nuclear in France), volatility in prices, energy security issues, technology transfer agreements being part of intergovernmental agreements for wider economic cooperation, social issues (public opposition), technical and environmental issues that create a high uncertainty in investing to a single technology, based on its cost-effectiveness compared to the others. This reason has led to an examination of the penetration capability of different technologies (Anderson and Winne, 2004), by estimating their substitution elasticities. This approach is in correspondence with similar approaches adopted to examine regional interdependencies in our globalized economy (Pesaran et. al. 2004)

Figure 4 shows the Market Share of marker technology and technology i and the Rate of Change of Market Share vs Relative Prices of marker technology to alternative technology i. The left scale shows the market share of the technologies (marker and technology i) based on their relatives prices. If they cost the same (considering their capital, operating and maintenance costs and also any incentives or taxes), they take the same share of the new investments. The right scale shows the substitution elasticity α between the technologies (marker and technology i), based on the frequency distribution of relative prices. Narrow distribution means small standard deviation and large value of the parameter α. The distribution presented in this table is symmetrical, but historical data lead in several cases to unsymmetrical distribution figures.

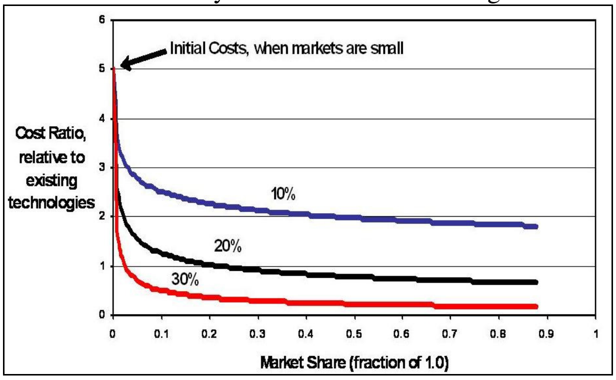

Figure 3: Threshold effects in Technology Development (learning rates in percentages)

The General Structure of the ETM

Some of the substitute technologies are restricted for technical reasons, for instance the amount of intermittent renewable energy that can be permitted on the electricity grids, and others for economic reasons, for instance the rising costs of land use by biomass or onshore wind. In the ETM, these restrictions are represented by a rising cost of use as the limits are reached or by imposing an upper level of penetration.

The main equations used in the ETM to model the switch from carbon technologies to non-carbon technologies, as costs decrease are listed below. For the electricity sector, the marker technology (n) or numeraire is the Natural Gas IGCC technology. The superscript E refers to the electricity sector.

Substitution equations for new technologies:

$$S_{it}^{E} = S_{it-1}^{E} + a_i^{E} S_{it-1}^{E} \left(\hat{S}_{it-1}^{E} (1 + S_{it-1}^{E} - \sum_i S_{it-1}^{E}) - S_{it-1}^{E} \right) \left(P_{it}^{E} - P_{it-1}^{E} \right)$$

(3)

where S is market shares in new investment.

Marker technology:

$$S_{nt}^{E} = 1 - \sum_i S_{it-1}^{E} \quad (4)$$

Investment:

$$I_t^{E} = D_t^{E} - D_{t-1}^{E} + \delta_n U_{nt-1}^{E} + \sum_i \delta_i U_{it-1}^{E} \quad (5)$$

where Dt is the demand for electricity at time t and is the retirement rate of technology i.

Cumulative net investment:

$$U_{it}^{E} = U_{it-1}^{E} + S_{it-1}^{E} I_{t-1}^{E} - \delta_i U_{it-1}^{E} \quad (6)$$

Ditto, marker technology:

$$U_{nt}^{E} = U_{nt-1}^{E} + S_{nt-1}^{E} I_{t-1}^{E} - \delta_n U_{nt-1}^{E} \quad (7)$$

Cost dynamics:

$$C_{it}^{E} = C_{it-1}^{E} - \frac{b_i^E}{W_{it}^E}\left(W_{it}^{E} - W_{it-1}^{E}\right)\left(C_{it}^{E} - C_{it-1}^{E}\right) \quad (8)$$

The ETM sub-model besides the electric system expansion, it estimates the dispatch of the power units, providing non-linear solutions as also as in the electric expansion problem. From equation (2) it can be derived that the electricity generation cost from the operation of the different units depends on its maintenance and fuel costs (incorporating carbon cost) and is in the form of:

$$C_i = a_i + b_i P_i + cP_i^2 \quad (9)$$

where Pi is the power output of each unit.

Considering the operation of the real electricity market, based on expertise gained from the Hellenic Transmission System Operator and other markets within the ENTSOE, the dispatch of the electricity generation units is estimated in European electricity markets according to the minimization of the following components:

Min (GenerationCost + StartUpCost + ShutDownCost - LoadRevenue + ReserveCost + PenaltyCost)

(10)

where the StartUpCost and ShutDownCost are the costs of restarting and switching off a unit respectively, while the ReserveCost and PenaltyCost are the costs for ancillary services and for violating the market mechanism respectively. All those costs, together with the GenerationCost of equation 9 are subtracted from the LoadRevenue, which represents the Load declarations from the Load Representatives. The LoadRevenue in case of the E4M-GAIA represents the electricity demand estimated through the econometric equations, multiplied by the electricity price. A process of obtaining detailed info from European Markets is underway, in order to from the electric dispatch problem with more robustness. However, as E4M-GAIA is not a detailed energy system model and its electricity units are representative units, the other components of the production costs for the units, have been considered as a fraction of the GenerationCost, therefore the Cost of the Units has the form of equation 9.

Moreover, it has been noted in several countries that this neoclassical cost-optimization modelling approach faces the same problem (divergence from real data), when implemented in the estimation of the mix in the electricity generation as in the electric capacity. For this reason, historical data is also used in the dispatch problem in order to consider the imperfection of markets. But we don't model in detail the causes of this imperfection for the different regions, e.g. different technical issues, oligopolistic conditions, speculation of the market, use of resources for different purposes (use of water for irrigation, water supply and electricity generation). In order to catch the effect of market imperfections (Skytte, 1999), we implement the economic dispatch problem (under any environmental constraints) for the last 5-10 years. This shows the divergence with the real data, which is attributed to a market imperfection factor. This factor, although it may have different actual meaning for the different regions, is not disaggregated any further for the time being, as this is done in other approaches (Martinsen and Krey, 2008) to model external factors. Therefore we consider the historical data as the starting point for the electricity generation, on which the different units readjust their electric output based on the operating (including fuel and carbon prices) and maintenance costs as the electric demand evolves.

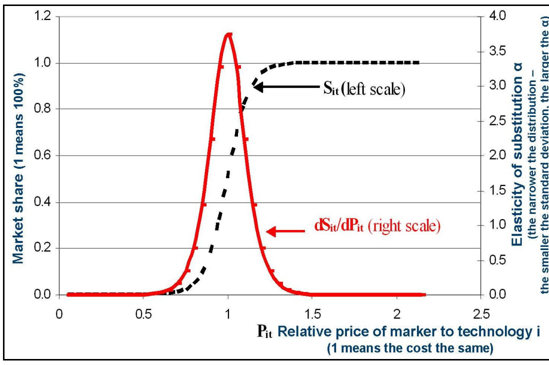

Figure 4: Market Share of marker technology and technology i (black line) and Rate of Change of Market Share vs Relative Prices of marker technology to alternative technology i (red line).

Energy demand equations

The energy demand equations For energy demand, a 2-level hierarchy is being adopted. A set of aggregate demand equations on annual data covering 19 fuel users/sectors and 20 regions is estimated and is then shared out among main fuel types (coal, heavy fuel oil, natural gas and electricity) assuming a hierarchy in fuel choice by users: electricity first for "premium" use (e.g. lighting, motive power), non-electric energy demand shared out between coal, oil products and gas. The energy demand for the rest of the 12 energy carriers is estimated based on historical relations with the main 4 energy carriers. All energy demand equations use co-integrating techniques, which allow the long-term relationship to be identified in addition to the short-term, dynamic one. A long-term behavioural relationship is identified from the data and embedded into a dynamic relationship allowing for short-term responses and gradual adjustment (with estimated lags) to the long-term outcome. The equations and identities are solved iteratively for each year, assuming adaptive expectations, until a consistent solution is obtained.

The economy aggregates, such as GDP, are found by summation. This enables representation of the wider macroeconomic impacts of policies focused on particular sectors, including rebound effects. These long-run energy demand equations are of the general form given in equation (11), where X is the demand, Y is an indicator of activity, P represents relative prices (relative to GDP deflators for energy), TPI is the

Technological Progress Indicator, the β are parameters and the ε errors. TPI is measured by accumulating past gross investment enhanced by R&D expenditures (Lee et al. 1990, p. 117) with declining weights for older investment. The indicators are included in many equations in the model, but only those for energy are analysed here. All the variables and parameters are defined for sector i and region j.

$$X_{i,j} = \beta_{o,i,j} + \beta_{1,i,j} Y_{i,j} + \beta_{2,i,j} P_{i,j} + \beta_{3,i,j} (TPI)_{i,j} + \varepsilon_{i,j} \quad (11)$$

In the equations, β2,i,j are restricted to be nonpositive, i.e. increases in prices reduce the demand. In the energy equations β3,i,j are estimated to be negative, i.e. more TPI is associated with energy saving. These parameters are constant across all scenarios. Further information on the energy demand equations can be found on a recent paper (Barker at. al. 2009). The E4M-GAIA model is under development and a detailed description of the whole model is expected in the medium term. However, information on the theory of the model can be found on several publications (Barker et. al. 2009; Barker and Scriescu, 2009; Barker at. al. 2006) and also on the description of the MDM-E3 (Barker and Peterson, 1987; http://www.camecon.com/suite_economic_models/mdme3.htm) and E3ME (http://www.camecon.com/suite_economic_models/e3me.htm) models, as all three models share similar structure and theoretical approach.

3. Implementation of mitigation policies

An important advantage of the E4M-GAIA model is that it is an energy-economy-environment model of the global economy, allowing for the global reduction in costs of technologies if adopted by many countries. The cumulative investments on alternative technologies at global level, allow their faster penetration. Deep emission reduction targets, such as those examined at this paper, could be achievable at much lower costs when implemented internationally. CO2 reduction targets are achieved through a portfolio of policies. This is in contrast with most energy system models or general/partial equilibrium models which impose a reduction target exogenously and the models estimate the marginal abatement cost for meeting this target. Examples of policies that can be considered in E4M-GAIA, when implementing a mitigation target, are:

- Carbon price (either through Carbon trading for the Emission Trading System (ETS) sectors or Carbon Tax for the rest of the economy) is implemented. The revenues are recycled via the following policies.
- Incentives for electricity technologies through revenue recycling. These revenues are raised from the auctioning carbon permits. This subsidy is spread across new technologies i.e. renewables and CCS (excluding nuclear and hydro).
- Accelerated diffusion of electric plug-in vehicles is assumed through technological agreements and behavioural shifts in transport demand.
- Revenues raised from carbon permits auctioning are recycled to energy-intensive industries in order to incentivize the conversion to low-carbon production methods.
- Carbon tax revenues from households are recycled via investments in energy efficiency by providing incentives for improving the energy efficiency of domestic dwellings and appliances and for introducing new ones such as low-emission dwellings and solar appliances.
- Accelerated carbon price increase at an earlier year e.g. 2020

Moreover, the mitigation scenarios are implemented under the following main modeling assumptions:

- The discount rate is required only in the energy technology sub-model (10%), for estimating the net present value of the different technologies.
- Penetration of technologies in electro-production is based on (Anderson and Winne 2007): the theory combines the estimation of net present value and a probabilistic approach fro the diffusion of technologies compared to a marker technology.
- Reduction targets are implemented through a set of polices. These reduction targets are not set, but achieved via specially designed policy packages.
- International drivers are assumed.
- Macro effects are assumed e.g. in energy efficiency policies the direct plus macroeconomic rebound effect is considered.
- Economy is not treated as being in equilibrium.
- Full utilization of resources (e.g. no unemployment) is not assumed.

4. Conclusions

This paper aims to present the theory of E4M-GAIA model, which shares similar theoretical background with the Cambridge “New Economics” school of thinking. Therefore it is a macro-econometric model of the global economy, its dynamic and structural and it more over emphasizes on a more robust representation of the energy system, which is crucial for implementing mitigation targets. Therefore it aims to model in more detail the interactions between the economic system and the energy and environment, considering also the critical role of the technology process and engineering. To do so it adopts a hybrid approach. The aggregate and disaggregate energy demand is estimated using econometric techniques, allowing for fuel switching for the 12 different fuel types and for the 19 fuel users, while the power sector is simulated using a probabilistic approach which considers the economic, technical, environmental characteristics of the power units but considers also the history. The electric system expansion is modeled by estimating parameters for the different technologies based on historical data, which allows new technologies to gain a share in the market even when their cost is higher than conventional technologies. Moreover the dispatch of the different technologies to meet the electric demand, although using the cost optimization approach comparing the penetration of the different technologies, takes historical data as its starting point. Both the energy demand system and the energy technology options are implemented so as to model market imperfections which exist in all markets and are not usually considered in the classical cost optimization techniques. These market imperfections, resulting either from socio-political factors or from the presence of oligopolies that speculate on the electricity price, cause differentiation in the electricity mix across countries and lead in many cases to significantly different profiles from those projected from cost-optimization approaches. Finally it considers a holistic approach, but considering the earth as one entity, adopting the general framework of the Gaia hypothesis, where the earth should be considered as one entity. A great challenge if the E4M-GAIA model, towards this direction, is to be linked with well-standing Earth System models, such as the NASA GISS models. E4M-GAIA can be considered as a useful model, for implementing E4 policies and facing challenges such as the climate change and the financial crisis.

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Modelling the Transport Energy System towards implementing climate policies

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Abstract: The transport sector is one of the major polluting sectors and one of the few that is still increasing rapidly its emissions even in the developing countries. Any climate portfolio incorporates structural changes in the transport energy system, towards deep reductions in its emissions and even its total decarbonisation. Therefore the modelling of the transport system and its interactions with the whole economy and the rest energy system is very important. This paper describes a transport model that has been developed to model passenger travel demand, freight demand and resulting energy consumption and pollution emissions in the transport sector, across the four modes of rail, road, rail, water and air. The transport model is disaggregated in several classifications and requires detailed historical data from several official resources.

Keywords: Transport Modelling, Transport Energy Demand, econometrics

5. Introduction

The transport sector is the fastest growing energy consuming sector worldwide (IEA, 2009), mainly linked to the urbanization in the developing countries and the globalization of trade. Moreover at a national level, transportation is an important part of national economy and functions as its foundation, support, and service provider. Several national and international studies, together with the national communications to the United Nations Framework Convention on Climate Change (UNFCCC), have attempted to analyze the trends in the transport sector, at national or regional level, towards identifying priorities for efficiency improvements, behavioural shift, green fiscal reform and advances in environmental protection. As the world concerns about the transportation for its sharply increasing energy consumption, are highlighted by different governments, international organizations, and experts, a comprehensive effort has been devoted on modelling the transport system in more detail.

A number of robust models have been developed towards producing impact assessment studies from the implementation of different policies in to the transport sector in the EU, including the TREMOVE software (www.tremove.org), the PRIMES (http://www.e3mlab.ntua.gr/) and the GAINS (http://www.iiasa.ac.at/webapps/apd/gains/) models, all of them being used officially by the European Commission. Moreover COPERT model (http://lat.eng.auth.gr/copert/) is highly regarded for vehicle stock detail and the methodology in the estimation of road transport emission factors.

At a national level, and more specific for the UK- which is the target of this paper, there also exist a number of alternative modelling approaches, such as the Society Energy Environment simulation transport models (SEE), The DfT's National Transport Model (DFT), the MARKAL transport submodel (UKERC MARKAL), the UK Transport Carbon Model (UKTCM), econometrics models (Bonilla, 2009) and more integrated approaches (Hall et al., 2010). Those approaches, although targeting to answer different research questions, consider the crucial role of the transport energy demand and its influence on the environment. Therefore, a new alternative approach of treating the transport energy demand is useful, when directed to examine the underlying trends.

This paper aims to provide a new approach in estimating transport system figures, the energy demand being one of them. Using cointegration econometric method with Error Correction Model (Engle and Granger, 1987), a new transport model is being developed, which is incorporated as a sub-model in the MDM-E3 model of the UK economy (Junankar et. al., 2007). The transport submodel is being developed to model passenger travel demand, freight demand and resulting energy consumption and pollution emissions in the transport sector, across the four modes of rail, road, rail, water and air. The transport submodel is disaggregated in several classifications, as described in section 2, and requires detailed historical data from several resources.

6. Modelling Framework

The development of the transport sub-model, and its incorporation in the MDM-E3 model, was in part funded by the Green Fiscal Commission (GFC) and partly by the UK energy research centre (UKERC). The sub-model was designed and implemented by Dr Athanasios Dagoumas, as part of the Cambridge Centre for Climate Change Mitigation Research (4CMR) in collaboration with Cambridge Econometrics (CE), and it is based on a relevant research (Johnston, 1995).

The transport sub-model, in addition to the activity and price effects found in the equations in the main energy MDM-E3 submodel, incorporates explanatory variables specific to transport. This allows for a more detailed analysis of the transport sector, notably;

- the distinction between freight and passenger km
- the distinction between efficiency gains and demand reduction
- the uptake of new vehicle technologies
- new vehicle characteristics and the characteristics of the overall stock

Three key variables are estimated over the historical and forecast period using econometric equations: passenger travel demand (passenger transport kilometres); fuel efficiency of new vehicles; and vehicle purchases. Passenger kilometres are then converted into vehicle kilometres based on average occupancy rates, which become the basis for the estimation of energy consumption and pollution emissions. Fuel demand is solved for each fuel as a function of vehicle km and average stock fuel efficiency.

Emissions from fuels are solved based on implied emissions coefficients for the different fuel types. There is an alternative specification for emissions using full vehicle and technology emissions to capture end-of-pipe measures for NOx, PMs, etc. The stochastic equations for the 3 key variables and the way these are used to estimate the sub-model outputs are described below.

Travel demand in passenger kilometres is solved across 15 network types and 22 vehicle types (eg cars on rural roads, buses on urban roads) and is a function of income (or activity proxy for freight), price (composition of running costs), vehicle and network availability, speed and safety, competing passenger km demand. As a further extension of the model we intend to further disaggregate passenger km demand by 13 trip length types and 7 trip purposes. For each vehicle type, there is a choice of technologies – 3 rail technologies, 10 road technologies, 2 water technologies and 2 technologies for air travel. For some of these technologies, alternative fuel choices are possible.

Fuel efficiency of new vehicles is solved across 18 technology types and 22 vehicle types (eg cars ICE petrol, buses ICE diesel, int. air kerosene eng.) and is a function of: investment, price of fuel, time and a dummy variable for new vehicle fuel efficiency standards, which for the time being is not used. Vehicle efficiency for new vehicles is estimated on the basis of econometric equations for existing technology choices and using exogenous forecasts for new technology choices. Then the efficiency of the entire stock is estimated.

Purchases of new vehicles are solved across 22 vehicle types and 18 technology types (eg cars: ICE petrol, buses: ICE diesel, international air: kerosene engines) and are a function of: income, price of vehicle, existing vehicle stock and a dummy variable for subsidies in specific transport vehicles, which for the time being is not used. Vehicle purchases are estimated on the basis of econometric equations. The vehicle stock is specified by age of vehicle. Changes to vehicle stocks are then calculated using vehicle purchases as new vehicles of less than one year old and old vehicles being scrapped according to a vehicle survival function.

The development of the transport sub-model enables the investigation many more scenarios regarding transport policy options with respect to climate change mitigation: • new vehicle technologies in the vehicle stock, eg plug-in hybrid

- efficiency gains (improvements to existing technologies)
- modal shift (switch from cars to buses)
- demand reductions (behavioural changes)
- varying fuel taxes (induced demand and efficiency effects)
- vehicle purchases taxes
- increased occupancy (max. use of air travel capacity)
- varying income growth and the effect on the vehicle stock profile

The existing linkages between the transport submodel and the MDM-E3 model are only through fuel demand for road transport.

This new submodel, enables the implementation of green portfolios, such as a green fiscal reform (Junankar et. al., 2009), the hybrid estimation of the transport energy demand or the electricification of the transport system. Therefore it is an important tool for understanding in more detail the transport system and therefore directing more carefully new strategies and policies.

7. Classifications

The transport submodel is disaggregated into several classifications, as can be seen in the following table. It has to be mentioned, that the submodel has been designed to estimate several variables for the passenger and freight transport, but for the time being the latter is not covered. Moreover, for the time being the submodel does not cover some of the classifications, such as the trip length and trip purposes.

The vehicle classification includes more disaggregated forms of Rail, Water and Air transport, but at present energy demand from these forms of transport is still solved using the top down equations. This comes from the fact that although passenger and vehicle demand is estimated for all modes, stochastic equations for estimating the vehicle efficiency exist only for road transport. The vehicle technology classifications differentiates between propulsion technologies such as petrol and diesel-fuelled internal combustion engines but also makes available, principally for scenario analysis, more recent technologies, such as hybrid, plug-in hybrid and hydrogen-powered technologies. In addition to the motor spirit and derv fuel types accounted for in the main energy submodel, the transport submodel is able to distinguish between different renewable fuels such as first and second generation biodiesel, methanol, ethanol and hydrogen. By differentiating network types it is. For example, possible to examine the effects on fuel demand of increasing the UK's motorway network compared to other major roads. Finally, the transport submodel is designed to allow the further disaggregation of transport demand by trip length and trip purpose, which will enable, once the appropriate data are collected, the examination of behavioural shift policies.

8. Data Sources

The submodel is disaggregated and requires detailed historical data from a number of official resources. Data for the period 1977-2005 have been collected for all stochastic and explanatory variables, while most variables have been updated with the very latest data (up to year 2008).

The main resources used are:

- Department of Business Enterprise and Regulatory Reform (BERR) publications
- Digest of UK Energy Statistics (DUKES), 2008 edition
- ECUK – Energy Consumption in the UK, 2008 edition
- Department for Transport (DfT) publications
- Transport Statistics Great Britain (TSGB), 2008 Edition
- National Travel Survey (NTS) 2007
- Public Transport Statistics Bulletin (PTSB): Great Britain, 2008 edition
- Vehicle Licensing Statistics (VLS), 2008 edition
- Various sources
- Office of Rail Regulation (ORR), National Rail Trends 2007-2008
- National Atmospheric Emissions Inventory (NAEI), data up to 2006
- SMMT – Society of Motor Manufacturers and Traders, UK New car Registrations by CO2 Performance, 2006
- International Civil Aviation Organization (ICAO), 2008 edition
- Sustrans, The national cycle network, data up to 2005

9. Stochastic Equations

Three key variables are estimated over the historical and forecast period using cointegration econometric method with Error Correction Model. Those are: passenger travel demand, fuel efficiency of new vehicles and vehicle purchases of new vehicles.

(I) Travel demand in passenger kilometres by vehicle and network type

Long-run equation:

$$\begin{aligned}\ln(TPKE_{i,k,t}) &= \beta_{12} + \beta_{13}\ln(RPDH_{t-1}) + \beta_{14}\ln(PROW_{i,t-1}) \\ &+ \beta_{15}\ln(TPKW_{i,k,t-2}) + \beta_{16}\ln(PCE_{i,t-1}) \\ &+ \beta_{17}\ln(TVAV_{i,t-1}) + \beta_{18}\ln(TNAV_{k,t-1}) \\ &+ \beta_{19}\ln(TSPD_{i,t-1}) + \beta_{20}\ln(TSFT_{i,t-1})\end{aligned}$$

Dynamic equation:

$$\begin{aligned}d\ln(TPKE_{i,k,t}) &= \beta_1 + \beta_2\, d\ln(RPDH_t) + \beta_3\, d\ln(PROW_{i,t}) \\ &+ \beta_4\, d\ln(TPKW_{i,k,t-1}) + \beta_5\, d\ln(PCE_{i,t}) \\ &+ \beta_6\, d\ln(TVAV_{i,t}) + \beta_7\, d\ln(TNAV_{k,t}) \\ &+ \beta_8\, d\ln(TSPD_{i,t}) + \beta_9\, d\ln(TSFT_{i,t}) \\ &+ \beta_{10}\, d\ln(TPKE_{i,k,t-1}) + \beta_{11} EC_{i,k,t-1}\end{aligned}$$

Where:

TPKEi,k,,t	transport passenger kilometres (billion kms)
RDPHt	real personal disposable income (RPDI) / number of households (RHLT)
PROWi,t	own price for transport vehicle types
TPKWi,k,t	inverse weighted lagged TPKE sum(TPK1)-TPK1(i,k)
PCEi,t	consumer price index for SC (SPC/SC)
TVAVi,t	transport vehicle availability (stock/departures * number of average seats) in Thousands

TNAVk,t	transport network availability in Kilometres / Aircraft Movements (Departures) in Thousands
TSPDi,t	transport vehicle speed in mph
TSFTi,t	transport vehicle safety as Passenger casualty rates per billion passenger kilometres
i = 1,..., 22	transport vehicle type
k = 1,..., 16	transport network type

The specifications of the passenger demand equations enable the analysis of the effect of critical factors:

- Vehicle availability (the size of vehicle stock; a larger fleet would be expected to increase kilometres travelled)
- Network availability (a measure of the quality or connectedness of the infrastructure; a larger network would be expected to have non-negative effect on demand)
- Vehicle speed (currently, the submodel does not allow for the possibility that greater travel demand on a given network type, such as motorways, may lead to greater congestion and reduce vehicle speeds)
- Casualty rates (a proxy for the safety of different modes of transport)

(II) New vehicle fuel efficiency by technology and vehicle type

Long-run equation:

$$\ln(TFFN_{n,i,t}) = \beta_8 + \beta_9 \ln(YKE_{t-1}) + \beta_{10} \ln(PFU1_{n,t-1}) + \beta_{11} \ln(PFU2_{n,t-1}) + \beta_{12}\, TIME_{t-1}$$

Dynamic equation:

$$d\ln(TFFN_{n,i,t}) = \beta_1 + \beta_2\, d\ln(YKE_t) + \beta_3\, d\ln(PFU1_{n,t}) + \beta_4\, d\ln(PFU2_{n,t}) + \beta_5\, d\ln(TIME_t) + \beta_6\, d\ln(TFFN_{n,i,t-1}) + \beta_7 EC_{n,i,t-1}$$

Where:

TTFNn,i,t	new vehicle fuel efficiency (l/100km)
YKEt	cumulated YK enhanced by YRD
PFU1n,t	lagged own prices for each transport technology type n
PFU2n,t	double lagged own prices for each transport technology type n
TIMEt	is time trend
n = 1,..., 18	transport technology type
i = 1,..., 22	transport vehicle type

(III) New vehicle purchases by vehicle and technology type

Long-run equation:

$$\ln(TVPV_{i,n,t}) = \beta_8 + \beta_9 \ln(RPDI_{t-1}) + \beta_{10} \ln(PCES_{i,t-1}) + \beta_{11} \ln(TVSE_{i,t-2}) + \beta_{12}\, TIME_{t-1}$$

Dynamic equation:

$$d\ln(TVPV_{i,n,t}) = \beta_1 + \beta_2\, d\ln(RPDI_t) + \beta_3\, d\ln(PCES_{i,t}) + \beta_4\, d\ln(TVSE_{i,t-1}) + \beta_5\, d\ln(TIME_t) + \beta_6\, d\ln(TVPV_{i,n,t-1}) + \beta_7 EC_{i,n,t-1}$$

Where:

TVPEi,n,,t	transport vehicle purchases by technology type (thousands)
RPDIt	is real personal disposal income
PCESi,t,	(vehicle purchases expenditure) / (general consumer price index)
TVSEi,t	transport vehicle stock (thousands)
TIME	is time trend
i = 1,..., 22	transport vehicle type
n = 1,..., 18	transport technology type

The net change in the vehicle stock each year is calculated as purchases of new vehicles (determined by the new vehicle purchases equations) minus the number of vehicles that have not survived from the previous year. The survival rates that determine the proportion of vehicles lost each year are based on an exponential function such that the rate at which vehicles are scrapped increases with their age.

The fuel efficiency of the vehicle stock is estimated using the latter set of equations, which enable the analysis of the effect of critical factors:

- Technological progress, represented by the quality-adjusted measure of investment found in many of the economic and energy equations of MDM-E3; in this case, it concerns the technological progress by the Motor Vehicle industry
- Purchase of more economical vehicles in times of high fuel prices (currently based on fuel prices in the previous two years)

Having calculated the kilometres travelled by each vehicle type, the fuel efficiencies of the vehicle technologies are applied to calculate the fuel demands (the fact that different vintages of vehicles will have differing fuel efficiencies is accounted for).

10. Conclusions

This paper provides an overview of a transport model that has been recently developed and incorporated in the macro-economic Multisectoral Dynamic Model of the UK economy (MDM-E3). The transport submodel is being developed to model passenger travel demand and resulting energy consumption and emissions in the domestic transport sector at disaggregated level (22 vehicle, 15 network, 18 technology types and 16 energy carriers). It covers the four modes of road, rail, water and air but in different detail. The submodel has been very recently developed at the Cambridge Centre for Climate Change Mitigation Research (4CMR) and Cambridge Econometrics.

The transport submodel estimates the passenger travel demand, the fuel efficiency and the vehicle purchases of the new vehicles over the historical and forecast period using co integration econometric equations. Several sources such as the Transport Statistics Great Britain, National Travel Survey, National Rail Trends, Society of Motor Manufacturers and Traders, Public Transport Statistics bulletin, ICAO and others have been used to obtain information on critical parameters of the transport system, such as stock, network infrastructure, speed, reliability and safety. Moreover the submodel gets feedback from the economic equations of the main model concerning critical economic figures such as general consumer price index, real personal disposal income, vehicle purchase expenditure and others. The transport submodel provides feedback to the main energy submodel which also estimates the energy demand for the transport sector, but at an aggregate level (road, rail, water and air). Such a hybrid approach allows a combined top-down and bottom-up examination of the driving forces of the energy demand in the transport sector. The transport submodel allows a detailed analysis of the transport sector such as the distinction between efficiency gains and demand reduction, the uptake of new vehicle technologies, the distinction between the characteristics of the new vehicle and of the overall stock.

This new submodel, enables the implementation of climate policies, such as a green fiscal reform [20], the hybrid estimation of the transport energy demand or the electricification of the transport system. Therefore it is an important tool for understanding in more detail the transport system and therefore directing more carefully new strategies and policies.

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Assessment of Emission Factors and Mitigation Options in Electricity Sector of Turkey: A Model Study

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Abstract: This study aims to analyze the future mitigation potential of CO_2 emission from electricity generation using LEAP (Long-range energy alternative planning system) model setting the year 2006 as the base year. LEAP is an energy planning model covers energy demand, transformation and supply. LEAP uses a simulation approach to represent the current energy situation and to develop forecasts under certain assumptions. Furthermore, current fuel specific emission factor for lignite has been calculated and the electricity supply scenarios up to 2020 are simulated. The results can guide policy makers on setting sectoral mitigation targets by fuel share and using available renewable energy sources for electricity production.
Keywords: CO_2 modeling and simulation, electricity production, mitigation potential.

Introduction

Increasing energy consumption has long been connected directly to economic growth. The electric power sector is the most critical to meeting development goals. Today coal is a key contributor to the EU's security of energy supply. By year 2006, about 29% of the power generation in the EU-27 is coal-based power plants (EUROSTAT,2009). It is expected that, coal and lignite based power generation will continue to play a major role in EU energy system. Turkey ranks among the fastest growing energy markets in the world. Gross electricity demand of Turkey increased from 57,500 GWh in 1990 to 194,100 GWh in 2009 (TETC, 2010). As a result of this, Energy-related CO_2 emissions have more than doubled since 1990 (In 2008, the highest CO_2 inrease is in energy sector by 114% comparing to 1990) (TURKSTAT,2010). It is likely to continue to increase fast in parallel with significant growth in energy demand. This indicates that the energy policies, energy supply and consumption all have major effect on occurring of GHGs. In Turkey the share of electricity in energy consumption is increasing. Therefore electricity is considered as the priority sector taking action for GHG mitigation measures while supplying the increasing electricity demand and mitigation potential should be identified. Turkey is ratified Kyoto Protocol (KP) in 2009 and is the only Annex-I country that has not set mitigation targets for the post-2012 period.

Turkey has now been working on further developing its post-2012 approach and determining its commitments as a party to the KP. Turkey has set a unilateral quantitative target for CO_2 emissions from the energy sector (-7% from the reference scenario level in 2020), as defined in its 2009 National Climate Change Strategy (IEA/OECD,2010). Turkey's approach is to implement policies and measures to protect the climate system. One of the approaches is the sector-based CO_2 emission mitigation policies. Turkey is planning to reduce the production of CO_2 in energy sector. Some new technologies could be implemented such as integrated gasification-combined cycle and circulating fluidized bed combustion from the continued use of coal in power plants while share of renewables are increasing. Besides, in the long term, carbon capture and storage will promise.

This study aims to analyse the future mitigation potential of CO_2 emission from electricity generation using LEAP (Long-range Energy Alternative Planning System) model which is an energy planning model covers energy demand, transformation and supply. In this study current fuel specific emission factors has been evaluated and emission factors for lignite was calculated. The electricity supply scenarios up to 2020 considering the base year 2006 are simulated.

Turkey's Electricity Sector

Turkey's total national installed capacity is about 45.000 MW by the end of 2009, while it was 16.318 MW in 1990 with the average annual growth rate of 5%. Total power generation rose from 57.543 GWh in 1990 to 194.100 GWh in 2009, average growth rate is 6,7% (Fig.1).Thermal power plants share in installed capacity increased from 58,4% in 1990 to 66% in 2008 and lignite+hard coal have 24,4% share in 2008.
Figure 2

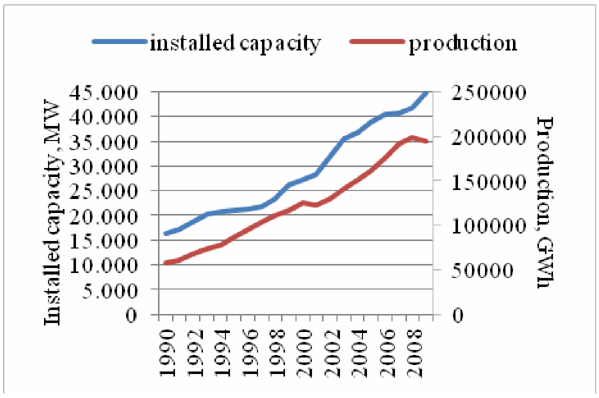

Figure 1: Development of Turkey's electricity sector (TETC, 2010)

However, Turkey has significant potential of renewable energy sources such as wind, solar, geothermal and biomass. The economically viable potential of 40.000 MW wind as medium efficiency, 36.000 MW hydro, 600 MW geothermal installed capacity, and 380.000 GWh/year solar and 11.575 GWh/ year biomass production capacity for electricity. Ministry of Energy and Natural Resources has explained in its recent Strategic Plan for 2010-2014 the aim the share of renewable energy resources within the electricity supply up to 30% corresponds to a significant CO_2 emission reduction potential. As demand projections in the report are up to year 2018 and the scenario analysis needed data till year 2020, last two years demand projections were calculated with the same rate of the previous years and given in Table 1. Turkey has 143.071 GWh electricity consumption with 34.466 MWh (24%) residential, 68.027 MWh (48%) industrial, 25.914 MWh (18%) commercial, 790 MWh (0,6%) transportation, 4.441 MWh (3%) agricultural and 9.433 MWh (6,6%) other sectoral consumption in year 2006. Electricity generated by fuel for year 2006 is given with the Table 2 (TETC, 2006)

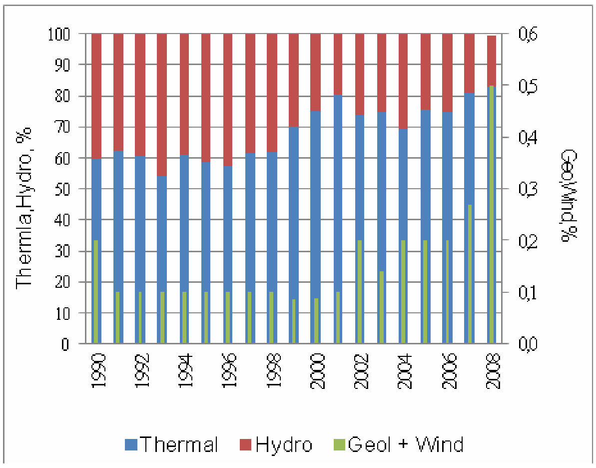

Figure 2: Distribution of energy sources in Turkish gross electricity production 1990-2008 (TETC, 2008)

Table 1: Turkey Demand Projection (TETC, 2009.)

Year	Electricity Demand, GWh	Rate (%)
2009	194.000	
2010	202.730	4,5
2011	215.907	6,5
2012	232.101	7,5
2013	249.508	7,5
2014	268.221	7,5
2015	288.338	7,5
2016	309.675	7,4
2017	332.591	7,4
2018	357.202	7,4
2019	383.635	7,4
2020	412.024	7,4

Table 2: Distribution of gross electricity generation by primary energy resources for 2006 (GWh)

	GWh
Lignite	32.433
Natural Gas	80.691
Hard & Imported	14.217
Fuel Oil	4.232
Diesel	58
LPG	0.1
Naphta	50.2
Renewable and	154
Hydro	44.244.
Geothermal and	221
TOTAL	176.300

Methodology

This study has used an integrated energy – environment and scenario based accounting model LEAP (Stockholm Environment Institute (SEI), 2008) to generate CO_2 emission scenarios for Turkish electricity sector. Base year is settled as 2006. First, specific emission factors have been evaluated as an input data of the model. Emission factor calculations are mainly based on IPCC methodology except lignite fuelled Public Thermal Power plants. Carbon content as weight percentage of lignite for all Public Thermal Power plants has been calculated as weighted mean of each plant. Data was taken from Arı, 2010. For year 2006 it resulted as 21,56%. For other power plants than the public IPCC adjusted emission factor is taken into account based on Arı, 2010. Lignite for all private power plants has an average low heating value (LHV) as 2.542 kCal/kg where public plants has 1553 kCal/kg (TETC,2006). Emission factor for private plants is 94,257 ton CO_2/TJ (Terajolue) from adjusted IPCC emission factors (Table 3) and for public plants it is calculated from the consumed fuel and heating values as 33,17 tC/TJ (ton carbon/terajoule). Taking into consideration of fuel oil and diesel as the secondary fuels for lignite power plants, the emission factor is calculated as 31,78 tC/TJ by assumption of 0,98 carbon oxidized fraction where IPCC (Intergovernmental Panel on Climate Change)'s emission factor is 27,6 tC/TJ. For the other fuels used for electricity generation such as, natural gas, hard and imported coal, fuel oil, diesel, naphtha emission factors are calculated based on IPCC carbon emission factors. The results is given in Table 4.

Table 3: IPCC Emission factors of lignite thermal power plants in Turkey

LHV, kCal/kg	IPCC Emission Factor ton CO_2/TJ
950	115,000
1300	110,441
1500	107,835
1533	107,405
1750	104,578
2100	100,019
2340	96,892
2350	96,762
2400	96,111
2500	94,808
2542	94,257
2600	93,505
2800	90,900

Table 4: Fuel specific carbon emission factors

	Emission Factor, ton C/TJ
Lignite	31.78 (calc.)
Natural Gas	15.3*
Hard&Import	25.8*
Fuel Oil	21.1*
Diesel	20.2*
Naphta	20.0*

calc:calculated
*: IPCC

The analytical procedure in the LEAP is given with the Figure 3. Content in the frame of broken lines are valid for all scenarios. The procedure includes electricity demand, corresponding sectoral production projection, CO_2 emissions and CO_2 abatement potential calculation.

Step 1: Electricity Demand Data

Electricity demand data is taken from Turkish Electricity Transmission Company, (TETC,2009) as given Table 1.

Step 2: Sectoral Production

Corresponding sectoral production output is supplied by different fuelled power plants such as lignite, hard and import coal, natural gas, oil, wind, geothermal, hydropower and biomass. Once whole installed capacity according to the fuel types is built, production output is acquired for both scenarios.

Step3: CO_2 Emission from electricity production

As details given above, fuel based CO_2 emission factors are used according to the Table 4 as input values of LEAP, and the primary energy demand is calculated by the model. The heating values of the fuels are obtained from statistical values from TETC, 2006 as annually total consumption.

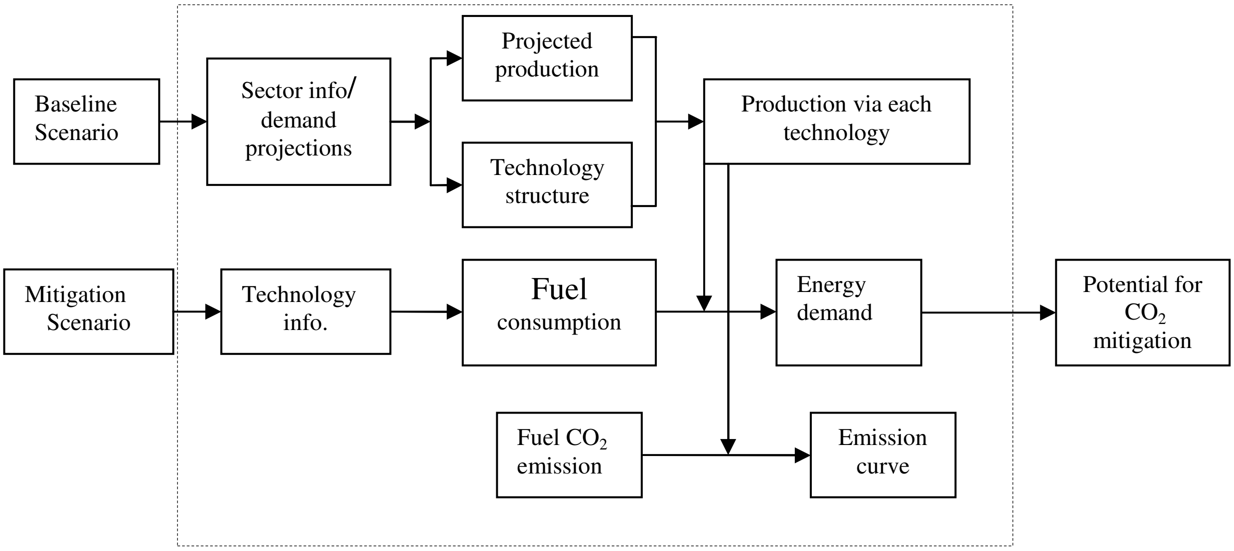

Figure 3: LEAP Analytical Procedure

Scenario Design

A Business As Usual (BAU) and a Mitigation (Renewable) Scenario have been generated in LEAP.

BAU scenario considers electricity supply rather than climate change. For this scenario share of each primary energy sources to generate electricity are estimated to have the same share ranges as year 2009 and according to the TETC Report (TETC, 2009). For the deficient supply from 2015 to 2020 same primary energy sources share is conserved. Supply projection as total installed capacity that's used for calculating the CO_2 emission and getting the mitigation potential is same for both BAU and Mitigation Scenario. Installed capacities are given with Table 5 and Table 6 for BAU and Mitigation Scenarios respectively. The technology composition is assumed to be the same in 2006 among the scenario years.

Main assumptions for both scenarios:

- Total electricity demand will be supplied by domestic energy sources.
- 1200 MW of total hard coal installed capacity will be added by 600 MW by the year 2019 and 600 MW by the year 2020 for both scenarios.
- CO_2 emissions were calculated according to the emission factors and consumed fuel,
- The fuel specific emission factors of all renewable energy sources are accepted as zero.
- Gross electricity demand was taken into consideration therefore transmission and distribution losses assumed to be zero in order to focus on only analyzing the electricity generation during scenario time span. However there's also reduction capacity at distribution losses which should be an issue of another scenario analysis.

Mitigation scenario is established due to the increased share of the renewable energy sources, such as hydropower, wind and geothermal with below assumptions:

- geothermal plant installed capacity will be increased up to 300 MW until 2015 and 600 MW by the year 2020.
- wind plant installed capacity will be increased up to 20.000 MW by the year 2020.
- % 86 of the total hydropower capacity will be used by the year 2020.
- as the national strategy, the priority will be given to the domestic energy sources natural gas installed capacity will be decreasing while lignite power plants trend to increase, and import coal installed capacity will decrease comparing to the BAU scenario.

Scenarios differ from each other with the share of the fuels. Percentage distribution of total electricity generated by each fuel type based on BAU and Mitigation Scenario is given in Table 7 and Table 8 respectively. In BAU Scenario, there is a sharp increase in renewable energy ratio at 2011 due to the high contribution of hydro energy into electricity generation. After 2011 the ratio of renewables begin to decrease slowly but 2020 year ratio is higher than that of 2006 and around 2010 levels. In Mitigation Scenario, there is a continuous increase in renewable energy ratio. There's sharp increase in 2011 especially due to higher contribution of wind energy. Its share increased from 2,5% to 14,6% in 2011 compared to 2010.

Table 5: Installed capacity by fuel type based on BAU scenario, 2006-2020, MW

	Lignite	H.Coal & Asphal.	Import Coal	NG	Fuel Oil	Diesel	Hydro	Wind	Geo	Biomass	Total
2006	8682	555	1431	14315	2123	273	13063	67	15	41	40565
2007	8683	555	1431	14560	1772	228	13395	154	15	43	40836
2008	8683	555	1431	15055	1771	48	13829	364	30	60	41824
2009	8683	555	1838	14693	1800	48	14886	1034	77	60	43674
2010	8692	470	2081	17094	1541	26,5	15100	1159	85	88	46337
2011	8692	470	2248	15862	1800	26,5	18058	1284	85	88	48614
2012	8692	470	3464	17845	1800	26,5	19877	1409	85	88	53757
2013	8692	470	4678	18619	1800	26,5	19877	1534	85	88	55870
2014	8692	470	4678	18622	1800	26,5	19877	1659	85	88	55998
2015	8886	470	4770	19197	1827	26,5	20163	1785	86	88	57299
2016	9551	470	5063	20862	1914	26,5	22270	1915	90	88	62249
2017	10429	470	5450	23080	2029	26,5	23469	2049	95	88	67185
2018	11493	470	5918	25729	2168	26,5	24920	2190	100	88	73103
2019	12367	1070	6303	27869	2281	26,5	26112	2335	105	88	78557
2020	13315	1670	6720	30267	2405	26,5	27405	2485	110	88	84492

Table 6: Installed capacity by fuel type based on Mitigation Scenario, 2006-2020, MW

	Lignite	H.Coal & Asphal.	Import Coal	NG	Fuel Oil	Diesel	Hydro	Wind	Geo	Biomass	Total
2006	8682	555	1431	14315	2123	273	13063	67	15	41	40565
2007	8683	555	1431	14560	1772	228	13395	154	15	43	40836
2008	8683	555	1431	15055	1771	48	13829	364	30	60	41825
2009	8683	555	1838	14693	1800	48	14886	1034	77	60	43674
2010	8692	470	2081	17094	1541	26,5	15100	1159	85	88	46337
2011	8403	470	2081	10645	1671	26,5	18016	7086	128	88	48615
2012	9203	470	2081	11645	1671	26,5	19792	8610	171	88	53758
2013	10503	470	2081	11645	1671	26,5	20139	9033	214	88	55871
2014	8503	470	2081	9755	1671	26,5	21690	11457	257	88	55999
2015	7503	470	2081	9155	1671	26,5	23086	12888	300	88	57269
2016	8503	470	2081	9755	1671	26,5	24991	14305	360	88	62251
2017	10003	470	2081	10760	1671	26,5	26337	15330	420	88	67187
2018	10153	470	2931	12055	1771	26,5	27977	17152	480	88	73104
2019	10153	1070	3931	12785	1771	26,5	29617	18576	540	88	78558
2020	10203	1670	4750	13955	1771	26,5	31456	20000	600	88	84520

Table 7: Percentage distribution of installed capacity by fuel type based on BAU Scenario, %, 2006-2020

	Lignite	H.Coal & Asphal.	Import Coal	NG	Fuel Oil	Diesel	Hydro	Wind	Geo	Biomass	Fossil	Renew.
2006	21,40	1,37	3,53	35,29	5,23	0,67	32,20	0,16	0,04	0,10	67,49	32,51
2007	21,26	1,36	3,50	35,66	4,34	0,56	32,80	0,38	0,04	0,10	66,68	33,32
2008	20,76	1,33	3,42	36,00	4,23	0,11	33,06	0,87	0,07	0,14	65,85	34,15
2009	19,88	1,27	4,21	33,64	4,12	0,11	34,08	2,37	0,18	0,14	63,23	36,77
2010	18,76	1,01	4,49	36,89	3,33	0,06	32,59	2,50	0,18	0,19	64,54	35,46
2011	17,88	0,97	4,62	32,63	3,70	0,05	37,15	2,64	0,17	0,18	59,86	40,14
2012	16,17	0,87	6,44	33,20	3,35	0,05	36,98	2,62	0,16	0,16	60,08	39,92
2013	15,56	0,84	8,37	33,33	3,22	0,05	35,58	2,75	0,15	0,16	61,37	38,63
2014	15,52	0,84	8,35	33,26	3,21	0,05	35,50	2,96	0,15	0,16	61,23	38,77
2015	15,51	0,82	8,32	33,50	3,19	0,05	35,19	3,12	0,15	0,15	61,39	38,61
2016	15,34	0,76	8,13	33,51	3,07	0,04	35,78	3,08	0,14	0,14	60,86	39,14
2017	15,52	0,70	8,11	34,35	3,02	0,04	34,93	3,05	0,14	0,13	61,75	38,25
2018	15,72	0,64	8,10	35,20	2,97	0,04	34,09	3,00	0,14	0,12	62,66	37,34
2019	15,74	1,36	8,02	35,48	2,90	0,03	33,24	2,97	0,13	0,11	63,54	36,46
2020	15,76	1,98	7,95	35,82	2,85	0,03	32,44	2,94	0,13	0,10	64,39	35,61

Table 8: Percentage distribution of installed capacity by fuel type based on Mitigation Scenario, %, 2006-2020

	Lignite	H.Coal & Asphal.	Import Coal	NG	Fuel Oil	Diesel	Hydro	Wind	Geo	Biomass	Fossil	Renew.
2006	21,40	1,37	3,53	35,29	5,23	0,67	32,20	0,16	0,04	0,10	67,49	32,51
2007	21,26	1,36	3,50	35,66	4,34	0,56	32,80	0,38	0,04	0,10	66,68	33,32
2008	20,76	1,33	3,42	36,00	4,23	0,11	33,06	0,87	0,07	0,14	65,85	34,15
2009	19,88	1,27	4,21	33,64	4,12	0,11	34,08	2,37	0,18	0,14	63,23	36,77
2010	18,76	1,01	4,49	36,89	3,33	0,06	32,59	2,50	0,18	0,19	64,54	35,46
2011	17,28	0,97	4,28	21,90	3,44	0,05	37,06	14,58	0,26	0,18	47,92	52,08
2012	17,12	0,87	3,87	21,66	3,11	0,05	36,82	16,02	0,32	0,16	46,68	53,32
2013	18,80	0,84	3,72	20,84	2,99	0,05	36,05	16,17	0,38	0,16	47,25	52,75
2014	15,18	0,84	3,72	17,42	2,98	0,05	38,73	20,46	0,46	0,16	40,19	59,81
2015	13,10	0,82	3,63	15,99	2,92	0,05	40,31	22,50	0,52	0,15	36,51	63,49
2016	13,66	0,76	3,34	15,67	2,68	0,04	40,15	22,98	0,58	0,14	36,15	63,85
2017	14,89	0,70	3,10	16,02	2,49	0,04	39,20	22,82	0,63	0,13	37,23	62,77
2018	13,89	0,64	4,01	16,49	2,42	0,04	38,27	23,46	0,66	0,12	37,49	62,51
2019	12,92	1,36	5,00	16,27	2,25	0,03	37,70	23,65	0,69	0,11	37,85	62,15
2020	12,07	1,98	5,62	16,51	2,10	0,03	37,22	23,66	0,71	0,10	38,31	61,69

Hydropower included share of renewable energy sources increased from 32,5% to 62% between 2006 and 2020, with partially usage of hydro, wind, geo and biomass energy sources and without using any of solar energy potential which is calculated as 380 billion kWh/year and no nuclear energy is used.

Scenario Analysis Results

The electricity demand in Turkey is expected to increase above 7% annually between 2010 and 2020 and reach to 412.024 GWh in 2020. Table 9 displays electricity supply and CO_2 emissions for BAU and Mitigation Scenarios obtained from LEAP. Business as Usual (BAU) Scenario shows if no controls were made to mitigate the CO_2 emissions in Turkey from 2010 and 2020, there's likely to be totally 1,4 billion tons of CO_2 will be emitting to the atmosphere corresponding to 3,4 million GWh electricity production in next decade. The results of this scenario are accepted as a reference point for the comparison with the other scenario. Mitigation Scenario is developed considering the economically viable renewable energy sources of Turkey with current national climate change policy. In this scenario, the contribution of renewable energy is increasing continuously till 2016 and in 2011 the peak increase occurs.due to the significant contribution of wind energy. Between 2017-2020 it is around 62% as a stable level. In mitigation scenario, the overall mitigation of CO_2 emissions between 2010 and 2020 is estimated as 298,3 million tons with the same electricity production. This result is obtained only partial renewable energy potential of Turkey except solar power plants.

Conclusion

This study presents the analyses of the future mitigation potential of CO_2 emissions from electricity generation using LEAP (Long-range Energy Alternative Planning system) model in Turkey. Electricity production and CO_2 emissions of Turkey are projected through the two scenarios on the model.

Turkey's fuel specific emission factors are evaluated first and carbon emission factor for lignite is calculated as 31,78 tC/TJ where IPCC's emission factor is 27,6 tC/TJ. As a reference point BAU Scenario is established first and Mitigation Scenario is developed due to the increasing share of renewable energy sources for electricity production for next decade. During scenario development only partial potential of hydropower, wind, geothermal and biomass energy is considered. As the result of Mitigation Scenario the overall CO_2 abatement potential of Turkey from 2011 to 2020 is 298,3 million tons. Based on this research, strict renewable policies should be established since Turkey has significant renewable energy potential for electricity production, which means significant reduction potential. Furthermore, in the long run, carbon capture and storage may be one of the most promising technological solutions to curb the CO_2 emissions from the continued use of coal in Turkey.

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