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A World Integrated Assessment Model of Global Trade Environment and Climate Change

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Abstract

This paper describes the structure of the **W**orld **I**ntegrated **A**ssessment model of global **T**rade, **E**nvironmental, and **C**limate change (WIATEC).The model consists of a multi-regional multi-sectoral core CGE model linked to a climate model. The core CGE is based on an existing global trade and environment model called GTAP-E (Truong, 1999; Burniaux and Truong, 2002). A suite of different and interchangeable ‘modules’ are then built around this ‘core’ to enable the model to be able to handle a range of different policy issues such as CO_2 emissions, abatement, trading, non-CO_2 (CH_4 and N_2O) emissions, land use land use change and forestry (LULUCF) activities, and changing technologies in the electricity generation sector. The approach which uses a core model structure with different additional modules built around this core structure allows the overall model to be flexible and can be adapted to a range of different policy issues. We illustrate the usefulness of this approach in a policy experiment which looks at the interaction between emissions trading scheme and the promotion of renewable energy targets in the European Union climate policy.

Keywords: Integrated Assessment Model, Technological Change, Climate Policy

JEL: Q 55, O38, C68

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1. Introduction

Climate change is an important and highly complex issue and the use of integrated assessment (IA) models to help in the analysis of the economic and environmental impacts of climate change policies is becoming more popular. An integrated assessment model often consists of a computable general equilibrium (CGE) sub-model describing the working of the economic system, linked to a (reduced form) climate sub-model which summarises the main features of the climate system. The two sub-models are used in an integrated fashion to describe the links between the economic system and the global climate environment. In this paper, we describe the structure of a **W**orld **I**ntegrated **A**ssessment model of global **T**rade, **E**nvironmental, and **C**limate change (WIATEC) and use the model in a policy experiment to illustrate its application. Section 2 will describe the basic structure of the model. Section 3 describes a policy experiment using the model. Section 4 analyses the results and Section 5 concludes.

2. Model Description

As the name suggests, the WIATEC model consists of a multi-regional multi-sectoral core CGE sub-model which can handle various policy issues of global **T**rade and global **E**nvironment (greenhouse gases emissions, carbon taxes, emissions trading, etc.). The core CGE sub-model is then linked to a climate sub-model to 'translate' these economic and environmental impacts into **C**limate change impacts (radiative forcing level, greenhouse gases concentration in the atmosphere, sea level rise, global mean temperature rise, etc.). The core CGE sub-model is built around the structure of a well known global trade-environment model.[1] In addition, a suite of different and interchangeable 'modules' are built around this 'core' to enable the model to deal with a variety of different policy issues such as CO_2 emissions (mainly from energy combustion), non-CO_2 (CH_4 and N_2O) emissions from other non-combustion economic activities (such as agriculture and energy-producing sectors), emissions trading and abatement, land use land use change and forestry (LULUCF) activities, the effect of changing technologies in the

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[1] See Truong (1999); Burniaux and Truong (2002).

electricity generation sector and their impacts on emissions abatement activities, etc.[2] The advantage of using a ‘module’ approach to the building of an integrated assessment model is that the specific form of the model being used in each particular application may be flexible and therefore, allowing the model to be more ‘compact’ depending on the particular policy issues being considered.[3] For example, if LULUCF is not a crucial issue in a particular application, then this specific module can be taken out and replaced by just the ‘core’ structure. Similarly, if changing technologies in the electricity generation sector is not an important issue in some applications then this detailed ‘bottom-up’ module can be replaced by just the top-down aggregate structure in the electricity sector. The non-CO_2 module (dealing with CH_4 and N_2O emissions and their emissions trading or taxes) can also be linked to the CO_2 module if these non-CO_2 gases are to be included in an emissions trading scheme or side-stepped if only CO_2 emissions are considered. In short, the final structure of the model can be flexible to reflect the particular policy question at hand.

2.1 Energy Substitution

At the heart of the CGE model is a ‘core structure’ which describes the production and consumption activities (including that of the government) in various sectors of an economy, their interrelationship and clearing in domestic as well as international markets, the imposition of taxes or subsidies or quantitative restrictions by governments on the production, sales, import, and export activities, the channeling of savings into investments, etc. On the production and consumption activity structures, WIATEC follows those structures described in the GTAP-E model (Truong, 1999) which in turn is a modification of the structures in GTAP (Hertel, 1997). An important feature of the structures adopted here is the assumption of energy substitution (see Figures 1-4). Since the objective of any climate change policy is a change in production and consumption activities towards improving on energy (and emission) intensity, this relies crucially on the assumption of energy substitution (in addition to the assumption of

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[2] Currently a module for handling changing technologies in the transport sector to complement the module dealing with similar issues in the electricity generation sector is being build and will be incorporated into the model in the future.

[3] Additional modules can also be built over time to allow the scope of the model to be extended without having to redesign and change the core structure of the model.

'technological change'[4]). For example, a reduction in energy intensity may involve a 'substitution' away from activities such as steel making towards less energy-intensive activities like electronics and communication, and within an energy-intensive activity like electricity generation, a substitution away from the use of emissions-intensive fuels like coal and oil towards less emissions-intensive fuels like natural gas, or even ‘clean' fuels’ such as hydro, wind, or solar power. The assumption and structure of energy substitution in an economic model therefore is a crucial factor in describing and analyzing the impacts of climate policies on greenhouse gas emissions.

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[4] Technological change is a difficult concept to describe in economic terms. For example, if there is no change in the relative prices of the fuel inputs which implies no fuel substitution, then any improvement in energy intensity occurring can be referred to as “autonomous energy efficiency improvement" (AEEI) . This can occur, for example, as a result of accumulated knowledge through ‘learning-by-doing’ or through research and development activities. In practice, however, it is difficult to isolate the ‘autonomous’ improvements from the ‘induced’ ones, the latter refers to an improvement in energy efficiency resulting from energy substitution which in turn is 'induced' by climate policy. We can refer to these latter effects only as 'induced' technological change. However, the literature seems to use the term 'induced' technological change' to include also the 'autonomous' technological change so long as this is explicitly linked to some investment policies described within the model(i.e. 'endogenously' determined) , rather than assumed to be given 'exogenously' outside the model. The term 'endogenous technical change' is also used in this case.

Figure 1: WIATEC production activity structure

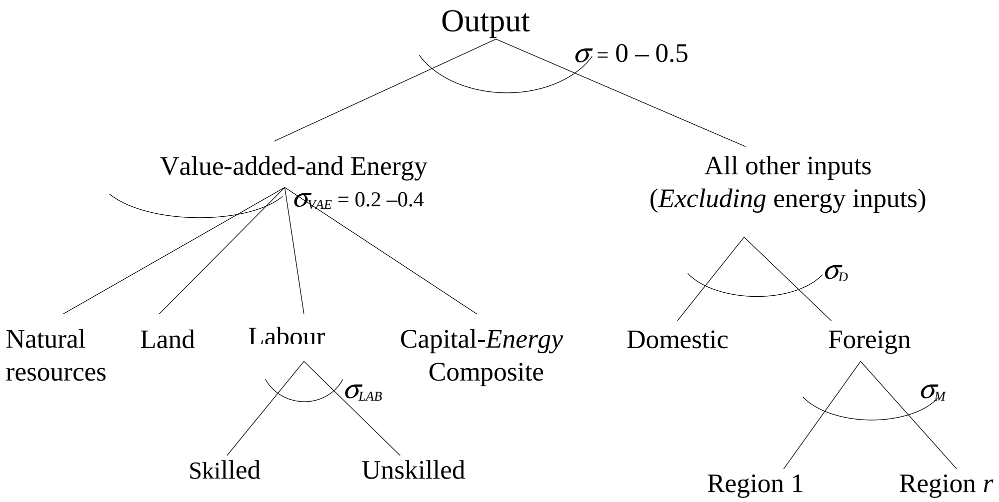


Figure 2: Capital-energy composite structure in WIATEC production structure

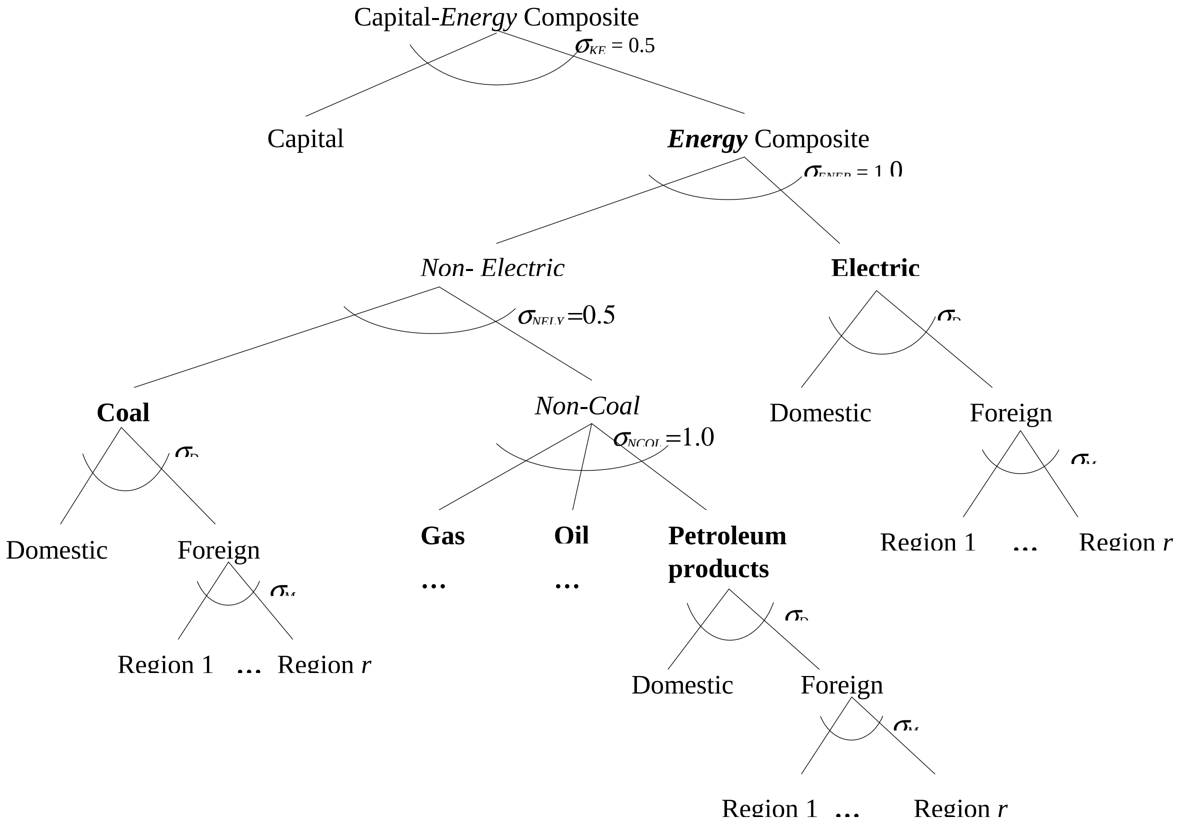


Figure 3: WIATEC household (private) consumption activity structure

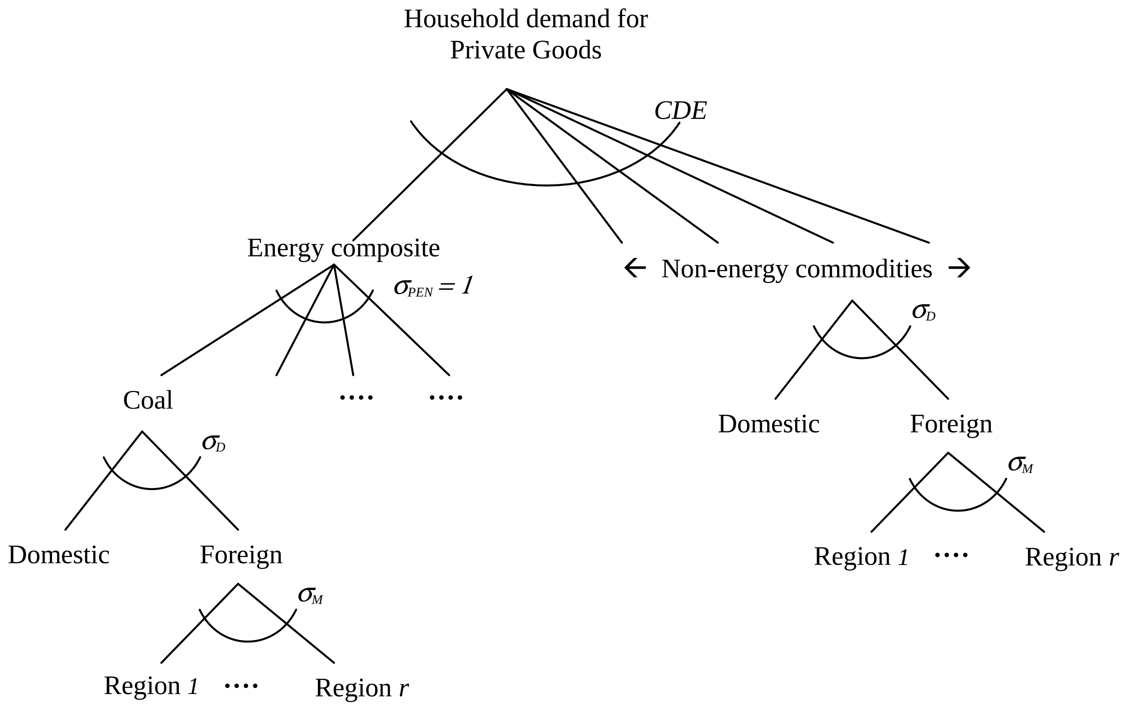
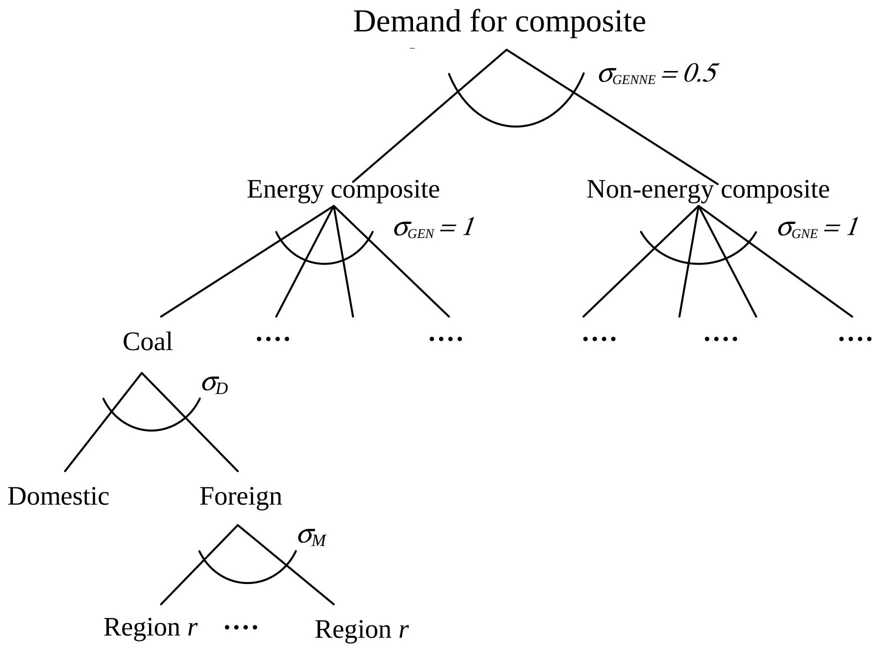


Figure 4: WIATEC government (public) consumption activity structure



2.2 *CO_2 emissions*

The emissions of CO_2 can be estimated from the burning of fossil fuels in various economic activities. To estimate the levels of CO_2 emissions, therefore, we need information on fossil fuels used in various economic activities. This information is published by the Center for Global Trade Analysis (CGTA)[5]. The CGTA also publishes information on CO_2 emissions which itself is based on this energy flow database.[6] From these two databases, therefore, the emission-intensity of each particular fuel used in different activities can be derived. When a particular climate policy such as emissions trading or carbon tax scheme is imposed on an economy, this will effectively put a price on emissions and therefore induce a substitution away from emissions-intensive activities towards less emissions-intensive ones. Depending on the particular objective of a climate policy and hence the nature of the emissions trading scheme or carbon tax regime imposed, the effective carbon tax imposed on each particular sector of an economy can be uniform or varied across these sectors and/or regions of the world. The CO_2 emissions module in WIATEC is designed to keep track of all these different schemes.

2.3 *Non-CO_2 emissions*

Non-CO_2 greenhouse gases such as CH_4 and N_2O are emitted mainly from agricultural and energy production activities. Their emissions levels are assumed to be related to the production output level of these activities, except for the case of N_2O emissions which can be assumed to be related to the level of input (fertilizer) into agricultural activities rather than production output. To model the abatement of non-CO_2 emissions, we assume that emissions are actually the use of an environmental input ('clean air'). Therefore in Figure 5, for example, the production of an 'output *with* CH_4 emissions' ('normal' output without abatement) implies the use of economic resources ('output *without* CH_4 emissions') in conjunction with an environmental resource ('CH_4 emissions'). More CH_4 emissions mean more clean air is to be used up. Therefore, abatement activity involves the use of more economic resources (more of 'output *without* CH_4 emissions') to substitute for less environmental input (less CH_4 emissions). The substitution elasticity can

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[5] McDougall and Aguiar (2008).

[6] Lee (2008).

then be calibrated using the marginal abatement cost function derived from engineering or bottom-up studies.[7]

The Non-CO_2 module can be linked to the CO_2 module via the specification of a general ‘global warming potential’ (GWP) index. This index can be assumed to be fixed exogenously or is to be determined endogenously, depending on a particular climate change scenario (see Truong and Kemfert, 2008).

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[7] United States Environmental Protection Agency (USEPA). (2006). See also Hyman *et al.* (2002).

Figure 5: Abatement of CH_4 and N_4O emissions in WIATEC

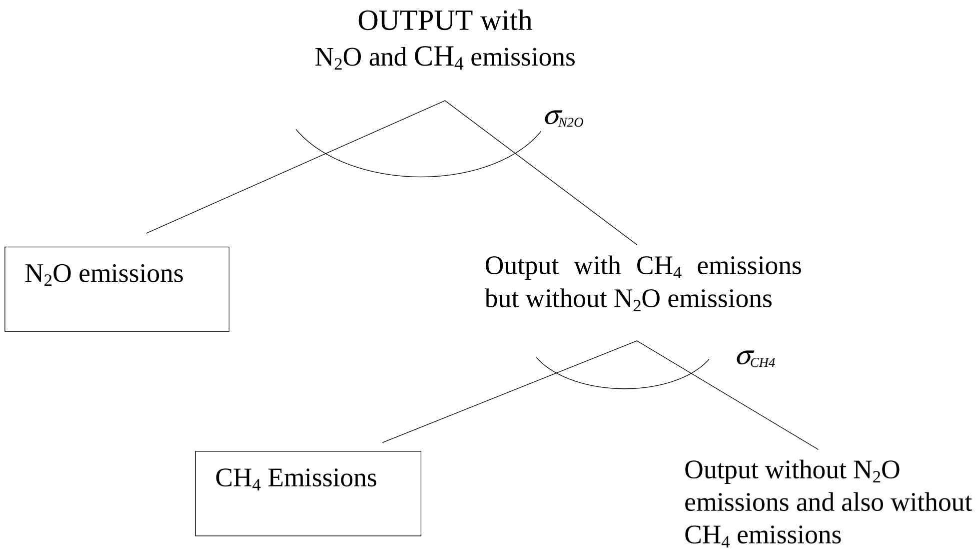
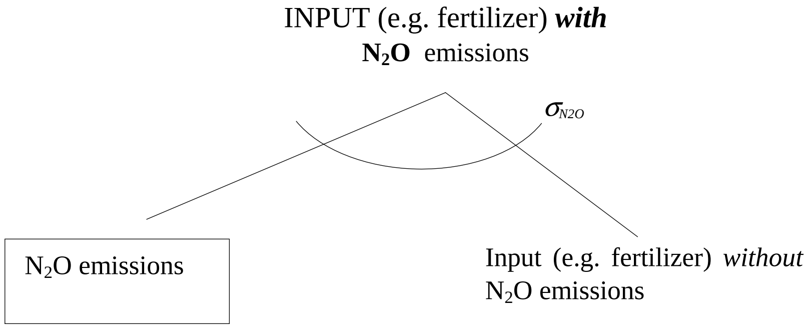


Figure 6: Abatement of N_4O emissions associated with the use of an input



2.4 Land use Land Use Change and Forestry (LULUCF) emissions

Land use activities such as forestry and agricultural production can act as a sink or source for GHG emissions. In response to climate change policies, land use activities can change and this can have significant impacts on land demand. Since land is a natural resource which is in relatively 'fixed' supply (because it cannot be 'produced' by human activities), it is important to keep track of changes in demand so that these can be matched with supply. Furthermore, land has a geographical-ecological dimension which makes it difficult to be 'exchanged' for different uses hence the demand for specific land types from different land-use activities must also be known accurately so that demand and supply can be matched.

The Centre for Global Trade Analysis has compiled a land-use database[8] which can identify land uses by various land types classified according to their Agro-Ecological Zones (AEZs). Based on this database, we build a LULUCF module which links land-use activities in the core WIATEC model to the demand for various types of land in different regions. The module can be used for analysing the impacts of climate change policies on land-uses and the estimation of the economic costs of climate change policies which rely on LULUCF activities. It is often considered (for example, in countries such as Australia) that using climate policies relying on LULUCF activities can be more cost effective than using policies which try to reduce emissions from energy consumption. A major drawback of LULUCF policy, however, is that it is more difficult to estimate the levels of greenhouse gas emissions/removals from LULUCF activities.[9] Nevertheless, it is important to consider this option[10] and try to develop a module which can handle this issue as accurately as possible. This is the objective of the LULUCF module in WIATEC

To do this, we first recognise that one of the main weaknesses in the treatment of land-uses in conventional CGE models is the fact that land is considered as a homogenous resource lacking in the spatial as well as biophysical characteristics. These characteristics make land less homogenous and more difficult to be "transformed" between alternative uses. For example, crop

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[8] Lee *et al.* (2005).

[9] For example, the case of forestry involves management which is very long term and often complex. Furthermore, there is the risk of reversal of emissions reduction through unforeseen events such as bushfires.

[10] Under Articles 3.3 and 3.4 of the Kyoto Protocol, greenhouse gas emissions/removals from LULUCF activities such as deforestation/afforestation/reforestation, cropland management, grazing land management and revegetation, can be counted towards meeting the Kyoto Protocol's emission targets for the first commitment period.

land cannot be easily converted into grazing land. Therefore, a first and important step in improving on the treatment of land is to give it an "agro-ecological" dimension as in the GTAP land-use database. Thus, instead of assuming land being homogenous which can be transformed into all different uses in various sectors (see Figure 7) we now assume that land is heterogeneous, consisting of different categories AEZ_j , j =1,...,N. Each category j can be transformed into specific land uses, and this is specified via a land-transition matrix such as described in Table 1. The rate of transformation is specific to each land category (σ_{AEZj}) and can be estimated independently or 'calibrated' using the limited information provided in the *AEZ* land use data base. The calibration is based on the concept of 'entropy' as follows. First, for each land category we define a (normalised) entropy measure defined as follows:

$$E_j = -(\sum_{k=1}^{M} S_{jk} \ln S_k)/(\ln M) \quad ; j = 1,..., N \tag{1}$$

where k =1,...,M are the land-use sectors, S_{jk} is the share of land use k for land category j. Quite clearly, if there is only one dominant land use (i.e. S_{jk} ≅1 for a particular k, and S_{jl} ≅ 0 for all others $l \neq k$), then $E_j = 0$. In this case, the entropy meausre is a minimum (zero) and the information regarding land-uses for this particular category is 'extremely concentrated', i.e. confined to just one land use. Homogeneity of land (and ease of transformation of land between alternative uses) in this case is said to be at a minimum. On the other hand, if land uses are distributed fairly evenly across all potential uses, i.e. S_{jk}=1/M for all k's, then the (normalised) entropy for this particular land category is a maximum (E_j = 1). In this case, land is 'maximally' homogenous and transformation of land between alternative uses is also 'maximally easy'. Since the elasticity of transformation is a measure of this 'ease' of transformation, and entropy measure is seen to be related to this 'ease', we can therefore use the entropy measure to 'calibrate' this elasticity. Table 2 shows the values of this entropy, or calibrated elasticities of transformation, for various land types of different regions of the world, based on GTAP version 7 *AE*Z data base. We note that if σ_{AEZj}'s are very different for different types of land then the traditional approach which treats land as though of a single (homogeneous) land type is inaccurate. On the other hand, if calibrated elatsicities are fairly similar across all different land types, (i.e. σ_{AEZj} = σ_{LND} for all j's) then this indicates that the the traditional approach which uses only a single elasticity of transformation σ_{LND} for all land is reasonbly accurate. The values of entropies (calibrated elasticities of land transformation (σ_{AEZj})) therfore, can be used to determine if the traditional approach (using aggregate land) is appropriate, or a detailed ‚bottom-up‘ land-use module is necessary for a particular application with certain regions. In Table 2, we see for example that in the case of Australia, AEZ_7 and AEZ_8 can be seen as 'similar' (with similar land uses (see Table 1) and their elasticities of transformation are also nearly equal, .794 and .805). These land types therefore can be aggregated to reduce the dimension of land types. The same applies to AEZ_2 and AEZ_4, and also AEZ_9 and AEZ_{10}.

Figure 7: Land use modelling in the standard structure of WIATEC

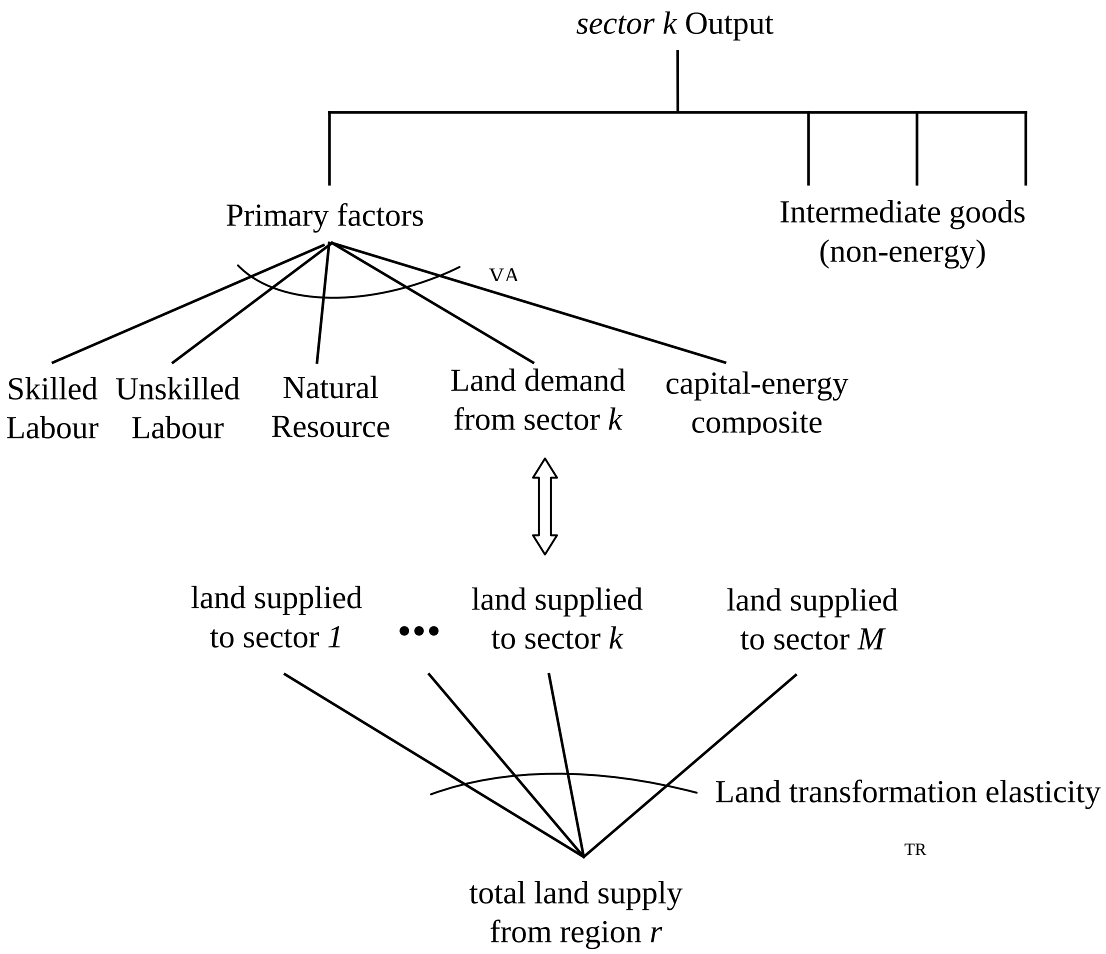

Figure 8: Land use modelling in the LULUCF-module of WIATEC

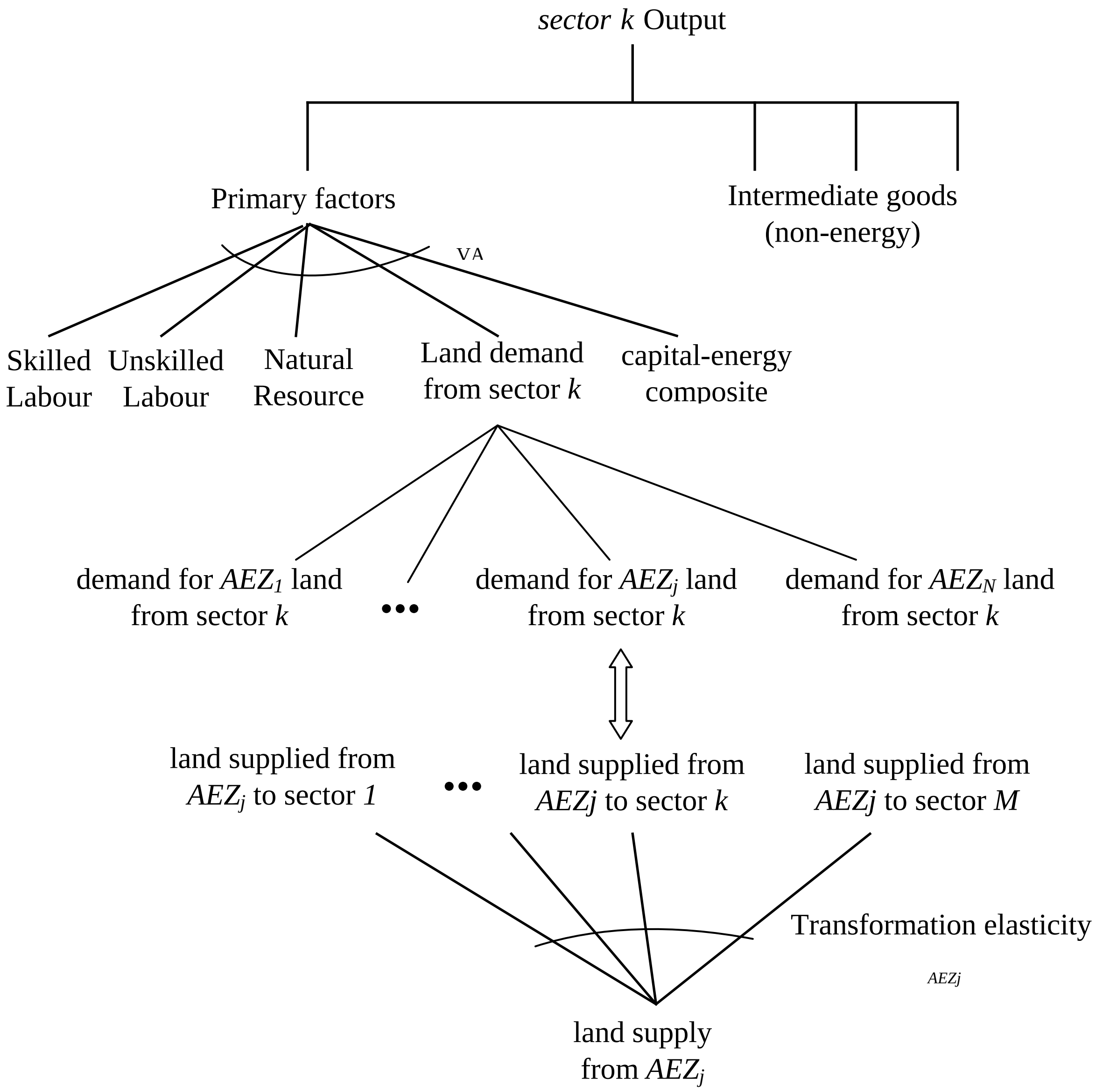

Table 1: Land Transformation Matrix (for Australia)

	Land Demand by different sectors ($2004US mill.)											
	PDR	WHT	GRO	V_F	OSD	C_B	PFB	OCR	CTL	RMK	WOL	FRS
Land supply AEZ*j*	Paddy Rice	Wheat	Cereal grains nec	Vegetables, fruit, nuts	Oil seeds	Sugar cane sugar beet	Plant-based fibers	Crops nec	Bovine cattle, sheep…	Paddy Rice	Wool	Forestry
AEZ1		0.22	0.09	0.67	0.00	0.34		0.36	74.01	23.41	40.66	
AEZ2		2.37	0.28	1.25	0.03	7.12		3.71	32.26	10.21	17.72	
AEZ3			0.16	19.85	0.09	9.44		2.26	11.94	3.78	6.56	
AEZ4		0.35	0.59	15.74	0.38	4.64		2.19	3.08	0.98	1.69	1.24
AEZ5			0.00	0.45		0.17		0.05	0.16	0.05	0.09	3.69
AEZ6			0.01	1.03		0.47		0.15	0.51	0.16	0.28	3.79
AEZ7	5.22	53.15	22.28	142.00	10.08	9.03	30.13	62.62	289.90	91.71	159.24	
AEZ8	2.89	118.05	37.02	121.14	10.78	4.48	35.57	128.82	36.85	11.66	20.24	
AEZ9	5.44	97.79	45.26	142.74	21.45	4.40	27.51	115.21	23.91	7.56	13.13	0.54
AEZ10	1.30	29.10	13.65	69.00	9.08	13.63	17.54	37.00	12.85	4.07	7.06	3.69
AEZ11	0.47	10.98	4.72	70.44	4.40	3.63	6.76	18.20	12.76	4.04	7.01	77.93
AEZ12		21.23	9.35	100.10	4.03	6.46	38.32	23.04	10.01	3.17	5.50	106.22
AEZ13												
AEZ14												
AEZ15												
AEZ16												
AEZ17			0.01	0.66				0.05	0.04	0.01	0.02	1.85
AEZ18												
TOTAL	15.3	333.2	133.4	685.1	60.3	63.8	155.8	393.7	508.3	160.8	279.2	199.0

Source: GTAP-AEZ database, version 7.

Table 2: Entropy of Land Transformation (E_j) for various land type *j*’s in different regions, used for the calibration of the Elasticities of land transformation (σ_{AEZj}).

	Australia	USA	China	India	Brazil	Russia	Great Britain	France	Germany	Italy	World
AEZ1	0.463			0.737	0.703						0.871
AEZ2	0.705			0.756	0.807						0.872
AEZ3	0.774			0.880	0.838						0.897
AEZ4	0.705		0.382	0.818	0.845						0.825
AEZ5	0.394		0.480	0.763	0.843						0.817
AEZ6	0.606		0.303	0.763	0.780						0.752
AEZ7	0.794	0.794	0.826	0.787		0.813					0.878
AEZ8	0.805	0.770	0.604	0.813		0.697					0.835
AEZ9	0.773	0.758	0.539	0.832		0.574				0.764	0.782
AEZ10	0.832	0.759	0.562	0.417	0.533	0.460	0.731	0.671	0.770	0.765	0.824
AEZ11	0.716	0.782	0.600	0.586	0.866	0.600	0.864	0.686	0.799	0.767	0.813
AEZ12	0.749	0.667	0.455	0.687	0.721		0.760	0.703		0.727	0.713
AEZ13		0.750	0.716	0.230		0.802				0.369	0.798
AEZ14		0.661	0.622	0.117		0.379				0.305	0.591
AEZ15		0.626	0.540	0.140		0.568	0.000	0.499		0.659	0.601
AEZ16		0.085	0.157	0.215		0.537	0.607	0.612	0.493		0.458
AEZ17	0.398		0.206								0.206
AEZ18											0.000
all land	0.882	0.858	0.608	0.886	0.859	0.684	0.798	0.687	0.778	0.775	0.855

Source: Calculation based on GTAP-AEZ database, version 7.

2.5 Technological change in the Electricity Generation Sector

In the electricity generation sector, we recognise that an important policy issue is the question of choice between alternative technologies to reduce CO_2 emissions. These technologies have very different cost structures which cannot be adequately distinguished and represented in a conventional top-down model which treats electricity generation as a single activity with a single aggregate economic production function. In this aggregate function, substitution between alternative technologies is represented as substitution between fuels and/or between fuels and other factors of production (capital, labour, materials). This form of representation does not adequately represent the underlying choices between the alternative technologies. For example, in the case of nuclear-powered electricity, the ‘fuel’ used in this technology (enriched uranium) is hardly represented. Other technologies like hydro-, geothermal-, wind-, solar-powered electricity have no (market-defined) fuel-input at all and therefore cannot be analysed in terms of fuel substitution. To represent these technologies in a bottom-up model factor constraints like capital (investment costs), materials and labour (maintenance and running costs) and in some cases, specific natural resources required for the production of electricity (such as water and land for the case of hydropower, wind and solar energy for the case of wind and solar electricity) must be specified. These characteristics cannot be described adequately in an aggregate top-down representation, therefore, a bottom-up module need to be constructed and linked to the top-down model.

A hard[11] link between a full scale bottom up model such as MARKAL[12] and a top-down model is difficult because both models can be built on different theoretical foundations and use different types of databases as well as computational techniques. An alternative is a soft link, or the use of a ‘reduced form’ representation of the bottom-up technologies in a top-down structure. This is the approach adopted for WIATEC. First, each technology is represented as a separate electricity generation sector but with a Leontief (fixed input-output coefficients) production function so as to indicate the inflexibility of the technology in the short run. Each electricity generation sector is assumed to produce a different output (‘electricity by conventional coal technology’, ‘electricity

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[11] A link is ‘hard’ when bottom-up and top-down structures are solved simultaneously. A link is ‘soft’ when these models are solved separately but the results are then linked and if necessary iterated to ensure consistency.

[12] See http://www.etsap.org/MrklDoc-I_StdMARKAL.pdf.

by advanced coal gasification technology', 'electricity by nuclear power', etc.). These outputs are then combined using a top-down structure such as a CES, CRESH, or linear logit production function.[13] where the 'output' is the aggregate or total electricity generated, and the 'inputs' are the various technology outputs. Quite clearly, this implies that different technology outputs are only imperfect substitutes. This gives rise to an 'adding up constraint' problem, and that is total quantities of electricity outputs produced by various technologies may not sum up to the output of the aggregate electricity sector (as represented by the CES, CRESH, or Logit function). This can present some difficulties which cannot be easily resolved either by theoretical or practical explanations.[14] As a result, some additional and arbitrary adjustment or constraint may need to be put in place, in addition to the use of the aggregate production function to 'add up' the various technological outputs. For example, if using a CES production function to aggregate these outputs, the output of the aggregate electricity sector will be given by the following function (in percentage change form):

$$y_i = y - \sigma[p_i - \sum_{i=1}^{n} S_i p_i] \tag{2}$$

where y_i is the percentage change of Y_i, (output of technology i), y is the percentage change of Y (output of the aggregate electricity sector), p_i is the percentage change of P_i, the price of Y_i, S_i is the *value*-share of technology i in total production, i.e. and $S_i = P_i Y_i / \sum_{j=1}^{n} P_j Y_j$, σ is the substitution elasticity parameter. Because of Y_i's are imperfect substitutes, we will have:

$$Y \neq \sum_{i=1}^{n} Y_i = Q \tag{3}$$

In percentage change form, this implies:

$$y = \sum_{i=1}^{n} S_i y_i \neq q = \sum_{i=1}^{n} Q_i y_i \tag{4}$$

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[13] See for example, the MEGABARE model (ABARE, 1996), a forerunner of the GTEM model (Pant, 2007) uses a CRESH production function (Hanoch, 1971) to aggregate the 'technology bundle' of different outputs, the "Second Generation Model (SGM) uses a linear logit function (see Schumacher and Sands, 2006).

[14] For example by attributing the short fall to 'transmission and distribution losses', etc.

Here, q stands for the percentage change of the linear sum of technology outputs and y is the percentage change of the output of the aggregate electricity sector. y is given by the *value*-share weighted sum of all the individual technology sector output changes (in percentage changes i.e. y_i's); q, however, is given by the *quantity*-share weighted sum, with quantity share given by $Q_i = Y_i / \sum_{j=1}^{n} Y_j$. Because $q \neq y$, we need to impose an additional constraint on the CES production function (2) so that the value of q will be close[15] to that of y:

$$y_i = y - \sigma[p_i - \sum_{i=1}^{n} S_i p_i] + \alpha[y - q] \tag{5}$$

where $\alpha > 0$ is a scaling or adjustment parameter.[16]

To allow bottom-up technologies to change over the medium to long run, we introduce 'technological shocks' parameters to the bottom up technology specification. For example, an improvement in thermodynamic or energy-conversion efficiency can be represented as follows:

$$\eta_i^E = y_i - e_i \tag{6}$$

where η_i^E stands for the percentage change in thermodynamic efficiency of a fossil fuel technology i, y_i is the percentage change in the electricity output of this technology, and e_i is the percentage change in the fossil fuel input in this technology (both y_i and e_i are measured in physical units). In a similar manner, we can also define the (percentage change in) 'CO_2 abatement efficiency' of a particular technology such as carbon capture and sequestration (CCS) as follows:

$$\eta_i^C = y_i - c_i \tag{7}$$

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[15] The value of q will not be equal exactly to y (i.e. Q will not be equal exactly to Y) unless the substitution elasticity σ approaches infinitive (i.e. all the Y_i's are assumed to be perfect substitutes).

[16] We choose the percentage change form rather than the level form of CES for easy illustration.

Here η_i^C stands for the percentage change in carbon emission efficiency (inverse of carbon emission intensity) of technology *i*, and c_i is the percentage change in the carbon or CO_2 emissions in this technology.

For renewable technologies such as wind or solar powered electricity, a natural resource efficiency parameter can also be defined:

$$\eta_i^R = y_i - r_i \qquad (8)$$

where η_i^R stands for the percentage change in natural resource efficiency of technology *i*, and r_i is the percentage change in the natural resource factor input into this technology.

The efficiency change parameters η_E, η_Z, and η_R can be assumed to be zero (i.e. efficiency levels are to remain unchanged) overtime, or they can be 'shocked' according to some exogenously given information. Alternatively, they can also be determined endogenously, for e.g. by linking these parameters with the level of research and development (R&D), or level of 'learning-by-doing' (LBD) associated with a particular technology. This is the case of so-called 'induced' or 'endogenous' technological change. Finally, these technology parameters can also be used to define the rate of penetration of a particular technology into a market according to information which are either given exogenously or determined endogenously within the model.

2.6 *Climate module*

To study the impacts of climate change policies on economic activities and also ultimately on climate change or conversely to assess the impacts of climate impact on economic activities, we need to link the economic model to a climate model. For this purpose, we use an existing climate model called ICM (ICLIPPS Climate Model) (see Brückner *et al.*, 2003; Tóth *et al.*, 2003). ICM is a 'reduced form' climate model using impulse response function and reduced forms of carbon cycle model developed by Maier-Reimer and Hasselmann (1987) and applied by Hooss (2001). The model allows for the inputs of the four main Kyoto gases CO_2, CH_4, N_2O, SF_6, as well as SO_2. Currently, our economic model only produces results for CO_2, CH_4, and N_2O emissions; hence assumptions on SF_6 and SO_2 emissions have to be given exogenously. The climate model then produces results for variables such as radiative forcing and greenhouse gases concentration levels, global mean temperature change and sea-level rise. The link between the economic model and the climate model can be 'one-way', i.e. results from the economic models are fed into the climate model to derive climate change impacts. To establish the reverse link, i.e. the assessment of economic change due to climate change, certain assumptions about climate change 'damage functions' must be made. Once a damage function is introduced into the link, the two models (climate and economic) can be run simultaneously (even though still sequentially over time).[17] Otherwise, the two models can be run separately and the results iterated so as to achieve a particular climate change 'target'.

3. Illustrative Experiment: The Analysis of Some Elements of Recent European Union Climate Policies

The European Union (EU) has committed itself to a range of pioneering climate policies since 2005. These policies aim at contributing to the objective of limiting the rise in global average temperature to 2°C above pre-industrial levels (CEC, 2008). The range of policies undertaken by the EU consists of three main components: (1) a commitment to reduce the level of greenhouse gas (GHG) emissions in the EU by 20% compared to 1990 level by the year 2020 (30% reduction if there is an international agreement), (2) an increase in the share of renewable energy in final energy consumption to 20% by 2020, (3) an increase in energy efficiency by 20% by 2020.

To reduce GHG emissions by 20% below 1990 level by 2020, the EU relies firstly on the EU Emissions Trading Scheme (EU-ETS). This scheme was launched on January 1, 2005 and aims to control the level of CO_2 emissions by large and medium sized installations in the energy and industry production sectors[18] which cover about 45% of the total CO_2 emissions in the European Union. Emissions by other installations and sectors not covered by the EU-ETS are controlled through other regulations. To reduce the total level of CO_2 emissions in the EU by 20% below

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[17] i.e. the combined (economic-climate) model can be made 'dynamic' but only recursively, rather than intertemporally (forward looking).

[18] The energy sector consists of combustion installations with a rated thermal input exceeding 20 MW, and also installations handling mineral oil refineries, coke ovens. The production sector consists of installations producing and processing ferrous metals, minerals (cement clinker, glass and ceramic bricks), pulp, paper, and also other activities.

1990 level (or about 14.6% below 2005 level) the level of emissions by the EU-ETS sectors need to be cut by about 20% below the 2005 level and that of the non-ETS sectors by about 9.1%. To increase the share of renewable energy usage in energy consumption activities, the EU introduced policies such as feed-in tariff in the electricity sector and the use of bio-fuels in the transport sector. The feed-in tariff (FIT) policy seeks to compel the electricity utilities to accept any amount of electricity provided by renewable energy producers at certain pre-determined tariff level. The level is fixed by the government but the burden of accepting the tariff is to be distributed among all the electricity suppliers (see Traber and Kemfert, 2009). To improve on energy efficiency in consumption activities, there are policies which help to provide finance for national and local schemes that aims to improve on energy-efficiency in the residential housing sector. This sector accounts for about 25% of the total energy consumption in the EU.

Because of the multiple objectives and wide ranging scope of EU climate and energy policies, there has been some debate about the cost effectiveness of such multi-targeted policies. For example, Böhringer et al. (2009) argued that the renewable energy policy target may conflict with the emissions reduction policy target and this can cause the total cost of the latter policy to increase by up to 90% - even if it may help to reduce the resultant emissions permit price. Kemfert and Diekmann (2009), on the other hand, argued that “[as] long as anticipated CO_2 reductions from renewable energy are taken into account in the determination of emissions caps, undesired displacement effects [caused by the renewable energy policy target] can be avoided”. From a theoretical viewpoint, it can be argued that whether multiple policy targets help or hinder each other depends on specific circumstances. For example, if there are significant market failures in the provision of renewable energy due to imperfect information and uncertainty about the future, then government intervention (in the form of renewable energy share target) may help to correct for these failures. On the other hand, if intervention only worsens rather than improves on market efficiency, then the overall cost-effectiveness of the multiple target policies will be reduced. To determine the extent of market failures in the context of European Union climate change policies, we need to define an ‘optimal’ or ideal market situation where the production of renewable electricity is assumed to be ‘efficient’ in the following sense: any *savings* in CO_2 emissions abatement costs which will result from an *increase* in the production of electricity by renewable energy should be counted as a ‘benefit’ (of renewable electricity generation) and therefore should be ‘deducted’ from its actual production costs. To reach this ideal situation condition requires not only optimal investment decision on *future* renewable technologies but also optimal pricing for current technologies. Leaving the issue of optimal investment decision for future studies we concentrate on the issue of optimal pricing level for current renewable technologies. If the market can ascertain with certainty and perfect accuracy the optimal CO_2 emissions permit price then adding this to the price of generating electricity by fossil fuel can provide a benchmark for optimally pricing renewable electricity. In practice, however, this optimal price may depend on many factors which the market (not the government) may be in a position to completely control, for example, the total volume of emissions permits allocated or auctioned and the use of the revenue from auctioning these emissions permits. We therefore assume that the model 'knows' this optimal market price for emission permit and use this to calculate the optimal production level for renewable electricity. We then compare this with the government policy 'target' of 20% share by 2020 to see if this target is 'optimal'.

3.1 *Data*

We use the GTAP (Global Trade Analysis Project) version 7 data base[19] for our experiments. From the database, we construct an aggregation which consists of 15 regions and 13 sectors as described in Tables 3 and 4. From the basic database, we also disaggregate the electricity sector into various technological components using the information published by the Nuclear Energy Agency/International Energy Agency/Organisation for Economic Cooperation and Development (NEA/IEA/OECD, 1998; 2005; NEA/OECD, 2006; IEA/OECD, 2006). The disaggregation characterize the electricity sector as consisting of six different technologies: ElyCoa, ElyOil, ElyGas, ElyBio, ElyNu, ElyHyd, and ElyOth, which stand or electricity generation technology using coal, oil, natural gas, biomass, nuclear energy, hydropower, and other renewable energy resources (solar, wind, geothermal, etc.) respectively. Table 5 shows the shares of these technologies in the electricity sector[20] for the year 2004. It can be seen from Table 5 that the share of electricity using fossil fuels in the EU27 (53.7%) is less than the average for the world as a whole (65.6%), while the share of renewable energy in electricity generation (excluding hydroelectricity) is about twice as much (4.5% compared to 2.1%). If we include hydroelectricity

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[19] Narayanan and Walmsley (2008).

[20] EU policy regarding renewable energy share refers to final energy consumption in all sectors and not just the electricity generation sector. However, in terms of the potential for increasing renewable energy share, the electricity generation sector is perhaps the most important one. Hence in this paper, we focus attention only on this sector.

power, then the share of renewable energy in the EU electricity generation sector is about 14.7%, compared to the world average of 18.7%.

3.2 *Experiments Design and Results*

3.2.1 *Reference Scenario*

First, we need to define a Reference or 'Business-as-Usual' (BaU) Scenario for use as reference for comparison with all other policy scenarios. Two major sets of assumptions are used to define the BaU scenario: one concerns real GDP growth rates and the other population growth rates. These growth rates are based on EUROSTAT and UNDP statistics and are reported in Table 6. From the reference scenario, CO_2 emissions levels can also be estimated and these are reported in Table 6 and Figure 8. In estimating the levels of CO_2 emissions for the Reference Scenario, we make use of the fact that actual emissions of CO_2 and levels of GDP and population are available for the period 2005-2007, hence, instead of using GDP and population figures to project the levels of CO_2 emissions, we use the actual the levels of CO_2 emissions to endogenise (i.e. estimate) the levels of "autonomous energy efficiency improvements (AEEI)[21] for this period. These are shown in Table 7 as 'historical' AEEI. From the average of these historical AEEIs, we then project the future levels for the Reference Scenario as shown in Table 7 and Figure 9. Based on these projected AEEIs for the period 2008-2020 (which are used as exogenous shocks to the model), we then estimate the emissions levels for CO_2. This is shown in Table 7 and Figure 8. Quite clearly, if there are no projected levels for the AEEIs (or implicitly they are assumed to be zero) then the projected levels of CO_2 emissions will also be different (and tend to be higher) as shown in Figure 10.

3.2.2 *EU-ETS Scenario*

Next, we define a scenario which can simulate the implementation of the first component of the EU climate policies (the reduction of CO_2 emissions in the EU by 20% by 2020). The reduction can be achieved via the EU Emissions Trading Scheme (EU-ETS) and hence we call this the

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[21] Defined as percentage increase in output minus percentage increase in energy input. AEEI can be estimated for individual sectors or for the economy as a whole. Here, we are reporting the aggregate AEEI for the economy for each region as a whole.

“EU-ETS” Scenario. The EU-ETS is implemented over three phases: 2005-2007, 2007-2012, and 2012-2020. In the first and second phases, it is assumed that there are national allocation plans (NAPs) which distribute emissions caps for the ETS sectors in each member countries of the EU. Although there are separate plans, because emission permits are traded freely between EU regions, this will result in a single uniform permit price for all EU countries. The ETS-sectors permit price however will differ from the shadow prices or marginal emission abatement costs in the non-ETS sectors. In theory there can be as many shadow prices as there are regulation regimes in the non-ETS sectors. However, to simplify the analysis and for comparison purposes with the ETS sectors, we assume that there is only a single uniform shadow emission price for the non-ETS sectors. When compared with the actual emissions price in the ETS sectors, if the shadow non-ETS price is greater (less) than the actual ETS price, then this implies total allocations of emissions permits to the ETS sectors is more (less) than the efficient level.

The results for the EU-ETS Scenario are shown in Tables 8 and Figures 11-12. In Table 8, it can be seen that if the EU27 decides to go alone with respect to the implementation of climate change policies without the cooperation of all other regions, there will be only a slight improvement in the levels of world emissions (from 44.47 $GtCO_2$/yr in the Reference Scenario reduced to 44.19 $GtCO_2$/yr in the EU-ETS Scenario). This is because despite the great efforts by the EU27 countries (reduction of CO_2 emissions by -14.6% in 2020 compared to 2005 level), there are some ‘leakages’ of emissions from EU27 to non-EU27 countries, hence the total CO_2 emissions level for non-EU27 countries in the year 2020 is seen to *increase* slightly from 38.78 $GtCO_2$/yr in the Reference Scenario to 39.25 $GtCO_2$/yr in the EU-ETS Scenario. These ‘leakages’ although not significant in this case, can be used to highlight the importance of linkages between trade and climate change policies and the importance of seeking international co-operation, not only in the area of climate change policies alone or trade policies alone, but also in the linkages between the two areas.

Figure 11 shows the ‘Induced Energy Efficiency Improvement’ (IEEI) for the EU-ETS Scenario for EU27 countries. Energy Efficiency Improvement’ (EEI) index is used to indicate technological improvements. For the Reference Scenario, when no climate change policies are imposed and therefore no changes in relative prices between energy and non energy commodities are occurring as a result of these policies, any improvement in energy efficiency is considered to be ‘autonomous’. In contrast, the EU-ETS Scenario involves some relative price movements and therefore there will be substitution between emissions-intensive and less emissions-intensive activities which are induced by climate policies, hence the improvement in energy efficiency in this case is considered to be ‘endogenous’ or ‘induced’. To measure the effects of these IEEIs for the EU-ETS Scenario, we assume that the EU27 regions experience no *exogenous*[22] shocks to their EEI levels (as was the case in the Reference Scenario)., and therefore, any improvement in energy efficiency in this Scenario must be considered as ‘inducement’ from climate change policies.[23] For the non-EU27 regions, however, since no climate policies are imposed, we continue to assume ‘autonomous’ (exogenous) shocks to their EEIs as is the case in the Reference Scenario.

Figure 12 shows the emissions permit prices for the ETS and non-ETS sectors and also the emissions-quantity weighted average price for the EU27 over the experiment period. It is seen that the permit price for the ETS sector is much lower than that[24] for the non-ETS sectors, indicating that the total permit allocations to the ETS sectors are overly generous.

3.2.3 *EU-RES (Renewable Energy Share) Scenario*

To analyse the second component[25] of the EU climate policy (20% renewable energy share in final energy consumption activities in the EU by 2020), we define an “EU-Renewable Energy Share (EU-RES) Scenario”. In this Scenario, we first establish a theoretically ‘optimal’ level of renewable electricity share based on the assumption that the market knows exactly what the optimal CO_2 emission abatement cost is for the EU27 as a whole. We then use this information to estimate the optimal market price for renewable electricity. In practice, the optimal permit price may depend, not only on the total volume of permits being allocated to various emitters,

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[22] To include *exogenous* shocks to EEI in this case would result in some ‘double counting’. Because it is difficult to separate out the purely ‘autonomous’ effect from the ‘induced’ effects, the actual EEI may include both.

[23] Induced EEI actually shows more than just the effects of climate change policies. For example, due to the severe downturn in most Western economies in 2009 (arising from the “Global Financial Crisis’), the EEIs are also affected. As seen from Figure 11, the EEIs of all EU27 regions went through a ‘dip’ in 2009, the year of the severe depression in GDP growth, and returned to normal and stable levels only after 2012. Note that the actual (or estimated) levels of GDP growth for the periods 2005-2009 are used in the experiment hence any downturn due to the GFC are in-built into the exogenous database.

[24] Since there is no emissions trading among the non-ETS sectors, this represents a shadow price or the most efficient marginal abatement cost for sectors.

[25] The third component (20% increase in energy efficiency) is not considered in this paper and is left for a future study.

but also on the manner in which they are allocated or auctioned, and the use of the revenue from these auctions (or revenue from CO_2 emissions taxes). We assume a simple – but theoretically optimal – situation: the governments (acting as though in the role of an ideal market) will use (part of) the proceeds of CO_2 emissions permits trading (or emissions tax) to 'subsidise' the production[26] of renewable electricity (ElyBio and ElyOth)[27] but only up to the point where the subsidy represents the actual value of the potential savings in CO_2 emissions arising from renewable electricity production. In an ideal market situation, this 'cross-subsidisation' between alternative technologies would have been performed by the market itself. However, in practice, lack of perfect information and uncertainty may prevent the market (and even the government) from reaching this ideal situation, hence the estimation (by the model) of this optimal outcome for the EU-RES Scenario may help to establish a benchmark against which the actual government renewable energy policy target (of 20% share by 2020) [28] may be compared and assessed.

Figure 13 shows the optimal shares of electricity generation by various technologies including renewable technologies for the EU27 as a whole, and Figures 14A-14D show the optimal shares for some selected countries of the EU27. In calculating these optimal shares, we have assumed that 'subsidy' rate to the production of ElyBio (biomass electricity) and ElyOth (electricity by solar, wind, and other renewable energies excluding hydro-energy) is based fully on the equilibrium CO_2 emissions permit price. However, in some cases (such as subsidy to ElyOth in Spain (ESP), to ElyBio in Rest of Western Europe belonging to EU27 (RWEU), or in France (FRA)), to prevent the increase in renewable electricity beyond what is considered to be 'unrealistic' physical capacity, we have relied on less than 100% of the equilibrium emissions

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[26] We consider only the issue of optimal *production* of renewable energy using *existing* technology but not the issue of *investment* in *future* renewable energy technologies to reduce current costs, i.e. we are not considering the issue of 'induced' or 'endogenous' technological change. This is left for future studies.

[27] We exclude hydroelectricity (ElyHyd) from the subsidy list because we assume that hydroelectricity is a more mature technology than biomass or other renewable technologies hence 'subsidizing' this technology will not be as efficient as subsidizing a 'younger' technology.

[28] The actual EU policy aims at renewable energy share in total *consumption* activities rather than in just electricity generation activities. However, since this is more difficult to simulate, we simplify the analysis in this paper by concentrating only on electricity generation sector and assumes that the target (20% renewable energy share) applies only to this sector.

price.[29] From Figure 13, it can be seen that the 'optimal' total share of renewable electricity (ElyBio and ElyOth) in 2020 for the EU27 as a whole is 12.1%. If we include the (rather stable) share of hydro-electricity in the EU27 of 10%, this amounts to an 'optimal' renewable share of approximately 22%, which is only slightly above the 'policy target' of 20%. Thus, it cannot be concluded that the EU policy target of 20% renewable energy share is unrealistic or cost-ineffective, as it is very close to the 'theoretically optimal' level of 22%.[30]

3.3 *Conclusions*

In this paper, we describe the structure of the **W**orld **I**ntegrated **A**ssessment model of global **T**rade, **E**nvironmental, and **C**limate change (WIATEC) model and use the model in some illustrative experiments to analyse the implications of recent European Union climate change policies. We have shown that the model is capable of being used to analyse quite complex policy issues such as the interactions between different policy targets and instruments. For example, in analyzing the current European Union policies of trying to (a) reduce CO_2 emissions by 20% by 2020 relative to 1990 level using an EU emissions trading scheme (EU-ETS) and (b) encouraging the use of renewable energy in the EU to increase its share to 20% by the year 2020, the model has shown that the cost-effectiveness of these multiple climate change policies depends on the actual sizes of the targets. Given the size of the EU-ETS CO_2 emissions reduction target, the optimal or first best marginal abatement cost (or emissions trading price) is then estimated. Once this is known, an 'optimal' target level for renewable energy share (at least in the production of electricity) can then be estimated. If this target is also set simultaneously with the CO_2 emissions reduction target, no reduction in cost-effectiveness of the policies will occur if the targets are consistent with these 'optimal' levels. In fact, it can be argued that in cases where market uncertainty and imperfection may result in the first best results (such as with respect to optimal renewable energy share given a particular CO_2 emissions reduction target) not being

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[29] For example, only 80% in subsidy to renewable technologies in Spain from 2013-2017 and reduced to 50% from 2017 onwards. This is to reduce the share of ElyOth in ESP from reaching a level exceeding 40% in 2020 which is considered to be unrealistically high.

[30] We have also run the experiment to estimate the renewable energy share for the case when the hypothetical 'subsidy rate' to ElyBio and ElyOth is zero – i.e. *no* part of the proceeds of emissions permits auctioning or emissions taxes are spent towards assisting with renewable electricity production but rather the government relies merely on the higher prices of electricity generation from fossil fuels to 'encourage' production of renewable energy, The results show quite clearly that this will not be sufficient to increase the share of ElyBio and ElyOth beyond existing levels (of 2.4% and 2.1% respectively -see Table 5) due to current high costs of these technologies.

achievable, government intervention in the form of a secondary target such as renewable energy share target may result in an enhancement rather than reduction of policy effectiveness. The model has not been used to analyse the third component of the EU climate change policy, namely the increase of energy efficiency by 20% by the year 2020. This can be considered as a possible application of the model in the future.

Table 3: Regional Aggregation for the Illustrative Experiments.

No.	Region	Description
1	FRA	France
2	DEU	Germany
3	ITA	Italy
4	ESP	Spain
5	UK	The United Kingdom
6	POL	Poland
7	RWEU	Rest of Western Europe which belong to EU27 (Austria, Belgium, Netherlands, Luxembourg, Sweden, Finland, Denmark, Ireland)
8	REU27	Rest of Eastern and Southern Europe which belong to EU27 (Czech Republic, Estonia, Hungary, Latvia, Lithuania, Slovakia, Slovenia, Bulgaria, Romania, Portugal, Ukraine, Rest of Eastern Europe, Portugal, Cyprus, Greece, Malta)
9	USA	United States
10	JPN	Japan
11	BRA	Brazil
12	RUS	Russian Federation
13	CHN	China &Hong Kong
14	IND	India
15	RoW	Rest of the World

Note: Regions 1-8 sum up to EU27. Switzerland and Norway do not belong to EU27; hence they are included in RoW.

Table 4: Sectoral Aggregation for the Illustrative Experiment.

No.	Sector	Description
1	coa	coal mining
2	oil	crude oil
3	gas	natural gas extraction + gas distribution
4	p_c	refined oil products
5	ely	electricity
6	CROPS	paddy rice, wheat, cereal grains nec, vegetables, fruit, nuts, oil seeds, sugar cane, sugar beet, plant-based fibers, crops nec.
7	OAGFF	other agriculture (bovine cattle, sheep and goats, horses, animal products nec, raw milk, wool, silk-worm cocoons), forestry, and fishing
8	MIN	minerals nec
9	CRP	chemical, rubber, plastic production
10	EII	energy intensive industries (ferrous and non-ferrous metals, metal products).
11	OMF	other manufacturing (textiles, wearing apparel , leather, wood, and paper products, publishing, motor vehicles and parts, transport equipment nec, electronic equipment, machinery and equipment nec, manufactures nec).
12	TRN	transport (air, water, sea, land)
13	SER	services (water, construction, trade, communication, financial, insurance, business services nec, recreational, public admin., defence, education, health, ownership of dwellings).

Table 5: Share of electricity generation by various technologies in 2004

Region	Technology						
	ElyCoa	ElyOil	ElyGas	ElyBio	ElyNu	ElyHyd	ElyOth
FRA	0.045	0.012	0.038	0.009	0.788	0.106	0.002
DEU	0.484	0.015	0.122	0.027	0.277	0.032	0.043
ITA	0.161	0.146	0.504	0.023	0.000	0.141	0.025
ESP	0.219	0.076	0.212	0.015	0.275	0.134	0.068
UK	0.384	0.013	0.357	0.024	0.206	0.011	0.005
POL	0.946	0.015	0.020	0.008	0.000	0.010	0.001
RWEU	0.184	0.021	0.235	0.057	0.273	0.210	0.020
REU27	0.410	0.062	0.148	0.009	0.243	0.122	0.005
EU27	***0.304***	***0.038***	***0.195***	***0.024***	***0.316***	***0.102***	***0.021***
USA	0.497	0.019	0.196	0.017	0.199	0.065	0.007
JPN	0.276	0.112	0.235	0.017	0.266	0.090	0.004
BRA	0.024	0.029	0.043	0.030	0.031	0.843	0.000
RUS	0.175	0.024	0.447	0.002	0.156	0.196	0.000
CHN	0.786	0.017	0.009	0.001	0.022	0.164	0.001
IND	0.704	0.044	0.086	0.003	0.024	0.133	0.007
RoW	0.244	0.122	0.279	0.006	0.086	0.256	0.007
World	***0.396***	***0.058***	***0.203***	***0.012***	***0.158***	***0.166***	***0.008***

Table 6: Reference Scenario

Macroeconomic drivers for emissions (average growth rate per annum)									
GDP	2005	2006-2007	2008-2012	2013-2020	Population	2005	2006-2007	2008-2012	2013-2020
FRA	1.90	2.38	0.66	1.61	FRA	0.77	0.55	0.57	0.56
DEU	0.80	3.07	0.35	1.72	DEU	-0.04	-0.12	-0.12	-0.11
ITA	0.70	2.04	-0.25	1.51	ITA	0.99	0.83	0.76	0.83
ESP	3.60	3.57	-0.16	0.92	ESP	1.64	1.81	1.80	1.82
UK	2.20	3.01	0.38	2.12	UK	0.60	0.65	0.50	0.65
POL	3.60	6.15	2.87	3.11	POL	-0.04	-0.05	0.00	0.00
RWEU	3.31	3.60	0.41	2.16	RWEU	0.53	0.66	0.58	0.63
REU27	5.39	4.47	-0.12	2.07	REU27	-0.03	-0.05	0.00	-0.03
EU27	2.00	3.10	0.32	1.81	***EU27***	0.48	0.47	0.44	0.49
USA	2.94	2.34	1.22	2.35	USA	0.97	0.97	0.97	0.97
JPN	1.93	2.53	0.00	1.54	JPN	0.05	-0.08	-0.04	-0.09
BRA	3.16	4.88	5.16	5.60	BRA	1.20	0.97	1.08	0.98
RUS	6.39	7.74	5.42	5.72	RUS	-0.48	-0.38	-0.49	-0.38
CHN	10.27	10.28	7.64	7.72	CHN	0.66	0.63	0.63	0.63
IND	9.33	8.35	6.47	7.06	IND	1.56	1.44	1.33	1.44
RoW	4.79	5.04	2.29	2.63	RoW	1.23	1.19	1.40	1.19

CO_2 emissions by regions ($GtCO_2$/year)				% change 2005-2020	CO_2 emissions by sectors ($GtCO_2$/year)				% change 2005-2020
regions	2005	2012	2020		ETS sectors	2005	2012	2020	
FRA	0.38	0.36	0.37	-2.3%	FRA	0.13	0.13	0.14	4.1%
DEU	0.77	0.72	0.72	-7.3%	DEU	0.48	0.46	0.46	-2.3%
ITA	0.44	0.41	0.42	-6.0%	ITA	0.23	0.22	0.23	1.0%
ESP	0.33	0.34	0.33	-0.1%	ESP	0.18	0.19	0.19	2.2%
UK	0.59	0.58	0.62	5.1%	UK	0.24	0.27	0.30	24.3%
POL	0.28	0.32	0.40	41.6%	POL	0.20	0.24	0.31	56.1%
RWEU	0.58	0.59	0.64	10.0%	RWEU	0.27	0.29	0.32	15.6%
REU27	0.56	0.55	0.60	8.0%	REU27	0.28	0.27	0.30	8.7%
EU27	***3.94***	***3.87***	***4.10***	***4.0%***	***EU27***	2.01	2.08	2.24	11.8%
					Non-ETS				
USA	6.08	6.34	7.02	15.4%	FRA	0.25	0.23	0.23	-5.8%
JPN	1.10	1.13	1.15	4.2%	DEU	0.30	0.26	0.25	-15.3%
BRA	0.30	0.35	0.41	35.2%	ITA	0.22	0.19	0.19	-13.3%
RUS	1.56	2.01	3.01	93.1%	ESP	0.15	0.15	0.15	-2.8%
CHN	4.97	7.75	13.12	164.2%	UK	0.35	0.31	0.32	-8.3%
IND	1.10	1.73	3.04	175.9%	POL	0.08	0.08	0.09	7.8%
RoW	7.73	9.33	11.04	42.8%	RWEU	0.31	0.30	0.33	5.1%
non EU27	22.84	28.63	38.78	69.8%	REU27	0.28	0.28	0.30	7.4%
world	26.78	33.65	44.47	66.1%	***EU27***	1.93	1.80	1.85	-4.1%

Figure 8: CO_2 emissions for the Reference Scenario ($GtCO_2$/yr)

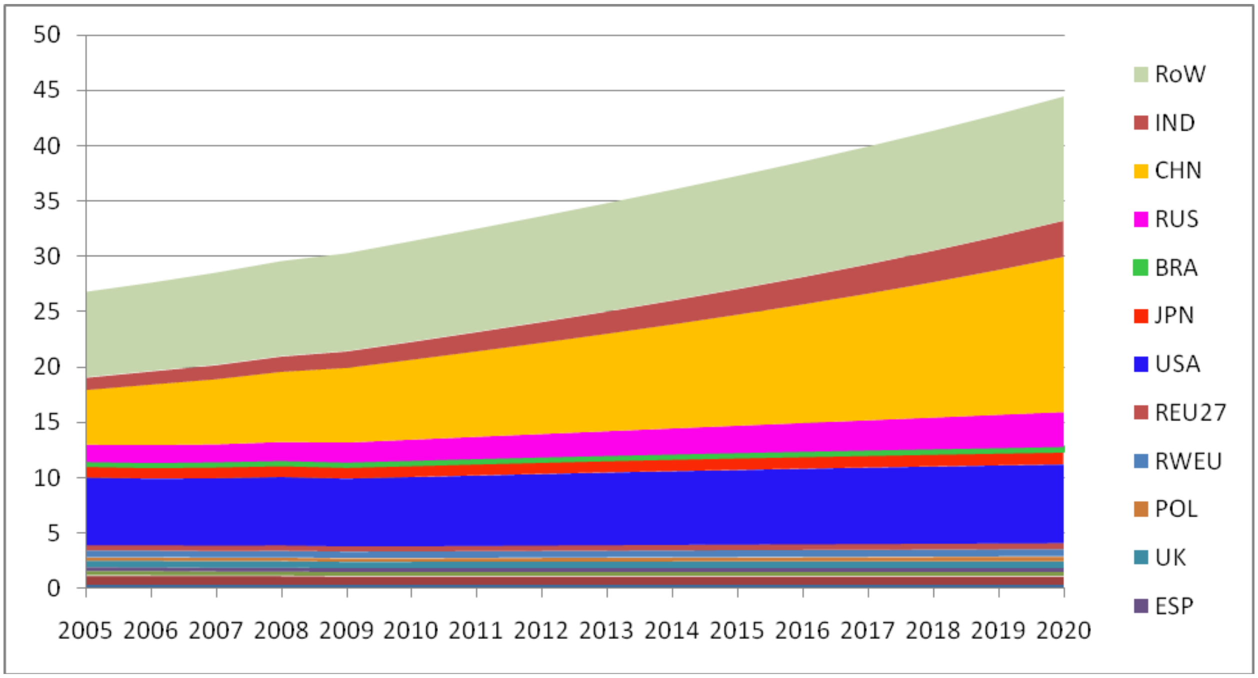


Table 7: Autonomous Energy Efficiency Improvement (AEEI) for the Reference Scenario (%)

Region	Historical			Projected			
	2005	2006	2007	2008	2012	2016	2020
FRA	-0.03	-0.01	-0.06	-0.02	0.16	0.33	0.50
DEU	-0.19	0.98	0.62	0.65	0.76	0.87	0.97
ITA	-0.23	0.40	0.13	0.17	0.31	0.46	0.60
ESP	0.17	0.24	0.10	0.14	0.32	0.49	0.67
UK	-0.03	0.25	0.37	0.39	0.49	0.60	0.70
POL	-0.19	0.74	0.96	0.97	0.98	0.99	1.00
RWEU	0.19	0.67	0.23	0.28	0.47	0.67	0.86
REU27	-0.02	0.57	0.35	0.38	0.52	0.66	0.80
USA	0.05	-0.08	-0.45	-0.38	-0.09	0.21	0.50
JPN	0.05	0.27	0.02	0.07	0.25	0.43	0.61
BRA	0.45	0.60	1.23	1.23	1.24	1.25	1.26
RUS	0.62	0.76	0.77	0.80	0.94	1.08	1.22
CHN	0.81	1.09	1.39	1.40	1.47	1.53	1.60
IND	0.05	0.25	0.14	0.18	0.33	0.49	0.64
RoW	0.18	0.26	0.18	0.22	0.38	0.54	0.71
EU27	-0.04	0.48	0.34	0.37	0.50	0.63	0.76
Non-EU	0.32	0.45	0.47	0.50	0.65	0.79	0.93

Figure 9: Historical (2005-2007) and projected (2008-2020) levels of Autonomous Energy Efficiency Improvement (AEEI) used in the Reference Scenario

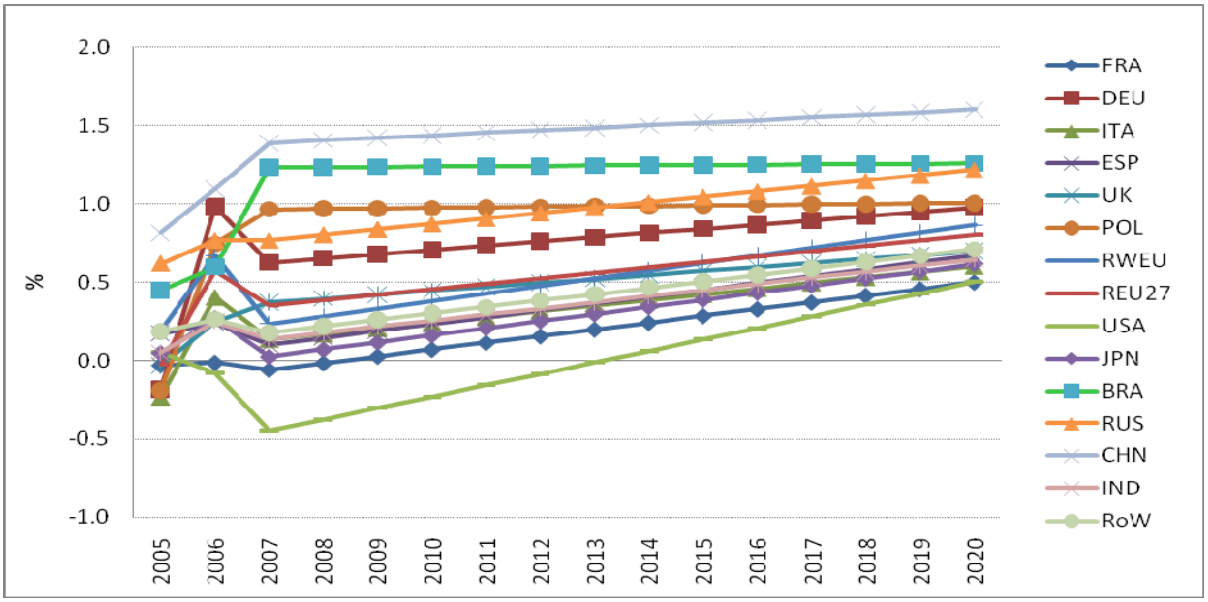


Figure 10: CO_2 emissions for the Reference Scenario ($GtCO_2$/yr) when AEEIs are assumed to be zero (for the period 2008-2020)

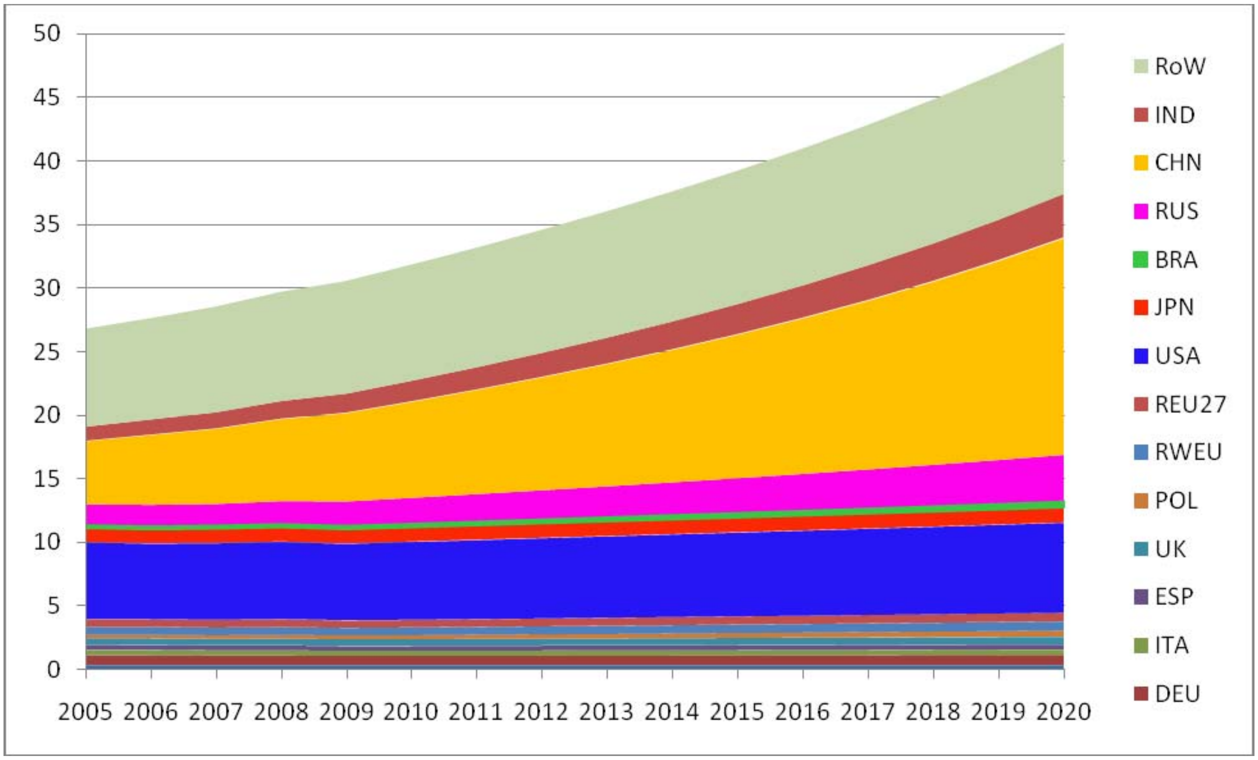


Table 8: CO_2 emissions for the EU-ETS Scenario

CO_2 emissions by regions ($GtCO_2$/year)				% change 2005-2020	CO_2 emissions by sectors ($GtCO_2$/year)				% change 2005-2020
regions	2005	2012	2020		ETS sectors	2005	2012	2020	
FRA	0.38	0.34	0.33	-11.6%	FRA	0.13	0.13	0.13	-0.9%
DEU	0.77	0.68	0.61	-21.2%	DEU	0.48	0.41	0.35	-26.0%
ITA	0.44	0.40	0.39	-13.0%	ITA	0.23	0.21	0.20	-9.5%
ESP	0.33	0.31	0.27	-17.7%	ESP	0.18	0.17	0.14	-24.2%
UK	0.59	0.51	0.49	-17.4%	UK	0.24	0.22	0.20	-16.6%
POL	0.28	0.28	0.25	-10.6%	POL	0.20	0.19	0.15	-22.7%
RWEU	0.58	0.56	0.57	-1.6%	RWEU	0.27	0.27	0.26	-4.5%
REU27	0.56	0.48	0.45	-19.9%	REU27	0.28	0.22	0.16	-41.0%
EU27	3.94	3.56	3.36	-14.6%	***EU27***	2.01	1.82	1.61	-20.0%
					Non-ETS				
USA	6.08	6.37	7.11	16.9%	FRA	0.25	0.21	0.20	-17.4%
JPN	1.10	1.13	1.16	5.4%	DEU	0.30	0.27	0.26	-13.6%
BRA	0.30	0.35	0.41	36.4%	ITA	0.22	0.19	0.18	-16.6%
RUS	1.56	2.03	3.06	96.2%	ESP	0.15	0.14	0.14	-9.7%
CHN	4.97	7.78	13.22	166.2%	UK	0.35	0.29	0.28	-18.0%
IND	1.10	1.74	3.08	180.0%	POL	0.08	0.09	0.10	17.5%
RoW	7.73	9.39	11.19	44.9%	RWEU	0.31	0.29	0.31	1.0%
Non EU27	22.84	28.80	39.25	71.8%	REU27	0.28	0.27	0.28	1.0%
world	26.78	33.47	44.19	65.0%	***EU27***	1.93	1.75	1.75	-9.1%

Figure 11: Induced Energy Efficiency Improvement (IEEI) in the EU-ETS Scenario for EU27 countries/regions

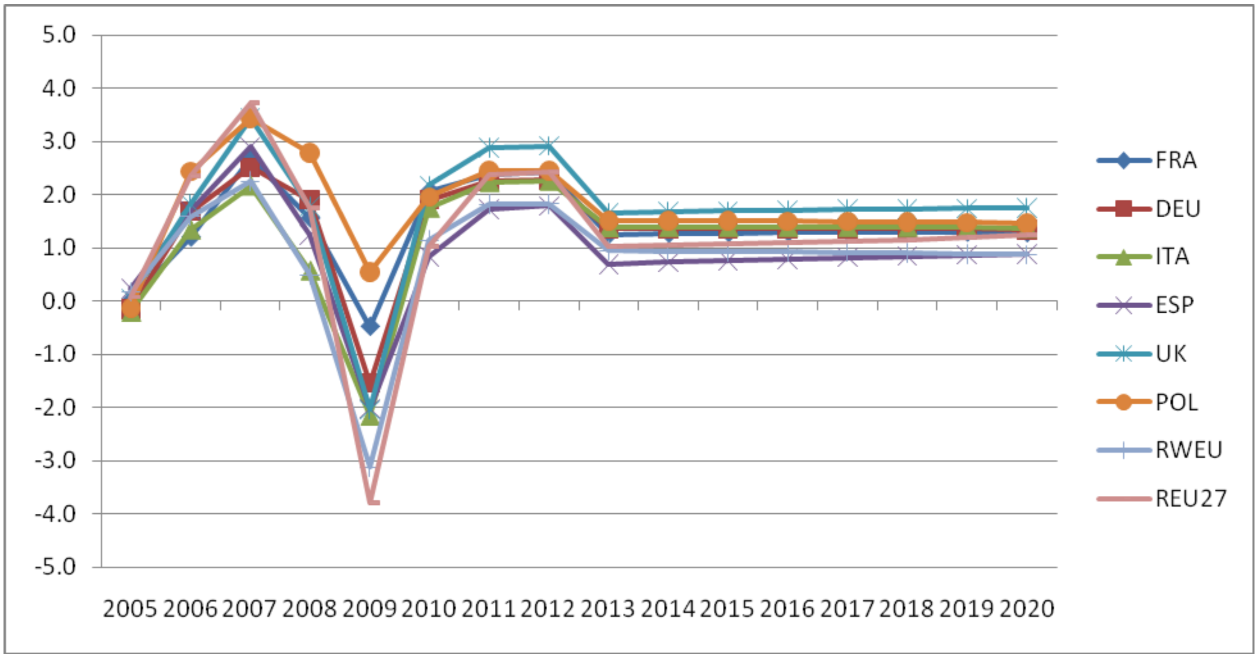


Figure 12: CO_2 emissions permit price (or marginal abatement cost) for the EU-ETS Scenario (2004US/tCO_2$)

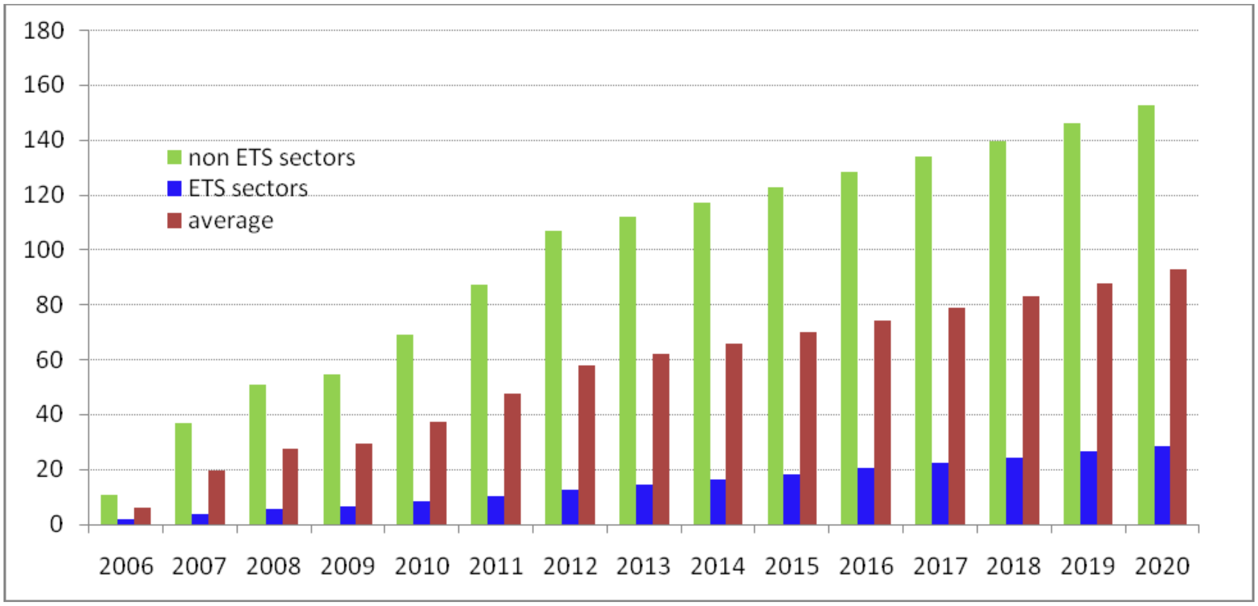


Figure 13: ‘Optimal’ shares of electricity generation by various technologies in the EU27 as a whole estimated for the EU-RES Scenario

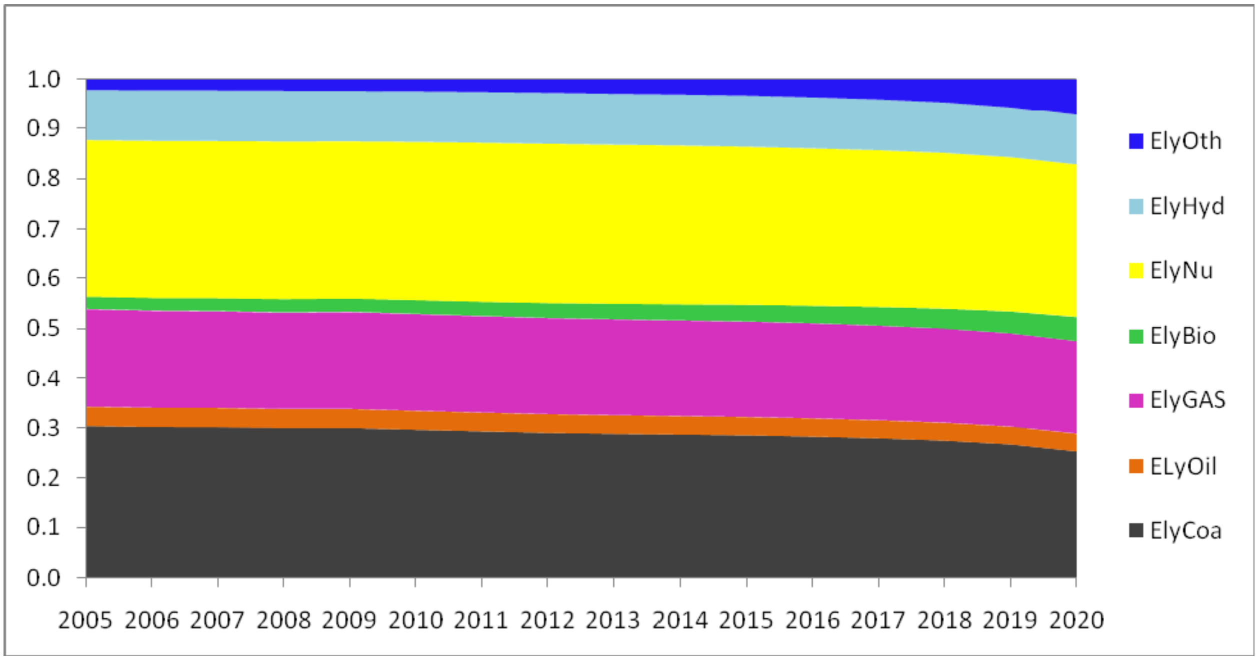


Figure 14A: ‘Optimal’ shares of electricity generation by various technologies for Spain

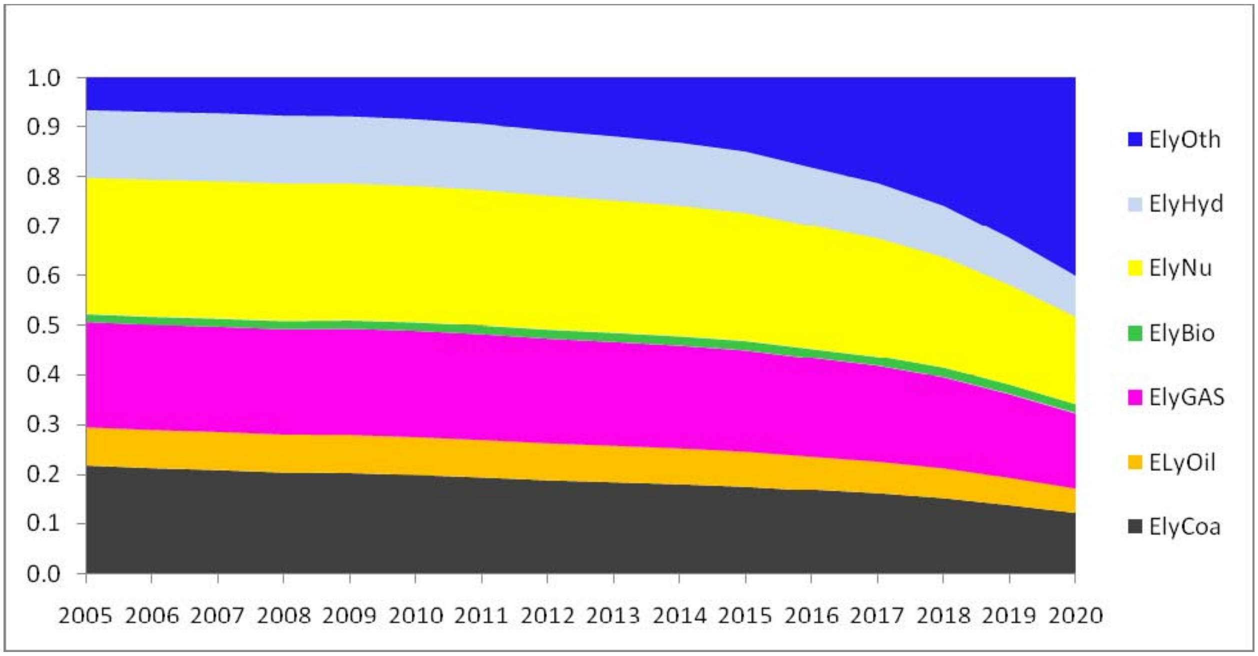


Figure 14B: ‘Optimal’ shares of electricity generation by various technologies for Germany

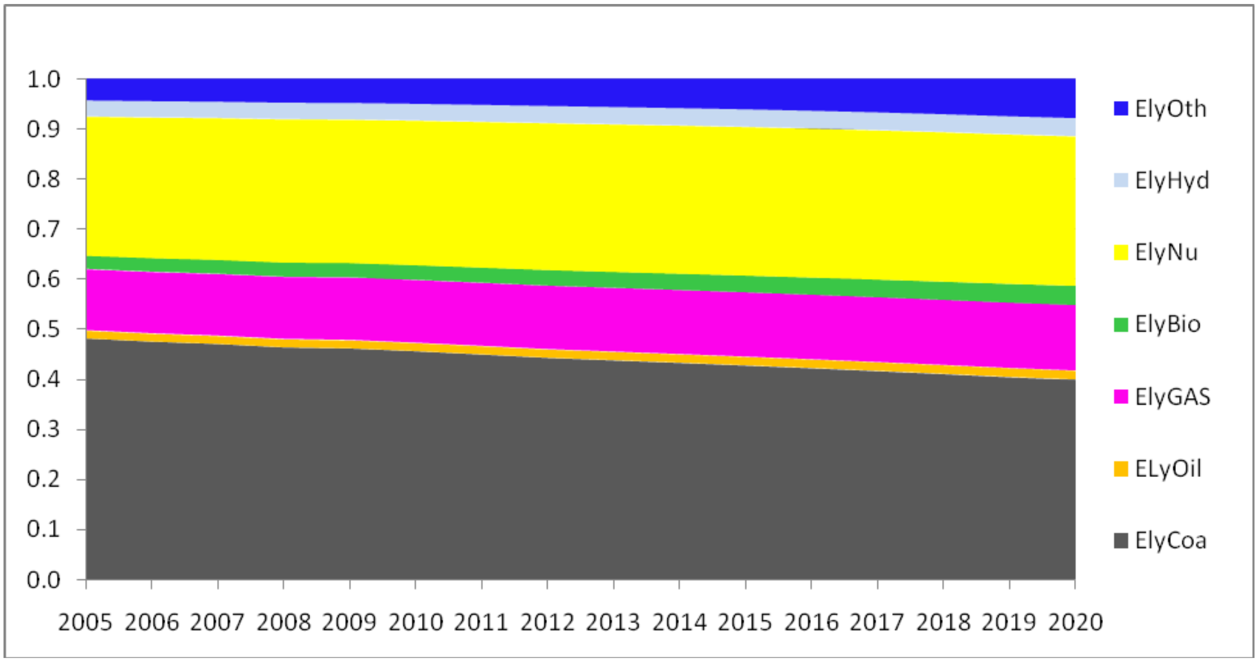


Figure 14C: ‘Optimal’ shares of electricity generation by various technologies for the UK

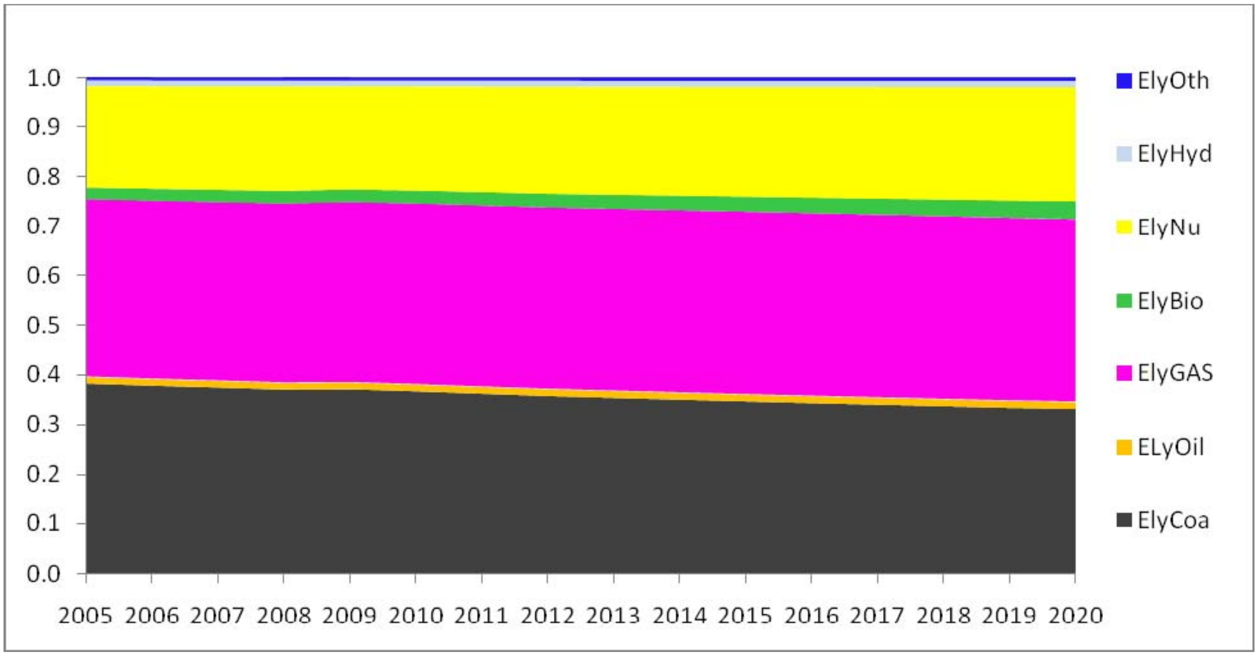
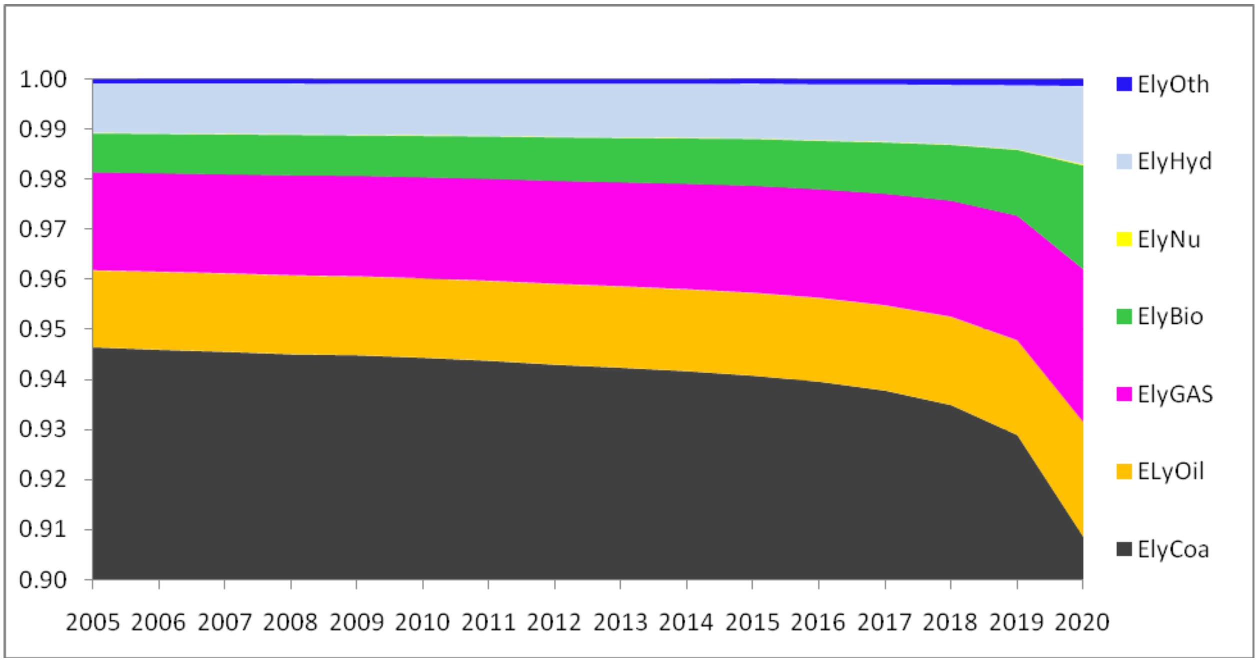


Figure 14D: ‘Optimal’ shares of electricity generation by various technologies for Poland



References

ABARE (Australian Bureau of Agricultural and Resource Economics), (1996), *The MEGABARE model: interim documentation,* ABARE, Canberra.

Böhringer, C., Rutherford, T., and R. Tol (2009), "The EU 20/20/2020 Targets: an Overview of the EMF22 Assessment", Working Paper 325, Economic and Social Research Institute, Dublin.

Burniaux, J. -M., T.P. Truong (2002), "GTAP-E: An Energy-Environmental Version of the GTAP Model", GTAP Technical Paper No. 16, Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana, USA.

Brückner, T., Hooss, G., Fuessel, H. -M., K. Hasselmann (2003), "Climate system modelling in the framework of the tolerable windows approach: The ICLIPS climate model", *Climatic Change*, 56, 119-137.

Carlo Perroni and Thomas F. Rutherford, "A Comparison of the Performance of Flexible Functional Forms for Use in Applied General Equilibrium Modelling" *Computational Economics* **11:** 245–263, 1998.

Commission of the European Communities (CEC) (2007), *Communication from the Commission to the European Council and the European Parliament: An Energy Policy for Europe*. Brussels, 10 January (COM (2007) 1 final).

Commission of the European Communities (CEC) (2008), *Proposal for a Decision on the European Parliament and of the Council on the Effort of Member States to Reduce their Greenhouse Gas Emissions to Meet the Community's Greenhouse Gas Emission Reduction Commitments up to 2020*, Brussels. COM(2008) 17 final.

Council of the European Union: EU position for the Copenhagen Climate Conference (7-18 December 2009) - Council conclusions, 14790/09, ENV 711, Brussels, 21 October 2009.

C., Diekmann, J.: Emissions Trading and Promotion of Renewable-Energy – We Need Both. DIW Berlin Weekly Report 14/2009

Gorecki, P.K., S.Lyons, and R.S.J.Tol (2009), *EU Climate Change Policy 2013-2020: Using the Clean Development Mechanism More Effectively,* Working Paper **299** ,Economic and Social Research Institute, Dublin.

Hanoch, G. (1971), "CRESH Production Function", *Econometrica*, 39, 695-712.

Hertel, T. (1997), *Global Trade Analysis. Modelling and Applications,* Cambridge University Press.

Hooss, G. (2001), “Aggregate models of climate change: development and applications. Max Planck Institute for Meteorology, Examensarbeit 83”, *Dissertation* am Fachbereich Geowissenschaften der Universität Hamburg.

Hourcade, J-C., Damailly, D., Neuhoff , K., and M. Sato (2007), . *Differentiation and dynamics of EU ETS industrial competitiveness impacts:Final Report*, Climate Strategies, Cambridge, UK. (http://www.climatestrategies.org/our-reports/category/6/37.html)

Hyman, R.C., Reilly, J.M., Babiker, M.H., De Masin, A., and H.D. Jacoby (2002), “Modeling Non-CO2 Greenhouse Gas Abatement”, MIT Joint Program on the Science and Policy of Global Change, Report 94.

IEA/OECD, (2006). *Energy Technology Perspectives, Scenarios & Strategies to 2050*, Paris.

Kemfert, C., and J. Diekmann (2009),“Emissions Trading and Promotion of Renewable Energy – We need Both”, DIW Berlin Weekly Report No. 14/2009.

Lee, H-L (2008), “The Combustion-based CO2 Emissions Data for GTAP Version 7 Data Base”, Centre for Global Trade Analysis, Purdue University. https://www.gtap.agecon.purdue.edu/resources/download/4470.pdf..

Lee, H-L, Hertel, T.W., Sohngen, B., and N. Ramankutty (2005), “Towards An Integrated Land Use Data Base for Assessing the Potential for Greenhouse Gas Mitigation”, GTAP Technical Paper No.25, December, Centre for Global Trade Analysis, Purdue University, Indiana, USA.

E.Maier-Reimer, E., and K. Hasselmann (1987), “Transport & storage of CO_2 in the ocean - an inorganic ocean-circulation carbon cycle model”, *Climate Dynamics*, 2, 63 – 90.

McDougall, R.A., and A.H. Aguiar (2008), “Energy Data”, Chapter 11 in Badri Narayanan G. and Terrie L. Walmsley (Editors) *Global Trade, Assistance, and Production: The GTAP 7 Data Base*, Center for Global Trade Analysis, Purdue University.

NEA/IEA/OECD Nuclear Energy Agency, International Energy Agency, and Organisation for Economic Co-operation and Development (1998), *Projected Costs of Generating Electricity Update 1998*, IEA, Paris.

NEA/IEA/OECD Nuclear Energy Agency, International Energy Agency, and Organisation for Economic Co-operation and Development (2005), *Projected Costs of Generating Electricity Update 2005*, IEA, Paris.

NEA/OECD (2006), *Nuclear Energy Data*, IEA, Paris.

Narayanan, Badri G. and Terrie L. Walmsley (Editors) (2008), *Global Trade, Assistance, and Production: The GTAP 7 Data Base*, Center for Global Trade Analysis, Purdue University.

Pant, H. (2007), *GTEM: Global Trade and Environment Model*. ABARE Technical Report. www.abareconomics.com/interactive/GTEM/, accessed 4 October 2007.

Schumacher, K. and R. Sands (2006), "Innovative energy technologies and climate policy in Germany", *Energy Policy*, 34(18), 3929-3941.

Traber, T. and C. Kemfert (2009), "Gone with the Wind?: Electricity Market Prices and Incentives to Invest in Thermal Power Plants under Increasing Wind Energy Supply," Discussion Papers 852, DIW Berlin, German Institute for Economic Research.

Tóth, F., Brückner, T., Füssel, H.-M, Leimbach, M., and G. Petschel- Held (2003), “Integrated assessment of long-term climate policies: Part 1 – Model presentation”, *Climatic Change* 56, 37– 56.

Truong, T. P. 1999. “GTAP-E : Incorporating Energy Substitution into the GTAP Model”, GTAP Technical Paper No. 16, December.

Truong, T.P., and C. Kemfert (2008), “A Flexible Global Warming Index for Use in an Integrated Approach to Climate Change Assessment”, *Environmental Modeling and Assessment*, 13, pp. 503-515. DOI 10.1007/s10666-007-9114-6.

United States Environmental Protection Agency (USEPA) (2006), *Global Mitigation of Non-CO2 Greenhouse Gases*, Washington, DC: USEPA.