Extending energy portfolio with clean technologies in the ICES model

Francesco Bosello
FEEM, University of Milan

Lorenza Campagnolo
FEEM, University of Venice

Fabio Eboli
FEEM, CMCC

Ramiro Parrado
FEEM, University of Venice

Elisa Portale
FEEM

Draft paper, please do not quote.

Extending energy portfolio with clean technologies in the ICES model

Abstract

Promotion of “clean” technologies is among the main challenging issues in climate policy agendas worldwide. Countries are increasingly recognising the potential role of renewable energy within a portfolio of low-carbon and cost-competitive energy technologies capable of responding to the emerging major challenges of climate change, energy security, and access to energy. As confirmed in the last UN Climate Change Conference in Cancun (2010), investments in renewables may lighten the effort or allow for more ambitious goals. Moreover, as a global problem, climate change requires international mitigation policies. These originate changes in world energy prices and lead to a re-composition of global energy demand, with a substantial radical change in the energy productive mix.

Top-down models, as a proper tool to investigate such a global issues, have a very reliable macro-economic structure, with interdependences at sectoral and regional level; unfortunately, they usually present a very poor detailed number of energy technologies within each sector.

This paper suggests a newly modified CGE model and database enriched with a range of clean energy alternative technologies. The starting point is the ICES (Inter-temporal Computable Equilibrium System) model, which is a recursive-dynamic multi-regional general equilibrium model, based on the GTAP dataset and GTAP-E model.

External data and statistics are used to split selected GTAP7 database sectors in order to isolate six new energy commodities: solar, wind, hydro and waste to energy, the so called renewable energy sources, mainly used in power generation; in addition, nuclear fuel and biofuels are included as primary energy sources. Renewables are presented in the model as imperfect substitutes for electricity from fossil fuels and the intermittency issue is also taken into account.

This higher detailed picture of energy sector proposed can give important insights on how inter-fuel substitution, governed by price signals, determines the composition of energy mix and their evolution across time. Referring to this, the paper presents a baseline scenario which reproduces the historical economic trend until 2020 reflecting occurrence and evolution of financial crisis for the EU27 and the rest of the world grouped in 8 regions. Moreover, a climate policy scenario is proposed focusing on the cost-efficient solution in coordinated action under low pledges of the Copenhagen agreement in a global CO_2 market.

Extending energy portfolio with clean technologies in the ICES model

1. Introduction

Climate change mitigation represents one of the most challenging issues of policymakers' agendas for the next future. Tackling the problem of global climate change requires a high level of international cooperation and shared effort and participation by all advanced and developing economies around the world mainly implying a deep revision of future development. Particularly, the expected increase in energy demand has to be faced with appropriate energy solutions, considering on the one hand a dramatic improvement in energy use of traditional and polluting fossil fuels and on the other hand the increased use of alternative and non-polluting non-fossil fuels.

Meanwhile, the negotiations in the framework of the United Nations Framework Convention on Climate Change (UNFCCC) led, in 2005, to the entry into force, for ratifying countries, of the Kyoto Protocol. The Protocol assigns binding targets relative to their emissions of carbon dioxide and other greenhouse gases (GHG), to countries listed in its Annex I (industrialised countries). More recently, the international community formally agreed (Cancun, Mexico, December 2010) to limit global warming to 2°C from pre-industrial level, and to consider in only a few years' time possibly strengthening this objective to limit global warming to 1.5°C.

Renewable energy technologies will play a very important role in reducing GHG emissions.

In understanding the costs of stabilizing greenhouse gases concentration in atmosphere to a specific level, different analysis may be performed. Bottom-up analysis typically focuses on a large range of technologies allowing achieving a new energy structure in line with the policy objectives. While the richness of technological details gives a very flexible picture of future achievements, bottom-up models lack the interaction of energy production with the rest of the economic system, assuming for example future trends in energy demand as given. Conversely, top-down models put in strong relationship energy production and economic system, including international trade of energy and non-energy commodities. This way, those models make possible the response of economic agents induced by change in relative prices. Nevertheless, the flexibility of the energy system is quite low and only a few alternatives, described as energy macro-categories, are available. To give a most complete picture of possible scenarios, it is now recognised the role of using hybrid approaches considering reciprocal advantages in a common framework. That is, linking the micro-economic and technological detail for energy production to the macro-economic system.

This work aims to describe one attempt to make a top-down model more informative by introducing a higher specification of energy technologies. It relies upon the GTAP database that is consistently extended to capture several more technologies and a recursive-dynamic models tailored for climate change impacts and policy economic assessment.

2. The inclusion of renewable energy in CGE models

Renewable energy sources (RES) are a key element in the process of energy system transformation towards sustainability. Countries are increasingly recognising the potential role of RES within a portfolio of low-carbon and cost-competitive energy technologies capable of responding to the emerging major challenges of climate change, energy security, and access to energy. Renewable substitutes energy derived from fossil fuels. Recent years have seen a major scale-up of wind and solar technologies. Other renewable technologies — including hydropower, geothermal and biomass—continued to grow from a strong established base, adding thousands of megawatts of new capacity worldwide (IEA, 2011). Thereby those energy technologies contribute to climate protection through the reduction of carbon dioxide emissions associated with the combustion of fossil fuels. Moreover GHG emission target and the rising in carbon prices will increase renewable energy technologies development. The early deployment of renewable technologies is a cost-effective measure for long-term climate change mitigation, even if it looks too costly when only short-term reductions are considered. This argument is often challenged on the basis that research and development would lead to the cost reductions required for later, large-scale deployment

The support to RES may have various drivers other than climate change mitigation. These include: 1) a contribution to increased energy security, reducing dependence from imported fossil fuels; 2) hedging against price volatility and long-term price increase of fossil fuels; 3) a contribution to the reduction of other pollutants and related risks arising from the use of other energy sources; 4) and a willingness to develop local employment, sometimes reinforced by a perception of the first mover’s advantage (IEA, 2011). Energy sector typically features a large number of energy technologies to capture substitution of energy carriers on the primary and final energy level and process substitution.

Computable General Equilibrium (CGE) models in last twenty years have widely become one of the most used tools to address economic analysis of climate change mitigation policies. In fact, as a global problem requiring global solutions, one main feature in assessing such policies is how sharing the costs such that policies will result environmentally effective and economically efficient. It is well-known that this requires stable agreements among signatories leaving no room for defecting or free-riding the agreements themselves. To make governments more aware and responsible of the role taken in mitigating possible adverse effects of climate change in case of inaction, cost and effort sharing must be as clear as possible. CGE models allow taking into account all possible economic interactions, therefore keeping trace of possible future scenarios implied by different commitments that can be gradually fine-tuned in order to potentially produce win-win solutions.

When approaching such models, one of the most difficult actions is constructing the initial economic benchmark referred to an existing equilibrium of the real economic systems. Collecting data is hard and time-intensive, especially when looking at global models covering all world countries. Since 90s, the GTAP network works on this respect aggregating data from national accounts throughout the world in a very large database, consistent and ready to be used for different analyses on various fields (climate change but also agriculture policies, international trade and so on). Unfortunately, such a huge work mainly relies upon input-output matrices released by national statistical offices and institutes, extended appropriately, but still having many simplifying assumptions and missing data.

Particularly affecting climate change analyses is the poor detail of energy technologies. At the very largest database’s extension, there are only several energy vectors: coal, oil, oil products, natural gas production and distribution, electricity. Particularly electricity, in this shape, is not very informative, while keeping trace of what happens within the electricity sector represents a crucial point of climate change policies effectiveness. These typically increase the costs for fossil fuels use through the introduction of a carbon price aimed to internalise in the production or consumption function of fossil fuels users the externalities of dirty emissions in atmosphere. This leads to changes in relative prices with respect to a situation with no policy and to a new energy technology mix capable to match the new stabilisation target. Indeed, most CGE models have a rather abstract representation of the energy system. Fuel production or electricity generation is described at an aggregate level by continuously differentiable revenue functions which capture substitution possibilities through constant elasticity of substitution (Bohringer and Loschel, 2006).

This is the main reason why, starting from the GTAP database that we greatly acknowledge, we worked to extend it introducing a set of RES and then to project it in the future by means of a recursive-dynamic model, ICES. This way, we are now able to address more clearly future implications of any climate policies also adding information about the future trend in energy technologies under different assumptions and scenarios.

Several CGE models have considered RES among their commodities and also extended the nest in which these are located with a different analysis of the elasticity of substitutions. For example, the EPPA[1] model (Paltsev *et al.*, 2005) includes Wind, Solar, and Hydro among the generation technologies in the electricity sectors. Other technologies (biomass, natural gas combined cycle with and without carbon capture and sequestration, and integrated coal gasification combined cycle with carbon capture and sequestration) are considered in the electricity branch and they enter as perfect substitutes for existing technologies.

In GTEM[2] model electricity is generated from fourteen different technologies. These industries can substitute between technologies in response to changes in their relative profitability. By modelling energy intensive industries in this way, GTEM restricts substitution to known technologies, thereby preventing technically infeasible combinations of inputs being chosen as model solutions. The basic idea imposed here is that the learning function is applied to infant industries as RES ones. Currently, most of the RES use primary factors (labour and capital) as the only inputs. Hence, as the reference case, economic growth is driven by factor productivity growth of some sort, RES get double benefits with respect to fossil fuel based technologies.

WITCH is a top-down neoclassical optimal growth model with an energy input specification which analyzes optimal climate mitigation strategies within a game-theoretical framework, while portraying the evolution of energy technologies and allowing for endogenous technological progress (Bosetti *et al.*, 2006). Optimization growth models are usually very limited in terms of technological detail and this severely constraints the analysis of climate change issues. WITCH separates electric and non-electric uses of energy, features seven

[1] The MIT Emissions Prediction and Policy Analysis (EPPA) model is a multi-region, multi-sector, recursive-dynamic multi-regional computable general equilibrium (CGE) simulation of economic growth, energy use and greenhouse gas (GHG) emissions over the next 100 years.

[2] GTEM can be considered a ‘top down’ model in that it is a highly aggregated model of complete economic systems and the energy sector is only one of the many sectors identified. Energy centred ‘bottom up’ models are highly detailed models of the energy sector identifying alternative technologies that can be used in the production of a given output. These models usually incorporate capacity constraints and are solved by using linear programming or nonlinear programming techniques.

power generation technologies and includes the use of multiple fuels: oil, natural gas, coal, uranium, traditional biomass and biofuels. This kind of detail in the energy sector – although still much simpler than that of large scale energy system models – is a novelty for this class of models. Therefore, it enables future energy and technological scenarios to assess their compatibility with the goal of stabilizing greenhouse gas concentrations.

3. The extended GTAP7 database

GTAP7 database

The first step to enlarge the GTAP database was the data collection about physical energy production (in terms of Mtoe = Million tons of oil equivalent) from the different energy vectors around the world. To be as consistent as possible with data on energy volumes already provided by the GTAP package, we used the Extended Energy Balances (both OECD and Non-OECD countries) from International Energy Agency (IEA) for the new sources discarded in GTAP7.

Once data collection was complete, data were grouped when necessary and ordered according to the list of 113 countries/regions of GTAP7. Technologies which we focused on are hydro, wind and solar electricity, and nuclear processing for power production; corn-based ethanol, sugar-based ethanol and biodiesel as fuels for the transport sector.

Once completed the physical quantities database, the following points were developed: 1) assign an economic value to the physical production; 2) define a production function, i.e. how much of primary factors and intermediate inputs are used to produce the corresponding monetary amount; 3) determine destinations of these commodities (e.g. who are the users of wind power, solar power…).

In order to assign an economic value to the physical quantities, we collect data on unit cost of each technology at country level (according to data availability), so taking into account, when possible, differences among technologies and specific resource availability.

General references on renewable power costs, mainly focused on Europe, can be found in OECD/IEA (2005), EC (2008), ISI (2007) and GTZ (2009); in addition IEA country profiles and REN21 website were used to cover other countries. As it is understandable, we can be quite confident that data for developed economies well resemble the real value, while for developing countries energy statistics are often incomplete and sometimes we transfer value per unit of power produced in one country to others located relatively close or comparable in economic and technological structure.

Additional sources considered in estimating levelised unit cost ($ / kWh) of wind power were ABS Energy Research (2008) and IEA (2006). For solar electricity no additional sources were used, except JRC (2008) for Japan, but it was explicitly considered the different unit cost of photovoltaic and thermal electricity technology. For hydro power other references can be found in EC (2008), ESMAP (2005) and ESHA (2004). Usually costs of different technologies present a wide dispersion across countries. Table 1 presents world average costs for each renewable technology considered, which sum up the regional detail reached.

Table 1: Unit cost renewable technologies, world average ($/kWh)

Wind	Solar	Hydro
0.07	0.38	0.05

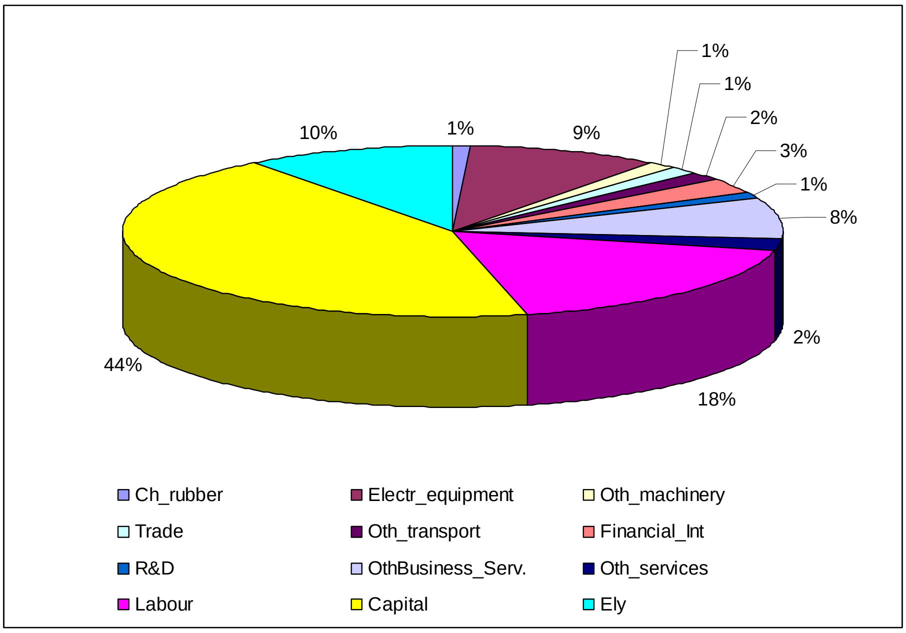
Relatively to other energy sources, nuclear fuel and biofuels, not at the moment focus of this paper, a similar procedure was followed.

As usual in input-output and social accounting matrices, the value of a specific production must be mirrored by the input used in the production process in order to satisfy constant return to scale and perfect competition properties. In this case, we derived for each energy production based on specific resource a related production function relying upon available information on technological features, costs of inputs and primary factors and the mix necessary to produce one unit of energy. Renewable technology is capital intensive, according to OECD/IEA (2005) the share of capital on projected generation costs is for wind power are on average 74%, for solar 86%, for hydro 81%. Other sources (Sue Wing, 2008) state for wind power a capital cost share around 83% and a labour one 17%; for solar respectively around 92% and 8%; for hydro 0.75 and 0.25. Most of the literature does not consider the use of intermediate inputs; otherwise natural resources can be included (Sue Wing, 2008).

The difficult task is to merge blend this information with an extremely detailed database, as GTAP, which require specifying the contribution of 57 intermediates commodities to production; in addition, it is worth to maintain the sufficient consistency with more engineering sources such as Life Cycle Assessment studies, which are the only source of information about the use of intermediate factors. The purpose of taking in account all this information implies some adjustments in input share.

Kannan (2006) gives a break-down of cost distribution of a solar PV system: solar PV modules, installation costs, inverters and supporting structure are considered as capital costs (and accounts for 96% of the overall expenditure), and the residual (4%) includes O&M and decommissioning costs. Clearly this component, commonly embodying provisions for repair and spare parts, maintenance, land rent, insurance, management and administration, considers the costs occurring during plant lifetime and excludes cost of labour and materials, proper of installation period. For this reason, in constructing production function capital costs were not considered as equivalent to physical capital (primary factor), but a country-specific share were attributed to labour cost, according the proportions of the original power sector. The same consideration can be applied to O&M costs, which do not include the overall cost of intermediates, given the use of electrical equipments, services and other materials also in the installation phase. Intermediate cost share is estimated around 38%, in Figure 1 are presented principal components of production function.

Figure 1: Solar power production function (world average)



Blanko (2005) describes generating costs of wind energy (Europe focus), using the common distinction between capital costs and variable costs; in the first aggregate include costs of turbines, other capital (development costs, land rent and licences), civil works and grid connection. According to Blanko (2005), capital cost share amounts to 80% of the total. Then combining this information with to estimates from OECD/IEA (2005) and Sue Wing (2008), the production function was drawn redistributing part of capital cost as labour and intermediate cost (see Figure 2).

Regarding to hydropower technology, the production function (Figure 2) is shaped according Life Cycle Assessment (Ecoinvent, 2007), which specifies materials and equipment used during installation and lifetime of a hydroelectric plant.

Figure 2: Production function for Wind power (World average)

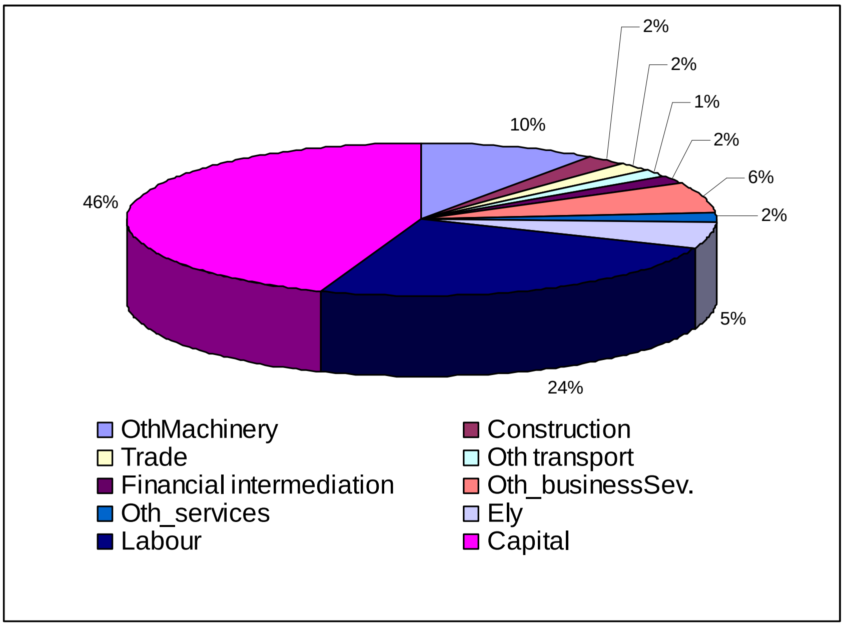
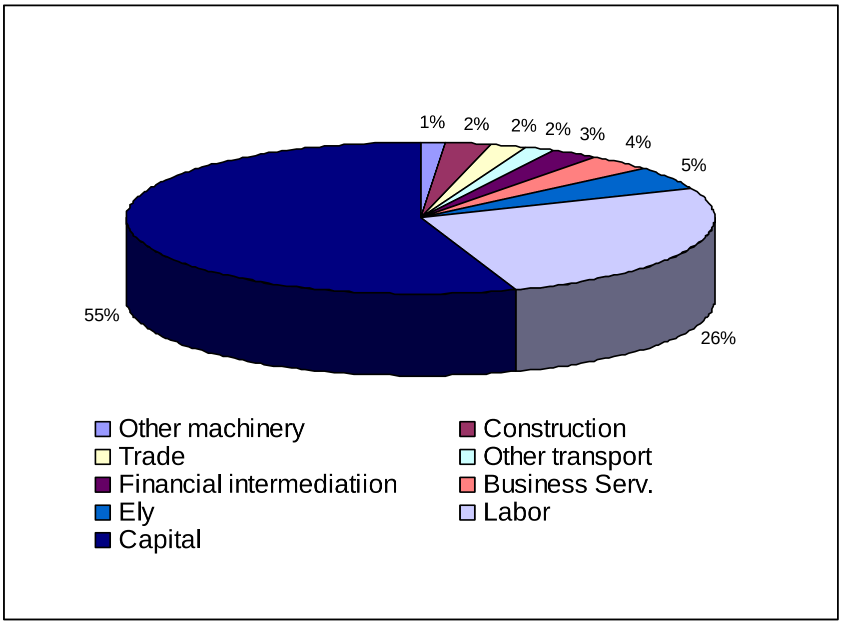


Figure 3: Production function for Hydro power (World average)



Finally, with respect to the destinations of power from renewable energy sources, it is generally assumed the physical homogeneity of electricity, this leaded us to adopt the same distribution across users as the original electricity; the downscaling is performed at regional level. Trade flows were obtained applying production shares of each renewable to import-export of the original sector.

As said earlier, the GTAP7 database presents the sector electricity as a whole without discriminating on the origin of electricity itself. Operatively, to incorporate what required in the extended database, we use the Splitcom (Horridge, 2008) utility provided by the GTAP consortium. Splitcom is a program written in Gempack language that allows splitting a sector originally present in GTAP in its main components, according to the research purpose. This tool is quite flexible, it allows using data at different detail levels, and guarantees coherence of database and compliance with fundamental equivalence (industry costs equal sales of locally made goods, trade equivalence).

After deciding in how many sectors we would have liked to split the power sector, we introduced our matrices, two (one national and one with bilateral trade) for each renewable introduced and for the residual sector. Clearly these matrices represent production functions derived by external sources; in detail the information provided to Splitcom facility includes a matrix containing use of intermediates and .primary factors in producing solar, wind, hydro e fossil electricity; a matrix relative to destinations of these production; a matrix focused on self-consumption (sales and purchases of the new sectors of the old one); a bilateral trade matrix.

Energy volumes and emissions data

According to McDougall *et al.* (2006), IEA (extended energy balances) data on renewable energy volumes were added to EDS commodities (GTAP energy data set), because usually they are explicitly discarded. The energy volumes used by the new sectors (wind, solar, hydro, biofuels and nuclear processing) was split from EDS electricity one according to the economic flows. Also energy volumes consumed by households and import-export figures were split from the electricity sector according to sectoral economic flows.

The database is extended with emission data (CO_2 and Non-CO_2) for all sectors. No emission are associated to renewable electricity (the same as other kind of power).

4. The extended ICES model

ICES Production function

The ICES model (Eboli *et al.*, 2010) is a recursive-dynamic model mainly based on GTAP-E (Burniaux and Troung, 2002) model, relying upon the GTAP-E structure (Burniaux and Troung, 2002) with several extensions aimed to capture dynamic features (endogenous dynamics for investment and capital accumulation), to include data about non-CO_2 GHG and to model their future evolution. Exogenous drivers are change in stock and productivity of primary factors (labour, land, and natural resources) and population. International trade is explicitly modelled considering possible switching from domestic to foreign production and vice versa through Armington elasticities.

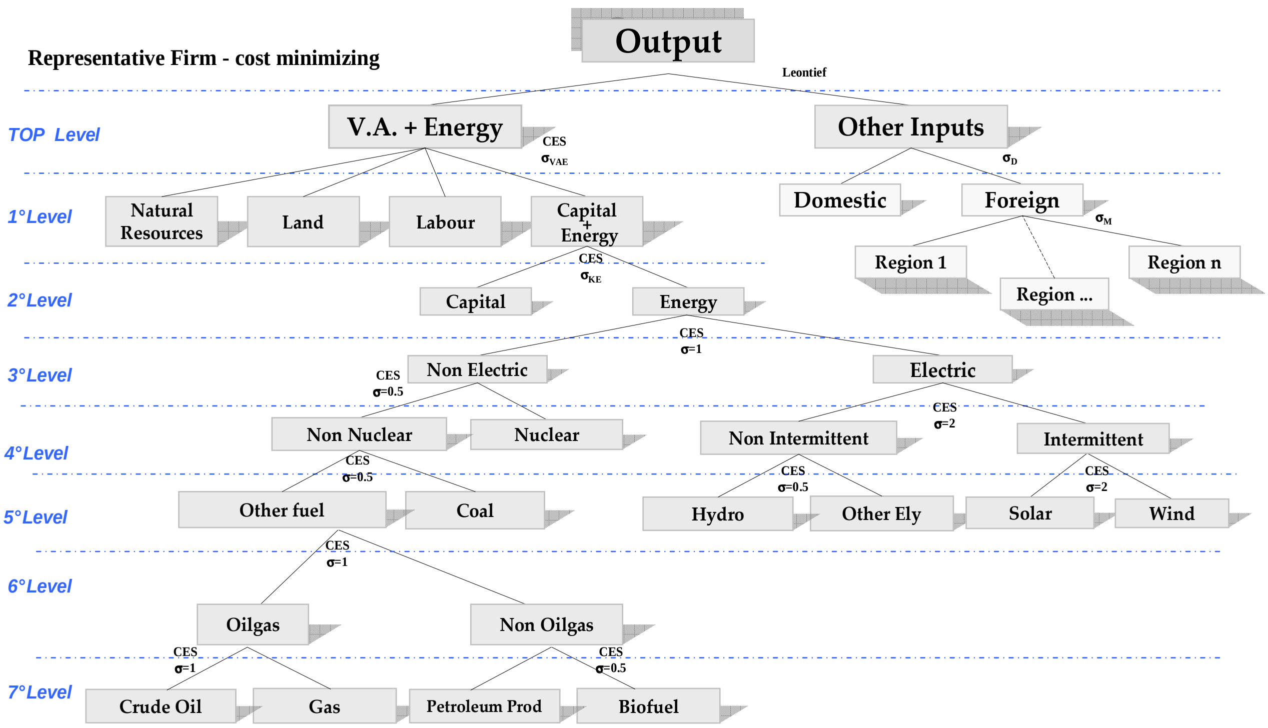
In the basic structure, ICES production function is similar to the GTAP-E standard version. However, the introduction of alternative energy sources requires a substantial modification of the bottom nests that in order to capture interactions within the energy sector.

As described in Burniaux and Troung (2002), the main innovation of GTAP-E with respect to GTAP is moving away from the assumption of a Leontief relationship between the set of primary factors and the group of intermediates for commodity production. On the basis of strong empirical evidence, energy sources are no longer considered perfect complement of primary factors. Rather, they are at some extent substitutes of capital stock, through a Constant of Elasticity of Substitution (CES) function. Starting from this assumption, the energy is in turn produced by different combination of sub-energy sources: first, mixing electricity and non-electricity; second, non-electricity is brought about combining coal and non-coal fossil fuels; finally, non-coal fossil fuels are produced by a mix of gas, oil and oil products.

We developed a new structure consistent with the energy sources now explicitly described in the database (Figure 3). We enriched the electricity production, originally undistinguished, dividing it in intermittent (Wind and Solar) and non-intermittent (Hydro and Other Ely) power production. Here Other Ely includes electricity produced with different energy sources: fossil fuels, nuclear, geothermal, biomass, waste to energy.

As regards the non-electric energy, at the top, we introduced the nuclear energy as possible substitute of fossil fuels to provide base-load energy. The relation between coal and non coal fossil fuels is left unchanged. Finally, at the very bottom nest, petroleum products are put in relation with alternative fuels available for transport (bio-fuels).

Figura 3: ICES nested production function



Elasticity of substitution

The introduction of three new electricity sectors/commodities opens the issue about the elasticities of substitution governing their contribution to the production functions.

Currently in the literature there are few models able to describe renewable technologies in the functional form. In the EPPA[3] model (Paltsev at al. 2005), renewable power (wind, solar, hydro, and back stop technologies) concurs to determine electricity sector output. In doing so nuclear, hydro and backstop are perfect substitutes with conventional fossil electricity; otherwise wind and solar power shows a low elasticity of substitution (around 0) with electricity from other sources. The reason underlying this choice is that they suffer from intermittency that can add to their cost if they were to provide a large share of electricity production. The elasticity of substitution parameter allows gradual penetration only as the prices of other generation technologies continue to rise, and tends to limit the share of electricity that can be generated by wind & solar. As a result, this functional form tends to be share preserving and will not allow large scale expansion of wind and solar technologies without recalibration over time[4].

GTEM model (Pant, 2007), using the 'technology bundle' approach, considers fourteen different technologies for electricity generation. The imperfect substitutability between outputs of various technologies is modelled by a CRESH (or CES or some other suitable function) aggregation function.

In WITCH model (Bosetti *et al.*, 2009), the parameters governing the production function take into account the technical features of each power generation technology. Also here electric energy condensate power produced with different technologies (hydro, wind & solar, backstops technologies and conventional fossil fuels); the elasticities ruling substitution are in general high: in some nodes perfect substitutability is assumed (e.g. among hydro and others), in other cases elasticity is 2 (among fossil fuels, nuclear/backstop and wind & solar).

In our model, we assumed that the electricity is a homogenous commodity whichever is the source. The attribution of a high level of substitution is commonly accepted when we consider

[3] The MIT Emissions Prediction and Policy Analysis (EPPA) model is a multi-region, multi-sector, recursive-dynamic multi-regional computable general equilibrium (CGE) simulation of economic growth, energy use and greenhouse gas (GHG) emissions over the next 100 years.

[4] Other approaches to characterizing these resources that explicitly treats intermittency through construction of back-up capacity or storage were investigated by Cheng (2005).

hydro, nuclear and fossil fuel power, but this is not true for wind and solar. These are commonly considered everlasting sources, but their intensity changes substantially over time (within the same day and across seasons) and across regions, in such a way that production may not be ensured in a continuous way. This means that they cannot guarantee base-load energy and usually this technical constraint is captured by a low enough elasticity of substitution with other more reliable power sources. Unlike EPPA model (Paltsev *et al.*, 2005), we decided to attribute a high level of substitution between wind and solar power (ε = 2) and between intermittent and non-intermittent electricity. This choice, even if compliant with other sources (Pant, 2007; Bosetti *et al.*, 2009), can be motivated by the necessity of eliminate constraints on wind and solar electricity growth in the future. A Leontief elasticity of substitution tends to maintain original input proportion across time and does not respond to impulses due to price variations; this is not so realistic if we consider that the sluggish spreading of these renewables is mainly imputable to high unit cost of production compared with the fossil fuels technologies. Therefore we implemented a certain level of substitution for wind and solar in order to favour renewable penetration and to guarantee a direct responsiveness to technological change in these sectors. A similar explanation can be adopted also for the choice of a low elasticity of substitution between hydro and other electricity (ε = 0.5), in this case we aim to slow down expansion of hydro power, which is considered a mature technology and then not susceptible to high variation in production prices.

5. Baseline and policy scenarios

Reference scenario

Geographical and sector details are reported in next table. EU is divided in 17 countries plus 1 bundle grouping the ten smaller countries (Table 2). Non-EU distinguishes 7 regions based on their specific pledges from the Copenhagen Accord (NonA1 considers Indonesia, Mexico, South Africa and South Korea) plus 1 main bundle with all developing no constrained countries. With reference to sectors, there are 9 energy sectors (5 power sources), 4 ETS sectors, agriculture, transport[5], other (light) industries and services.

[5] The transport sector considers jointly land, water and air transport. In the present analysis, transport is considered through the full time horizon considered as a non-ETS sector (in reality, aviation is expected to become an ETS sector in the third commitment period of ETS).

Table 2: Regional and sectoral detail

Regions	
Austria	USA
Belgium	Russia
CzechRep	RoA1 (Rest of Kyoto's Annex1)
Denmark	China
Finland	India
France	Brazil
Germany	NonA1_T (Kyoto NonAnnex1 with pledges)
Greece	RoW (Rest of the world)
Hungary	
Ireland	
Italy	
Netherlands	
Poland	
Portugal	
Spain	
Sweden	
UnitKingdom	
RoEU (Rest of EU27)	

Sectors
Agriculture
Coal
Oil
Gas
Oil_Pcts
Nuclear
Solar
Wind
Hydro
OthEly
Paper
Minerals
Chemicals
Iron_Steel
Transport
Oth_ind
Services

The baseline scenario focuses on short run (2004-2020), and represent a business as usual scenario without mitigation policies. It replicates the historical economic trend until 2009 and then reproduces the effects of financial crisis. Data on population have been taken from Eurostat (2010) and World Bank (2010) for EU and non-EU, respectively. GDP has been replicated according to information provided by EC (2010) reporting data for both EU and non-EU countries. CO_2 trend are in line with information in IEA (2010). Finally, fossil fuel prices changes according to Eurelectric (2009). GDP data projections were collected by different sources for EU countries, showing a low growth trend until 2012 (EC, 2010), a slightly higher in 2013-2015, and only after 2015, the economic growth rate will return in line with the pre-financial crisis (around 2% per year for EU on average) (EC, 2009). For non-EU countries GDP projections we use data from World Energy Outlook 2009 (IEA, 2009) unless for the region RoW for which data are taken from IMF (2010).

Policy scenario

Climate change mitigation requires air polluting emissions reduction in order to stabilise the level of GHG concentration atmosphere below specific thresholds that, if exceeded, may provoke irreversible adverse impacts on human kind and environment. Tackling the problem of global climate change requires a high level of international cooperation. Broad based participation is needed, involving not only developed, but also developing countries.

At the Copenhagen Conference of Parties (COP-15) of the UN Framework Convention on Climate Change (UNFCCC) in December 2009, the international community took note of the Copenhagen Accord, a political agreement on climate change. To date, more than 120 countries plus the European Union have associated themselves with the Accord – ranging from major emitters such as the United States and China, to smaller countries that are vulnerable to climate change impacts, such as the Maldives. The Accord recognises the scientific view that the increase in average global temperature should be below 2°C.

Mitigation strategies rely upon a more sustainable trend capable to jointly satisfy the expected increase in energy demand and reduce the level of pollution deriving from fuel combustion. Two main channels are generally indicated as key-factors to succeed at the purpose: energy efficiency improvement and increase in the share of RES for energy production. Electricity and transport are mainly considered as the most promising sectors to realise the above points. The Accord also invited all Parties to the UNFCCC to submit pledges for targets or actions to reduce their greenhouse gas (GHG) emissions.

EU seems to have a leading role[6] in global warming strategy. At the end of the first period commitment (2005-2007) EU translates the Kyoto target in a 20% GHG emissions reduction with respect to 1990 by 2020. Two more targets were proposed for 2020 to create a full sustainable development strategy, at the same time fostering innovation processes: the increase in the share of renewable energy sources (RES) over total EU energy consumption from the current 8.5% to 20% and in energy efficiency resulting 20% higher than expected in the business as usual scenario.

The financial crisis has resulted in both economic and emission current trends lower than expected. Therefore, EU proposed during the recent summits in Copenhagen (2009) and Cancun (2010) as its own commitment the achievements of -20% GHG emissions target by 2020 with respect to 1990, possibly moving to -30% target whether other Kyoto Protocol's Annex 1 countries would be committed to similar targets and given the GHG emissions reduction already occurred in the recent historical trend due to the financial and economic

[6] To accomplish to the Kyoto mandate to reduce between 2008 and 2012 GHG emissions by 8% with respect to 1990, from 2005 it was established the EU – Emission Trading System (EU-ETS). It established a market mechanism promoted by the Kyoto Protocol that, focusing initially on specific energy-intensive sectors and CO_2 only, in principle allows achieving a given mitigation target in a cost-effective way. http://ec.europa.eu/climateaction/index_en.htm. See also: "*An Energy Policy for Europe* - Com(2007) 1 final", "*Limiting Global Climate Change to 2 Degrees Celsius – The Way Ahead for 2020 and Beyond* - COM(2007) 2 final"

crisis. We refer to a companion paper (Bosello *et al.*, 2011) to see the possible outcomes when alternative policy schemes are implemented.

The policy scenario considered here aims to represent the cost-efficient solution in coordinated action under low pledges of the Copenhagen agreement in a word CO_2 market. . Allowances and targets are initially allocated uniformly across sectors and countries and CO_2 emission target is defined for each region and then permits trade is allowed among all sectors and all countries in order to obtain a global emission reduction of 20% with a unique carbon price. Table 3 shows the low pledges under the Copenhagen Accord.

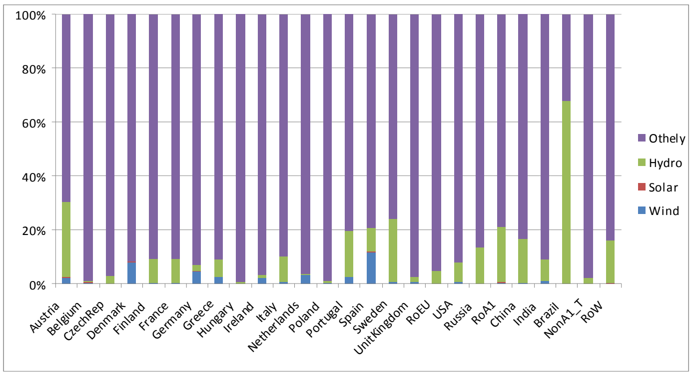
Table 3: Low pledges of Copenhagen Accord

	Low pledge
EU27	-20% (w.r.t.1990)
US	-17% (w.r.t.. 2005)
Russia	-15% (w.r.t.1990)
RoA1	-29% (w.r.t.2005)
China	-40% (CO2/GDP in 2020)
India	-20% (C/GDP)
Brazil	-5.3%(BAU)
NonA1_T	-2%(w.r.t.2005)

6. *The policy relevance of RES within the EU climate package*

The baseline scenario (2004-2020) does not consider any mitigation policies and then excludes climate policies and support to renewable energy, but it tries to account for future efficiency improvements in electricity sector and diminishing costs in producing power from renewable sources. Therefore also in the baseline scenario the production value of renewables is increasing, even if the overall value is a small share of the total electricity output (Figure 4); at global level wind, solar and hydro production show respectively a growth of 154%, 70% and 106%, which is definitely higher than the one of the rest of the electric sector (74%).

Figure 4: Regional electricity mix (right): baseline scenario in 2020



The chosen policy scenario does not involve any subsidy to RES and only considers the spillovers of climate policy towards clean energies sources. The global emission trading, aiming to reduce up to 20% world CO_2 concentration with respect to 1990, is implemented with an initial auction. The increase in fossil fuel prices, due to introduction of a carbon price, triggers a substitution effect among productive inputs and favours the penetration of wind, solar and hydro electricity. In Figure 5, we give a snapshot for EU27 in 2020: wind and solar show a similar growth in all EU27 countries (on average 7.8% and 6.9% respectively); hydroelectricity which is already considered a mature technology present only small variations; the contraction of other power differs across countries. In Figure 6, it is possible to have a picture for all principal regional aggregates; it is worth to notice that wind and solar evolution with respect to the baseline scenario is more pronounced in Non-EU27 countries, with the exception of RoW which shows the usual leakage effect due to the lack of an emission cut commitment.

Figure 5: % change baseline vs. policy scenario EU 27 in 2020

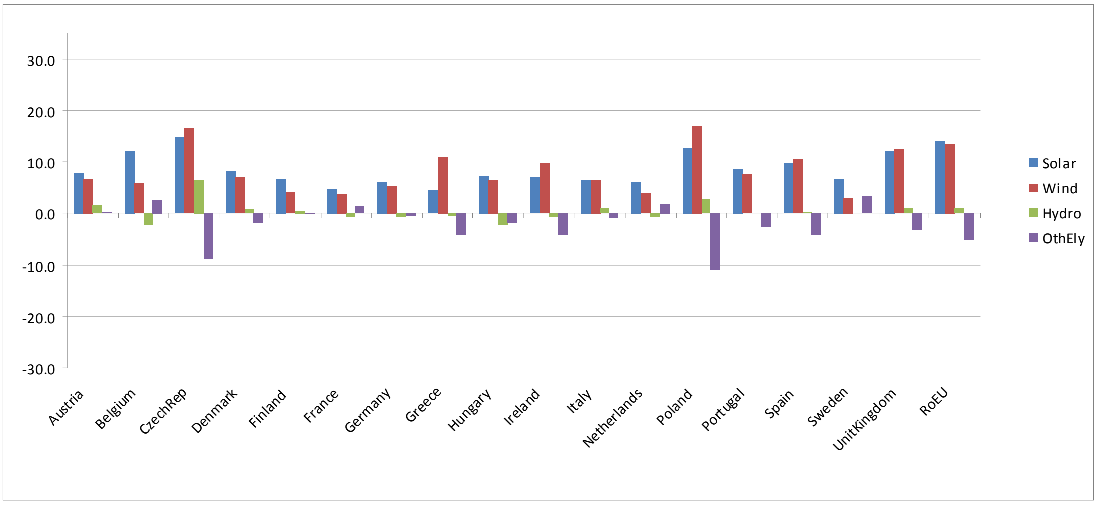
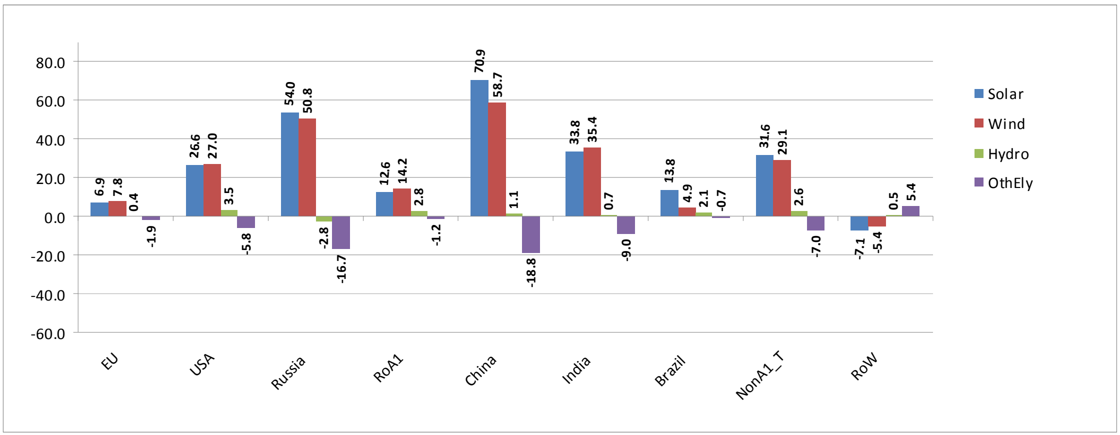


Figure 6:% change baseline vs. policy scenario in 2020: World

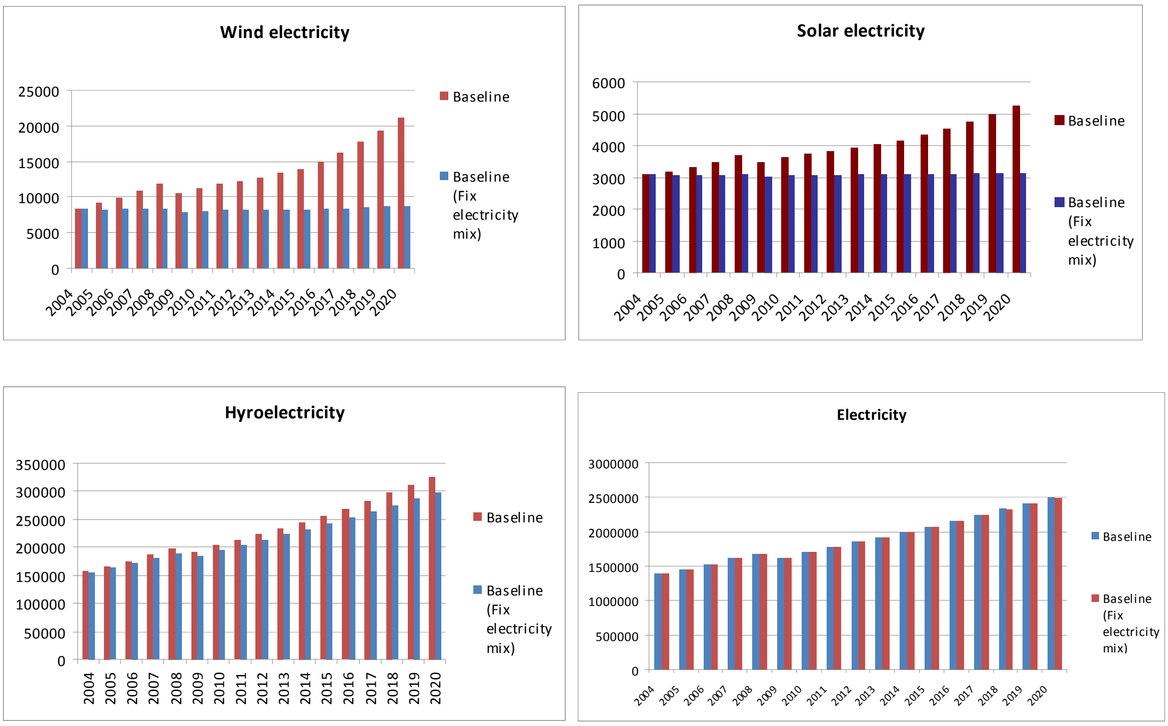


In 2020, the overall loss in GDP attributable to the climate policy is 0.45%, but the resulting emission reduction with respect to the baseline is 13.3%, where Non-EU27 countries contribute with -13.8% and EU27 with -7.6%.

Clearly these results could not be achieved in a model where renewables are not explicitly isolated; in the first place, it is not possible to consider the decreasing trend in cost of production characterizing renewable sources, in addition it is not possible to understand implication of a policy (climate policy or not) on energy mix, being completely disclosed substitution effect among productive inputs generated by any price change. Furthermore it is worth to consider also the relation between energy mix and emissions.

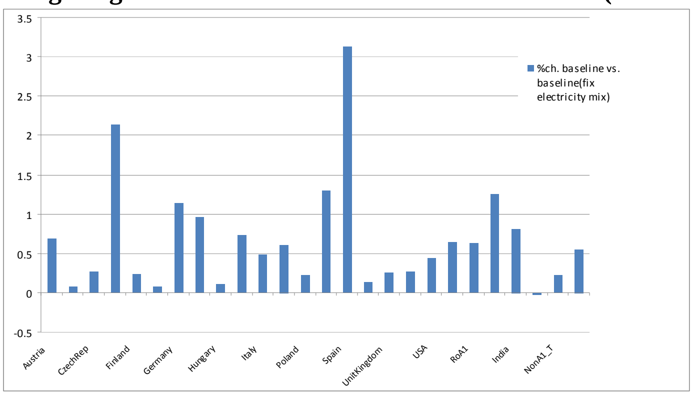
In order to understand the implications of having different electricity sectors and a production function able to express different elasticities of substitution at each node, we decided to perform a parallel baseline scenario where electricity mix is constrained to maintain fixed proportions across time. We obtained this result setting the elasticity parameters between intermittent and non-intermittent electricity, and hydro and other electricity to 0 (where before they were respectively 2 and 0.5). In Figure 7, the comparison between the previous baseline scenario and the new one shows a flattening of wind and solar power production across time and then the ineffectiveness of technological change imposed in these sectors. The overall electricity production does not shows substantial variation and this can be explained by a compensative increase in hydro and other electricity productions.

Figure 7: Renewable and total electricity across time (World): Baseline and Baseline (Fix electricity mix) scenarios



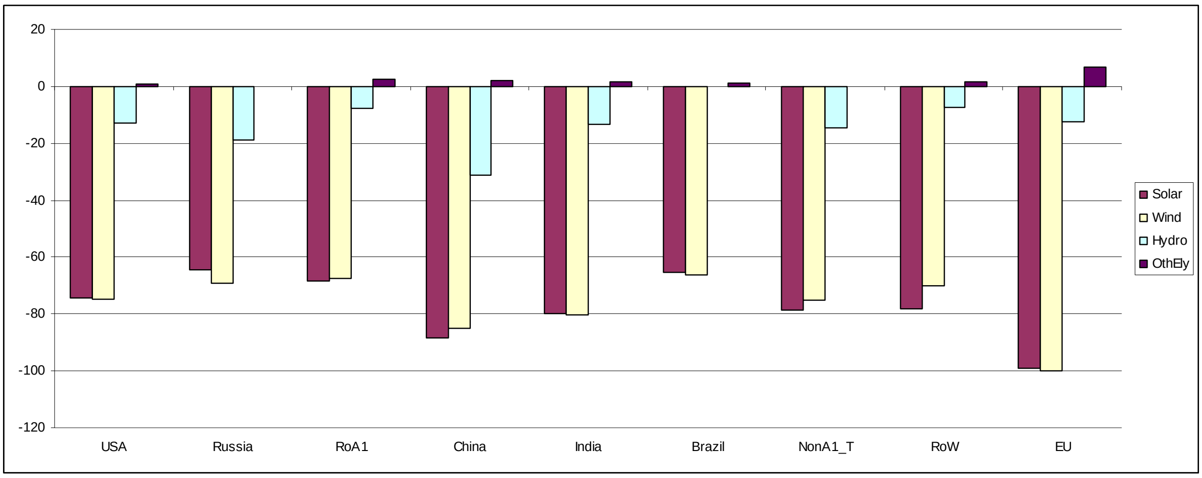
Even if GDP is not subjected to any variations, a small change in CO_2 emissions in the two baselines can be motivated by adjustments in energy mix (Figure 8). The overall increase in CO_2 emission is very low (0.8%).

Figure 8: % change in global CO2 emissions: baseline vs. baseline (fixed electricity mix)



Finally we implemented the same climate policy as before.

Figure 9: % change electricity typologies in 2020: Policy (fixed elecetricity mix) vs. Policy



7. Conclusions and further research

Renewable energy technologies have an important role in assuring a more flexible energy system, creating a reliance on sustainable energy sources and contributing in carbon emission reductions. Those are among the main challenging issues in policy agendas worldwide.

The electricity sector is a major source of the carbon dioxide emissions. Potential climate impacts, coupled with the growing demand for electricity in both developed and developing countries, are motivating a shift towards less CO_2-intensive generation technologies. Switching a substantial fraction of world electricity generating capacity from fossil fuels to renewable technologies such as geothermal, biomass, or wind powered turbines would help to reduce carbon emissions from this sector. In addition to the reduced environmental impacts, energy from renewable resources increases overall fuel diversity and lessens dependence on fossil fuels. This diversification is particularly important because fossil fuels such as oil and gas are often subject to rapid price fluctuations and supply problems.

The European Union has taken a lead in supporting environmental policies to counteract climate change and to increase the utilization of renewable energies. The ambitious “20-20-20” goals postulate a reduction of greenhouse gas emission of 20%, a share of renewable energy sources of 20%, and an increase of energy efficiency of 20% by 2020. Emission trading, the promotion of renewable energies, and efficiency measurement, all contribute to the reduction of greenhouse gases and impact electricity market prices.

Therefore, the introduction of newly modified CGE model (ICES) and database enriched with a range of electricity alternative technologies is relevant in order to strengthen the scenarios analysis under climate policy implementation conditions.

External data are used to split selected GTAP7 database sectors in order to isolate six new energy commodities: solar, wind, hydro and waste to energy. Renewables are presented in the model as imperfect substitutes for electricity from fossil fuels and the intermittency issue is also taken in account.

The paper presents a baseline scenario which reproduces the historical economic trend until 2020 reflecting occurrence and evolution of financial crisis for the EU27 and the rest of the world grouped in 8 regions. Moreover, a climate policy scenario is proposed focusing on the cost-efficient solution in coordinated action under low pledges of the Copenhagen agreement in a word CO_2 market.

In the baseline scenario wind, solar and hydro production at the global level show respectively a growth of 154%, 70% and 106%, which is definitely higher than the one of the rest of the electric sector (74%). The chosen policy scenario does not involve any subsidy to renewables and only considers the spillovers of climate policy towards clean energies sources. The global emission trading, aiming to reduce up to 20% world CO_2 concentration with respect to 1990, is implemented with an initial auction. The increase in fossil fuel prices, due to introduction of a carbon price, triggers a substitution effect among productive inputs and favours the penetration of wind, solar and hydro electricity. In 20202, wind and solar show a similar growth in all EU27 countries (on average 7.8% and 6.9% respectively); hydroelectricity which is already considered a mature technology present only small variations; the contraction of other power differs across countries.

References

ABS Energy Research (2008), Wind Power report Ed.5, London

Blanko (2005), The economics of wind energy, Renewable and Sustainable Energy Reviews 13 (2009), 1372–1382

Bohringer C. and A. Löschel (2006), "Computable general equilibrium models for sustainability impact assessment: Status quo and prospects", *Ecological Economics*, 2006, vol. 60, issue 1, pages 49-64

Bosello F., L.Campagnolo, F. Eboli, R.Parrado, E.Portale (2011), EU and the 30% target on GHG emissions: macro-economic impacts through a CGE analysis, mimeo.

Bosetti, V., Tavoni, M., De Cian, E. and A. Sgobbi (2009), The 2008 WITCH Model: New Model features and Baseline, FEEM Working Paper, 2009.085

Burniaux, J-M. and T. Truong (2002).GTAP-E: An Energy-Environmental Version of the GTAPModel, GTAP Technical Papers 923, Center for Global Trade Analysis, Department ofAgricultural Economics, Purdue University.

Eboli, F., R. Parrado and R. Roson (2010), Climate-change feedback on economic growth: explorations with a dynamic general equilibrium model, Environment and Development Economics, 15:515-533

ESHA (2004), Small hydropower situation in the new EU member states and candidate countries, FP5 Project Thematic Network of Small Hydropower

ESMAP (2005), Renewable Energy Potential in Selected Countries, The International Bank for Reconstruction and Development/THE WORLD BANK, Washington

EC (2008), An EU energy security and solidarity action plan. Energy Sources, Production Costs and Performance of Technologies for Power Generation, Heating and Transport, SEC(2008) 2872

Eurelectric (2009), Power Choices - Pathways to Carbon-Neutral Electricity in Europe by 2050, November 2009. [Online]. Available: http://www.eurelectric.org/PublicDoc.asp?ID=63875

European Commission, DG Economic and Financial Affairs (2009), *Ageing Report: Economic and budgetary projections for the EU-27 Member States (2008-2060).* EUROPEAN ECONOMY 2|2009, http://ec.europa.eu/economy_finance/publications/publication14992_en.pdf.

European Commission, DG Economic and Financial Affairs (2010), *Economic Forecast Spring*, EUROPEAN ECONOMY 3/2010, Ecoinvent (2007),Life cycle inventory of Energy system: Results for current systems in Switzerland and other UCTE countries, Ecoinvent report No.5

European Commission (2010) “Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage” Commission Staff working document SEC (2010) 650.

Eurostat (2010), *Europop2008 - Convergence Scenario, national level*, available on line at: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database

GTZ (2009), Energy-policy Framework Conditions for Electricity Markets and Renewable Energies, Eschborn, Germany

IEA (2006), IEA wind energy annual report 2005, USA

IEA (2009), *World Energy Outlook 2009*, OECD/IEA, Paris

IEA (2010), Extended Energy balances: OECD and Non_OECD countries database, IEA, Paris

IEA (2011), Clean Energy – Progress Report, IEA Paris

International Monetary Fund (2010), *World Economic Outlook - April 2010*, available on line at: http://www.imf.org/external/pubs/ft/weo/2010/01/weodata/index.aspx

ISI (2007), “OPTRES: Assessment and optimisation of renewable support schemes in the European electricity market” http://www.optres.fhg.de/OPTRES_FINAL_REPORT.pdf

JRC (2008), PV status report 2008, European Communities, 2008

Kannan, R. et al. (2006), Life cycle assessment study of solar PV systems: An example of a 2.7 kWp distributed solar PV system in Singapore, Solar Energy 80 (2006), 555–563

McDougall, Robert and Huey-Lin LeeIn (2006), Chapter 17: An Energy Data Base for GTAP, in Dimaranan, Betina V., Editor (2006). Global Trade, Assistance, and Production: The GTAP 6 Data Base, Center for Global Trade Analysis, Purdue University.

OECD/IEA (2005), Projected costs of generating electricity, IEA, Paris,

Paltsev, S. et al.(2005) the MIT Emissions prediction anad policy analysis (EPPA) Model: Version 4, MIT Joint Program on the Science and Policy of Global Change, Report no. 125

Pant, H.M. (2007), GTEM: Global Trade and Environment Model, ABARE Technical report

Sue Wing, I. (2008), The synthesis of bottom-up and Top-down approaches to the climate policy modelling: Electric power technology detail in a social accounting framework, Energy economics 30, 547-573

WorldBank (2010), *World Development Indicators – Population, total*, available on line at: http://data.worldbank.org/indicator/SP.POP.TOTL