European Climate Goals to 2020 and the Electricity Sector

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Abstract

EU's objective of attaining 20% reductions in greenhouse gas emissions by 2020 is analysed with a general equilibrium model detailing electricity generation technologies and capital vintaging. Consistent with theory and other analysts we find that the nonuniform treatment of emitting sectors in EU raises abatement costs – by a factor of two to three. Under cost effective emission reductions – a more comprehensive tradable cap - electricity generation abates more than its proportional share in emissions. The European economy abates by substitution towards natural gas, by energy efficiency improvements, and by reductions in emission intensive manufactures. Applied policies such as renewable support – and responses such as carbon leakage - hold down the prices for emission and electricity, thus also incentives for energy efficiency and technological change this leads to little preparation for the future and global mitigation.

Keywords: Climate change policy, Welfare cost, Renewable energy

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1 Introduction

What are the consequences of Europe's 2020 goals, both for the period up to 2020 and in terms of objectives regarding emissions from Europe and elsewhere later in this century?

The European Union (EU) has stated its commitment to limit global mean warming to less than 2 °C (above pre-industrial levels) by stabilizing greenhouse gas (GHG) concentrations in the atmosphere this century (European Commission, 2008a). As an intermediate goal on the way towards significantly reduced global GHG emissions by the middle of the century, the EU aims to have reduced its total emissions by 20% relative to 1990 in 2020. [1]

We are thus reminded that the EU's 2020 goals are politically determined, aiming for a balance between what is perceived as environmentally effective and what is politically feasible in this time-frame. Political feasibility depends in part on implementation, for which the EU has prioritized both political and economic considerations. One key instrument reflecting the economic objective of limiting abatement costs is the EU's Emission Trading Scheme (ETS), which allows firms in sectors with large point source emitters to trade and bank their emission allowances. It is, however, by no means the only instrument. Emissions from other sectors are addressed in other ways, and even for the emissions covered under ETS, there will be other instruments working – such as feed in tariffs in the electricity sector. These may certainly contribute to emission reductions, but in doing so may jeopardize the cost effectiveness objective, since they typically will not provide a 'level playing field' across emitting sectors or across possible ways of reducing emissions. Policy instruments such as feed-in-tariffs, green certificates, and even the free distribution of quotas under ETS do, however, serve political goals such as shifting the burden and thus easing transition towards the emission reductions.[2]

Nevertheless, the near-term cost-effectiveness sought with the ETS is not the sole concern, and the EU's supplementary climate-related policies reflect additional considerations – notably long-term technological change in the energy sector and a process towards a comprehensive international climate change agreement under the UNFCCC. An important consideration may certainly be to ensure consistency between the EU's near-term policies and long-term global achievement of the 2°C target. As such, Europe aims by 2020 to raise the share of renewable energy in final energy consumption to 20%, and to reduce total energy consumption relative to projections by 20%; the so-called energy efficiency target (European Commission, 2008a). Additionally, the EU has offered to increase its emission reductions in 2020 to 30% should there be a wider international agreement, and has also pushed for a 50% reduction in global emissions (and 80% reduction by developed countries) by 2050, during the COP-15 negotiations in Copenhagen.

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[1] There has certainly been raised concerns that the such emission targets (along with others promised in the developing world) may be insufficient to reach the 2 °C goal in the longer term (Rogelj et al., 2009). Such an examination is, however, not the focus of this study.

[2] See Skodvin et al. 2010, who demonstrate the role of free CO2 quotas in the EU political process; and, Carlson et al. 2000 for the case of SO_x trading in USA.

The objective of the following analysis and the associated model development is to explore how the European economy can meet this goal. We emphasise, particularly, what role is played by the electricity sector with all its linkages. Also, we ask what are the implications of observed policies such as support for renewable energy and the burden sharing following from the EU directive, since these are aspects of policy that do not follow from the 20 percent emission reduction goal. Moreover, we ask questions about whether could imply shortcomings in terms of longer term- and broader goals.

An understanding of the impacts of policies in advance is important to policymakers and firms. It can help identify risks as well as opportunities, aid policy implementation and reduce the risk of costly policy reversals. The present study complements similar model-based studies assessing the EU's 2020 targets, including some focusing exactly on EU's 2020 goals, such as Clarke et al., 2009 and Bernard and Vielle, Böhringer et al. 2009a;2009b, and Höhne et al., 2009. In our concluding section, we discuss our findings in the light of this literature, and provide an annex table that summarizes a comparison across a somewhat broader universe of studies.

Our special interest in the electricity sector is due to its major role in emissions, its potential for emission reductions, and also as a supplier of a non-traded or semi traded input and consumption good. Also, the sector is in many countries addressed by climate policy instruments supplementary to the textbookish ones of permits and taxes. The sector has long lived assets, motivating the role we give to capital rigidity and vintage.

The electricity sector is highlighted in EU's policies and with good reasons: it contributes a large proportion (about 31%) of emissions and is very heterogeneous with respect to emission intensity. There are numerous alternative generation technologies for decarbonisation, though renewable sources have been particularly targeted for stimulus by the EU. Electricity sector costs and other implications are of great importance due to the role of its output both in final consumption and as inputs in manufacturing and services. In the longer term longer term questions regarding electricity includes whether electrification shall play more of a role in decarbonizing transport and whether electricity shall be further decarbonized through carbon capture and storage.

A particular objective of our model development and work has been to focus on the role of the electricity sector: its technologies, its flexibility, its links to the economy. The research has been conducted in projects with this as focus, but this again is rooted in the importance of the sector in emissions, mitigation and adaptation[3].

In next section, we provide an overview of the model. In Section 3 and 4, we detail the policy simulations and results. We conclude in Section 5, discussing the implications of our results and their limitations.

[3] Adaptation to climate change will be in part through changes in heating and cooling (Eskeland and Mideksa, 2010) and the electricity generating sector is affected directly through precipitation and inflow, thermal efficiency and cooling water (Mideksa and Kallbekken, 2010; Linnerud et al, 2011; McDermott and Nielsen, 2011).

2 The GRACE-EL model

The analysis further develops the Global Responses for Anthropogenic Changes to the Environment (GRACE) model. The model is extended with a more detailed treatment of the electricity sector (GRACE-EL), incorporating technology-rich information on power generation into its otherwise top-down macroeconomic framework. GRACE is a multi-sector, multi-region, recursive dynamic model, calibrated on the GTAP v6 database (Dimaranan, 2006). Like other CGE models, it is formulated as a mixed complementarity problem (MCP) (Mathiesen, 1985), written up as an MPSGE model (Rutherford, 1998) and solved in GAMS (Brooke et al., 1988). Detailed documentation of the GRACE model and GRACE-EL is found in Aaheim and Rive (2005) and Rive and Mideksa (2009) respectively. Earlier applications are found in Rypdal et al. (2007), Rive (2010), and Aaheim et al. (2009).

In the model, each sector produces a single commodity, employing intermediate good and factor inputs. Production in each sector is modelled as nested, constant elasticity of substitution (CES) functions, allowing substitution between energy and factor inputs, and between alternative energy inputs. Elasticities of substitution in the model are taken primarily from the EPPA model (Paltsev et al., 2005), and are tabulated in the GRACE-EL documentation. Countries (or regions of several countries) trade bilaterally, with an Armington function differentiating between imported and domestically produced versions of each commodity. Income in a country from wages, resource rents, capital returns, sale of permits, and taxes accrue to a representative agent, which distributes this income to the household, government, and savings in constant proportion. Savings are invested both domestically and globally, based on expected rates of return. Investment in one period is available to use as capital input in the next period. The model is run from 2000 to 2020 in five 5-year steps. For this paper, the model is set up with 10 European and two other regions, 19 sectors, and 6 electricity generation technologies, shown in Table 1.

Group	GRACE Region	Group	GRACE Sector
EU 27	Estonia, Lithuania, Latvia, Poland	Transport Services	Air transport services
	Belgium, Netherlands, Luxembourg		Surface transport services
	France & Switzerland	Energy Production	Coal production
	Austria & Germany		Gas production
	Greece		Crude oil production
	Spain & Portugal		Refined oil production
	Italy & Malta	Electricity	Electricity generation and distribution
	Denmark, Sweden, Finland, Norway, Iceland	Agriculture	Agriculture and food
	United Kingdom & Ireland	Metals	Iron and steel
	Rest of Eastern Europe		Non-ferrous metals (aluminium and zinc)
Developed	North America, Australia, New Zealand, Japan, Russia	Heavy Industry	Chemicals and rubber
Rest of World	Rest of World		Paper, pulp, and print
Group	**GRACE Generation Technologies**		Cement and glass
Electricity	Gas		Other mining
	Coal	Other Industry	Other heavy industries and machinery

	Refined Oil	Services	Services: financial, telecom, and municipal
	Nuclear	Households	Household (including own transport)
	Hydro	Other Final Demand	Government expenditure
	Wind/Solar Renewables		Investment sector

Table 1: Regions, sectors, and electricity generation technologies (EU region only) in the GRACE model, and aggregate groupings used in presentation

The regional aggregations used in the model are chosen based on the sizes of the economies, and contiguous regions with cross-border electricity distributions. Sectoral aggregations are chosen based on their relative carbon-energy-electricity-intensity of inputs, inclusion in the EU ETS, and importance in trade. It should be noted that the household sector includes expenditure and emissions from private own transport (so emissions from cars are found under household emissions, not under transport), in line with the accounting in the GTAP model.

The model includes anthropogenic emissions of the three most important greenhouse gases: CH_4, N_2O, and CO_2,, excluding emissions due to land use change. Emissions data is taken from the GTAP CO_2 and non-CO_2 emissions databases (Lee, 2007; Rose and Lee, 2008), with non-CO_2 emissions converted to tons of CO_2 equivalents (CO_2eq) using the global warming potential (GWP-100) metric, consistent with the Kyoto Protocol. Like most CGE models, the emissions enter the model accounting as inputs to production. In the nested CES functions, CH_4 and N_2O enter at the top level, and as such are associated with output. Emissions of CO_2 are linearly associated with fossil energy combustion, and are modelled as complements to the respective fossil energy inputs. Reductions of CO_2 require substitution towards less CO_2 intensive energy inputs, or towards increased capital input (i.e. energy efficiency improvement).

CGE models like GRACE have been widely used for analysing climate policies (see, for example, Manne et al. (1995), Ellerman and Decaux (1998), and Vennemo et al. (2009)). They are well suited to the application due to their internal consistency and economy-wide coverage of consumption and production activities. They can capture the inter-sector linkages and feedbacks (channelled through prices), which govern how emissions reductions take place and with what impact. The aspects that one may miss through such comprehensive macro-coverage is that CGE models are limited in their detail of economic activities and technologies. They generally do not consider the intricacies of particular production or consumption processes, which may be of importance to emission control. ‘Hybrid’ CGE models can be developed to include more detailed treatment for particular sectors such as transport (Sandoval et al., 2009; Schafer and Jacoby, 2005) or electricity generation (Bohringer and Rutherford, 2009) with the help of supplementary databases and modelling techniques.

In this study, the GRACE model is extended to include a disaggregation of electricity production in the European regions into specific and substitutable generation technologies – hydro, nuclear, gas, oil, coal, and other renewables (wind/solar). The disaggregation of the original GTAP electricity sector is done with the help of EUROSTAT energy data (European Commission, 2008b), an assortment of bottom-up technology data sources such as IEA and NEA. We reconcile bottom-up data about the costs, capacity, and thermal efficiencies of European electricity generation technologies with the existing top-down social accounting matrix provided by GTAP using a calibration technique proposed by Sue Wing (2006;2008).

Each of the six electricity generation technologies in the model represent the aggregate technologies applied for one fuel type in each region. As is the case with other sectors, the electricity sector is modelled with nested CES functions. The top nest consists of generation and transmission & distribution activities. The generation nest splits into intermittent (i.e. wind/solar renewable) technologies and standard generation (i.e. the remaining) technologies, much as is done in the EPPA model (Paltsev et al., 2005). This split implies that electricity as an output from intermittent renewables is an imperfect substitute for electricity from other technologies (an elasticity of substitution equal to 0.7 is applied), so substitution towards these requires additional costs compared to substitution between non-intermittent technologies. One level down, the standard technology nest offers a high level of substitutability between the non-intermittent options (elasticity of substitution = 10), but prevents the awkward corner solutions that would be associated with an infinite elasticity of substitution. This approach is adapted from Sue Wing (Sue Wing, 2008), and is chosen for its simplicity and transparency. (Switching between technologies is further limited by the treatment of capital described below, which imposes a cost of redeploying capital.) The represented costs, base year generation levels, and efficiencies of the generation technologies are presented in the GRACE-EL documentation. This treatment currently leaves out longer-term technological developments – such as advanced coal and gas combustion or CCS – which are unlikely to play a major within our horizon of 2020. Biomass energy and biofuels are also excluded from the model, which has implications for how renewable energy policy is modelled in our scenarios (see below).[4]

A further development in the GRACE-EL model is capital vintaging and mobility treatment, with features of the putty clay model (Johansen, 1956). It reflects that once established for a purpose, capital cannot easily be transformed or redeployed to a different use. Thus, GRACE-EL distinguishes vintages: the one that is presently being invested, and capital pre-existing. New capital can be freely put to use in any sector or generation technology. The redeployment or transformation of pre-existing capital is, in contrast, moderated by a constant elasticity of transformation (CET) function. Capital in carbon-intensive sectors or generation technologies is thus prevented from being moved wholesale to a different sector or technology (e.g. if a carbon tax is imposed). In other words: coal plants to not become wind turbines or paper mills over night, but can 'transform' with the speed of depreciation. This approach adds generality (and flexibility) to the Putty Clay model. Like Sue Wing (2006), lacking empirical justification for a value for the elasticity of transformation, we use a value of 1 – and test the impact of alternative assumptions in a sensitivity analysis[5].

[4] It is acknowledged that employing a CES function involves limitations when accounting for electricity production in physical (e.g. MWh) units (Sue Wing, 2006). To aggregate electricity production properly, summation at the technology level, rather than at the generation nest level.

[5] Elasticities of substitution between fuels in generation and – in our case – elasticities of transformation for generation capital using different fuels – can be estimated econometrically. A recent contribution is Serletis et al, 2010. They find elasticities between fuels in generation to exceed one only for the US. Our applied estimate of 1

In these developments of GRACE model, we have employed intuitive approaches that aim to represent from the bottom up what is happening in the real world. Alternative approaches can be readily found in the literature, particularly the modelling of the power sector. For example, the EPPA model treatment of generation technologies lumps 'traditional' fossil generation technologies in a separate CES nest, which is substitutable (at infinite elasticity) with the non-fossil and advanced fossil technologies. This representation limits the rapid substitution away from traditional technologies in the near term, but is somewhat stylized. Frei et al. (2003) an alternative, more sophisticated hybrid treatment of the electricity sector which factors loss-of-load probabilities in the investment decision.

3 Model Scenarios

3.1 Scenario setup

The model is used to analyse alternative policy scenarios that can meet EU's stated policy goals for 2020. As a starting point, we run a baseline scenario: *business as usual* (BAU) that features no climate policy. As a first policy scenario, called *cost effective,* a single cap is modelled to reduce total emissions to 20 percent below the 1990 level. In other policy scenarios, our practical interest is the division of the emission reduction burden between ETS and non-ETS sectors, since along this division no efficiency mechanism is in the outset ensured. Further, we want to focus on the consequences of another policy feature observed: supplementing the emission reduction target itself and ETS with support for renewable energy. Again, this motivation is from the actual challenges of policy making. Most – or all – EU countries supplement ETS in the power sector with instruments such as feed-in tariffs or green certificates. The essence of support for renewables is an income stream (from new wind turbines, for instance) additional to revenues from the market price of supplied power. These scenarios are tabulated in

Parameter	**Scenarios**		
	Cost Effective	**Cost Effective + Renewable Support**	**Directive + Renewable Support**
2020 Emission Target	20% from 1990	20% from 1990	20% from 1990
Sector Burden Sharing	Uniform carbon tax	Uniform carbon tax	ETS/non-ETS split
Renewable Target	No target	20% of Primary Energy	20% of Primary Energy
2010 CER Imports ETS/non-ETS (MtCO2eq/yr)	30/50	30/50	30/50

may thus be deemed on the high side, but the literature is dominated by within-country estimates and short term responsiveness of one year. We report on alternative assumptions under Robustness and sensitivity analysis.

2020 CER Imports ETS/non-ETS (MtCO2eq/yr)	100/98	100/98	100/98

Table **2**. The emissions allowed in Non-ETS sectors are tabulated in the annex table A1.

Parameter	**Scenarios**		
	Cost Effective	**Cost Effective + Renewable Support**	**Directive + Renewable Support**
2020 Emission Target	20% from 1990	20% from 1990	20% from 1990
Sector Burden Sharing	Uniform carbon tax	Uniform carbon tax	ETS/non-ETS split
Renewable Target	No target	20% of Primary Energy	20% of Primary Energy
2010 CER Imports ETS/non-ETS (MtCO2eq/yr)	30/50	30/50	30/50
2020 CER Imports ETS/non-ETS (MtCO2eq/yr)	100/98	100/98	100/98

Table 2: Description of climate policy scenario assumptions to 2020

To implement its obligations from the Kyoto Protocol, the EU established an emission trading system (ETS) for particular energy-intense sectors with large plants (so-called 'big stacks'). This limited coverage of ETS was done for reasons including simplicity and competitiveness, and implies that other sectors must be addressed by other policy mechanisms (such as fuel taxes and emission standards for cars).

Under the period covered by the Kyoto Protocol (2008-2012) the ETS included electricity generation and the manufacturing sectors of oil refining, iron and steel, cement and glass, paper and pulp. The Member States' National Allocation Plans (NAPs) gave the initial distribution of emission allowances between the ETS sectors and non-ETS sectors. Firms in the ETS sectors could after this trade their allowances with other ETS firms, while reductions in the non-ETS sectors were to be driven by other domestically chosen policy measures. This sectoral differentiation is criticised by the economic literature, as it increases the overall costs of achieving the Kyoto targets (Kallbekken, 2005). In as much as tradability helps cost effectiveness of abatement among ETS emitters, policies for emitters in other sectors run greater risks of failing in cost effectiveness, even if succeeding in providing emission reductions. In spite of such weaknesses, the ETS vs. non-ETS burden split will continue to 2020, as described in the final compromise (European Council, 2008). Post 2012, ETS sectors include non-ferrous metals, chemicals, rubber and aviation.

The resulting cost differences are thus a natural focus of our study. In our policy scenarios, we compare the impacts of this sectorally differentiated burden sharing (labelled '*Directive*') compared to the scenario labelled '*Cost Effective*'. In each scenario except BAU, total EU emissions in 2020 are the same. Under the *Directive* burden sharing, the EU ETS sectors undertake a 21% reduction in 2020 relative to 2005 levels (see table A1), while on average the EU non-ETS sectors undertake a 10% reduction in 2020 relative to 2005 levels. The *Cost Effective* scenario is modelled as a uniform carbon tax applied across all emitting sectors and regions such that the EU-wide emission target it met. This is equivalent to assuming that one overall ceiling for emissions apply across all sectors.

The EU's target of 20% of primary energy being from renewables by 2020 may contribute to emission reductions, but is motivated by an acknowledged need for technical change in the energy sector (European Commission, 2008c). Renewable energy is defined in the EU target as including biomass alongside wind, solar, tidal, wave, and hydro energy. Without such specific goals or policies for renewables, an expanding role for renewables could come about – and higher or lower – simply as a result of the tradable quotas under ETS. We assess the impact of the specific renewables' target alongside the two alternative sectoral burden sharing approaches. In two of our scenarios, we assume that the renewable target (labelled '*Renewable Support*') is met in 2020. Incorporating the target into our simulations requires some simplification, however, as the GRACE-EL model does not include explicit treatment for biomass energy or biofuels, which may appear in transport, households and the electricity sector. GRACE-EL covers only the hydro and wind/solar renewable technologies in the electricity sector and reaches the overall renewable target by assuming that the share of renewables in primary energy consumption must grow by 120% in 2020 compared to 2005 levels. Renewable support is modelled as an EU-wide government subsidy to wind and solar in electricity generation, which adjusts endogenously to meet the target.

3.2 Common assumptions

All four main scenarios feature a set of common assumptions related to economic growth and energy use. GDP growth projections to 2014 are from the IMF (IMF, 2009), and these rates are applied through to 2020; 1.5% for Western Europe, 3.6% for Eastern Europe (Estonia, Lithuania, Latvia, Poland, and Rest of Eastern Europe), 1.8% for the Developed region, and 5.6% for the Rest of World. Between model periods, we apply exogenous annual energy efficiency improvements in all sectors and households, taken from the SRES A1B scenario (IPCC, 2000); 0.9% in Western Europe and Developed region, 4.7% in Eastern Europe, 3.1% in the Rest of World.

The quantity of labour available is assumed to grow at the rate of the economy. We adjust the energy resource growth to control the trajectory in energy prices over time. We first establish this resource growth rate in the baseline scenario where we target a 15% price increase for coal, 20% for gas, and 40% for crude oil over the period 2000-2020. We subsequently apply the same rates of energy resource growth from the baseline scenario to the policy scenarios. As a consequence, differing energy price trajectories will arise in each scenario on account of the policies applied. The consequences of alternative fossil fuel assumptions, such as higher oil prices, are discussed in Robustness and sensitivity analysis section.

In the climate policy scenarios, we assume 100% auctioning of quotas under both the Kyoto Protocol and 2020 reduction targets (thus the equivalence to a tax). Imports of Clean Development Mechanism (CDM) credits to the EU's ETS and non-ETS sectors are allowed but limited (in 2020 to 3% of the non-ETS 2005 emissions plus any credits banked by the ETS in the Kyoto period European Commission, 2008a). In line with this, total annually allowed CER imports to each sector grouping follow the assumptions by Höhne and Ellerman (2008), and are tabulated in

Parameter	Scenarios		
	Cost Effective	**Cost Effective + Renewable Support**	**Directive + Renewable Support**
2020 Emission Target	20% from 1990	20% from 1990	20% from 1990
Sector Burden Sharing	Uniform carbon tax	Uniform carbon tax	ETS/non-ETS split
Renewable Target	No target	20% of Primary Energy	20% of Primary Energy
2010 CER Imports ETS/non-ETS (MtCO2eq/yr)	30/50	30/50	30/50
2020 CER Imports ETS/non-ETS (MtCO2eq/yr)	100/98	100/98	100/98

Table **2**.

In all scenarios exogenous limits are imposed on the growth of nuclear and hydro generation in each region. These are meant to represent the physical and political constraints that are not otherwise captured in the model. We assume that no hydro generation capacity beyond the upkeep of existing levels is added in Europe through 2020. We apply similar exogenous constraints to nuclear generation on a region by region basis. In the Nordic region, construction in Finland is assumed to grow nuclear generation capacity by 15% in 2020 compared to 2000 levels. The France & Switzerland and the UK & Ireland regions are assumed to see growth of 10% and 78% respectively from 2000 to 2020. It is assumed that the planned decommissioning in Germany will be put on hold, and nuclear generation is capped (as in all other regions) at the 2000 levels. Generation from other technologies is capped at 2x the 2000 level. While this is clearly *ad hoc*, it is applied to represent political and other limitations. The exogenous limits are modelled with a shadow price of capacity expansion for each technology in each region, as seen elsewhere (Böhringer and Rutherford, 2005). Variations are documented in robustness and sensitivity section.

4 Results

4.1 Aggregate and regional patterns

We first present the headline results for our model simulations. In Table 3, we present the baseline emissions levels in 2020 from which abatement takes place, and the abatement undertaken by the EU as part of its 20% reduction target (from 1990 levels). Under climate policy in 2020, emissions are reduced by roughly 25% (or 1.56 $GtCO_2eq$) from the corresponding baseline level, of which 12% (0.14 Gt) results in carbon leakage to the remainder of the world. This leakage rate is roughly in line with similar studies (e.g. Bernard and Vielle (2009)), and highlights the difficulties in acting on climate change without global participation. Carbon leakage poses a difficult challenge to policymakers, both from environmental effectiveness and political feasibility perspectives. In the *Renewables Support* scenario, leakage is reduced somewhat, since emission prices and thus the price increases in emission intensive sectors are reduced. Minor differences also arise in the *Directive* scenario, since this implies a specific burden sharing between sectors. In particular, in the *Directive* scenario, the emissions allowances to non-ETS sectors in the Eastern European regions are found to be non-binding, manifested in the collapse in the permit price for these regions (see Table 4).

Emissions ($GtCO_2eq$)	Cost Effective	Cost Effective + Renew Support	Directive + Renew Support
Baseline Emissions Level	6.09	6.09	6.09
Gross EU Abatement	1.56	1.56	1.56
Carbon Leakage	0.14	0.13	0.15
Net EU Abatement	1.41	1.43	1.41

Table 3: Aggregate EU abatement from baseline reference emission level in 2020 under alternative scenarios

Grouping/Region (Year)	Cost Effective	Cost Effective + Renew Support	Directive + Renew Support
EU-Wide ETS price (2010)	10	10	10
EU-wide ETS price (2020)	48	44	57
Regional Non-ETS prices (2020)			
Nordics	48	44	129
UK & Ireland	48	44	51
France & Switzerland	48	44	66
Germany & Austria	48	44	93
Belgium, Netherlands & Luxembourg	48	44	36
Latvia, Lithuania, Estonia, Poland	48	44	0
Spain & Portugal	48	44	23
Italy & Malta	48	44	50
Greece	48	44	2
Rest of Eastern Europe	48	44	0

Table 4: Permit prices ($/$tCO_2eq$) in ETS (always uniform across countries) and non-ETS sectors under alternative scenarios in 2010 and 2020.

In table 4, we see that the ETS permit price is predicted at $10 /$tCO_2eq$ under the Kyoto Protocol period 2008-2012, rising to $44-57 /$tCO_2eq$ in 2020. In non-ETS sectors, permit prices under the *Directive* from vary from $0 in Eastern European regions, to $129 in the Nordic regions, where carbon intensity is low in the outset (see allowances in Non-ETS emissions, Annex table 1, underlying these). These permit price implications are comparable to recent estimates, but depend on growth assumptions (Böhringer et al., 2009b). The varying permit prices across sectors and regions in the *Directive* scenario give a first insight into the economic inefficiencies of differentiated emission reduction schemes.

In Table 5 we present the distribution across regions of emission reductions under each scenario, compared to 2020 baseline emissions. Eastern Europe take on a higher share of total reductions in the highly flexible *Cost Effective* scenario. The story is the reverse for regions with higher marginal abatement costs such as the Nordic region, and France & Switzerland: they reduce own emissions less under *Cost effective* than under *Directive*.

Region	Share of 2020 Baseline Emissions	Regional Contribution to Abatement (%)		
		Cost Effective	Cost Effective + Renew Support	Directive + Renew Support
Nordics	6 %	5 %	5 %	7 %
UK & Ireland	15 %	15 %	14 %	16 %
France & Switzerland	11 %	8 %	8 %	9 %
Germany & Austria	21 %	19 %	19 %	23 %
Belgium, Netherlands & Luxembourg	7 %	7 %	7 %	7 %
Latvia, Lithuania, Estonia, Poland	9 %	12 %	12 %	7 %
Spain & Portugal	9 %	8 %	8 %	8 %
Italy & Malta	10 %	7 %	7 %	8 %
Greece	2 %	3 %	2 %	2 %
Rest of Eastern Europe	12 %	17 %	17 %	12 %

Table 5: Regional breakdown of 2020 baseline emissions and abatement under alternative scenarios.

In Table 6, we report resulting abatement costs – measured as welfare loss compared to the baseline level in terms of equivalent variation. Since costs of emission reductions will be – in part – costs of reallocating consumption from emission intensive to emission lean goods and services – it is important to use such an expression of costs that reflects these adjustments in consumption composition. Eastern European countries actually feature welfare gains from the climate policies.

Region	Cost Effective	Cost Effective + Renew Support	Directive + Renew Support
Nordics	-0.5 %	-1.1 %	-1.2 %
UK & Ireland	-0.4 %	-0.5 %	-0.6 %
France & Switzerland	-0.3 %	-0.4 %	-0.4 %
Germany & Austria	-0.5 %	-1.3 %	-1.6 %
Belgium, Netherlands & Luxembourg	-0.2 %	-0.5 %	-0.5 %
Latvia, Lithuania, Estonia, Poland	0.8 %	0.6 %	0.1 %
Spain & Portugal	-0.1 %	-1.1 %	-1.2 %
Italy & Malta	-0.5 %	-1.1 %	-1.2 %
Greece	-0.1 %	-0.9 %	-1.2 %
Rest of Eastern Europe	0.9 %	0.7 %	0.3 %
EU Aggregate	-0.3 %	-0.7 %	-0.9 %

Table 6: Welfare impact (consumption loss measured in terms of equivalent variation is reported with a minus) in each region under alternative scenarios.

To summarize, regional welfare loss is minimized under the *Cost Effective* scenario, with welfare cost estimated at 0.3% of total consumption.[6] Perhaps as interesting, we find that the welfare cost of *Renewable Support* (relative to the scenario without it) is much greater. Adding *Renewable Support* to the *Cost Effective* scenario more than doubles aggregate EU welfare loss, from 0.3% to 0.7% in 2020. Shifting to the *Directive* scenario further increases costs to 0.9%. The welfare cost of renewable support should be expected, given that it is effectively both "picking additional winners" among the options for reducing emissions and providing subsidy to energy. Our estimates that welfare costs of abatement double in scenarios –and more- representing the EU directive's burden sharing are in line with the analysis provided by Bernard and Vielle (2009), who use a less detailed representation of the electricity sector technologies, and with Bôhringer et al 2009 a and b, who use several models to explore sectorally differentiated policies.

4.2 Sector patterns

In this section, we compare the pattern of abatement in 2020 across production sectors and households. In Table7 we see that under the baseline, the electricity sector is the largest single emitter of greenhouse gases, with 30% of the region's total. Its share is in fact higher (approximately 40%) if we only consider CO_2 emissions from fossil sources. Unsurprisingly, given the range of technology options available in the electricity sector, it provides a larger than proportional share of emission reduction. Under the *Cost Effective* scenario, its share of abatement is 42%, rising to 48% under the *Directives + Renewable Support* scenario.

Other significant contributors to emission reduction are the Heavy Industry and Services sector groups (see Table 1) at 13% and 11% in the *Cost Effective* scenario. According to table 7, two sectors contributing significantly less to emission reductions than in proportion to baseline emissions are transport and

[6] The welfare cost, in the rest of the discussion is, is measured by equivalent variation using a money metric utility function and this measure does not take into account the value society assigns to the climate goals.

households, consistent expectations generally held that has limited ability to abate emissions in transport (including households).

Sector group	Share of Baseline Emissions in 2020	Sector Contribution to Abatement (%)		
		Cost Effective	Cost Effective + Renew Support	Directive + Renew Support
Agriculture and Food	12 %	9 %	9 %	7 %
Electricity	31 %	42 %	43 %	48 %
Energy Prod	4 %	8 %	8 %	6 %
Heavy Industry	7 %	13 %	13 %	14 %
Metals	2 %	2 %	2 %	3 %
Other Industry	2 %	2 %	1 %	1 %
Services	8 %	11 %	11 %	8 %
Transport Services	18 %	9 %	8 %	8 %
Households	16 %	5 %	5 %	4 %

Table7: Sector shares of EU baseline emissions and abatement under alternative scenarios in 2020.

In Figure 1, we break down sectoral emissions reductions into changes in fuel mix, energy efficiency, structural change (increased or decreased output) and non-CO_2 control (this is reduction in CH_4 and N_2O). We employ the Shapley (1953) decomposition technique, which has been used to decompose changes in carbon emissions in economies over time (Albrecht et al., 2002).

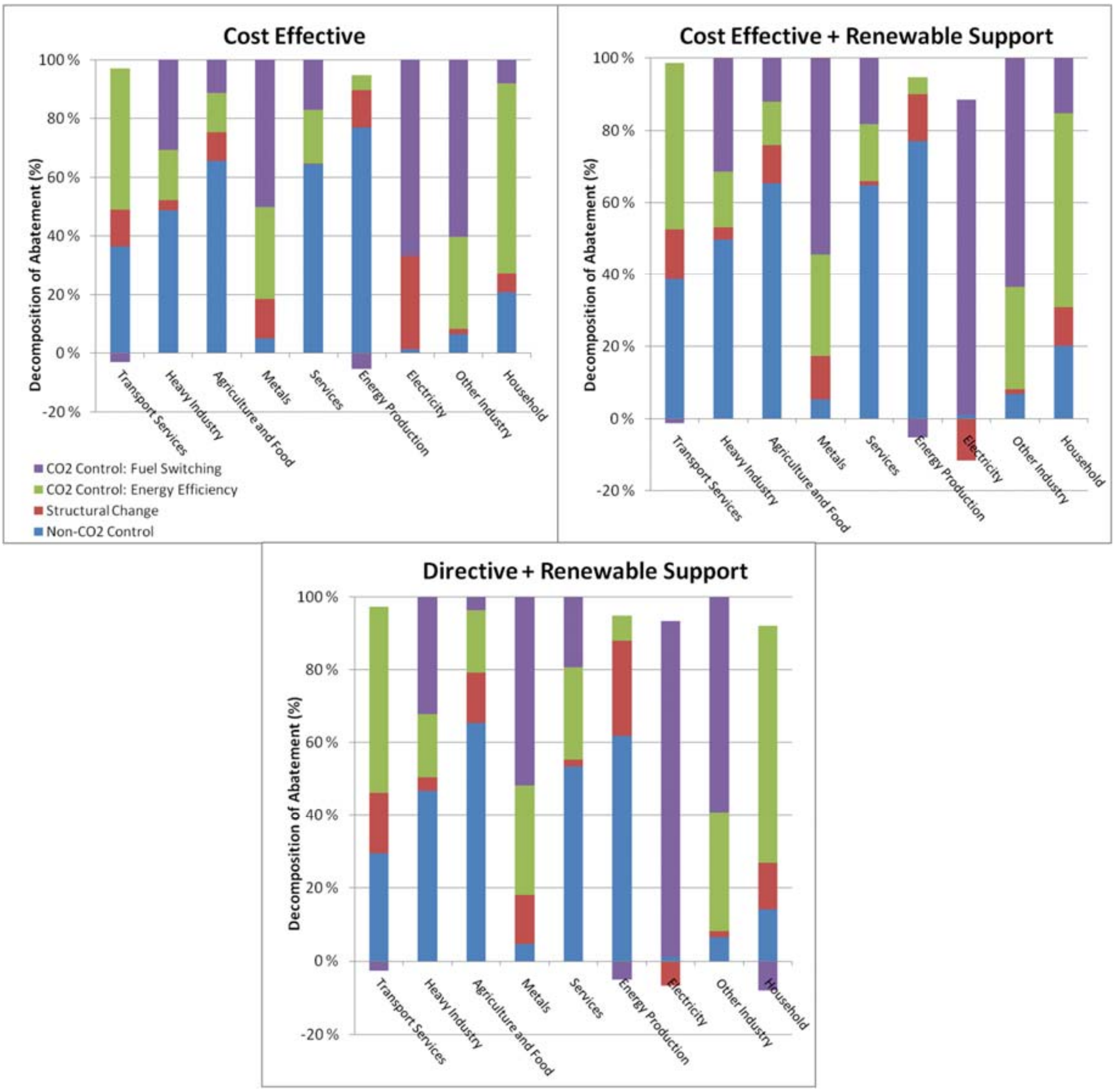

Figure 1: Shapley decomposition of gross EU abatement (from the baseline) in 2020 under alternative scenarios.

We may notice that *how* emission reductions are provided differs in important ways across sectors. Agriculture and Energy Production sectors achieve abatement primarily by reductions in N_2O and CH_4, while fuel switching is a dominant contributor to abatement (of CO_2) in Electricity, Metals, and Other Industry. In households and transport, energy efficiency improvements alone provide about half the emission reductions. In the electricity sector, reduced output makes up approximately one third of abatement in the *Cost Effective* scenario, but with the addition of *Renewable Support* (and under *Directives)*, the level of electricity generation in fact increases (panel b and c). Thus, with renewable support Europe increases electricity production and use more than what is cost effective. We see this in Figure 2, shows changes in EU electricity generation. There is a notable rise in gas generation, as existing capital and new investments are diverted from coal based generation. Under the *Cost Effective* scenario, we find that the share of generation from wind/solar renewables increases only slightly compared to the baseline (2.5% compared to 1.7%), so the cost effective solution is very far from the result under *Renewable Support* (to 20%). This reflects that costs of renewables are higher than what can be sustained merely through emission costs.

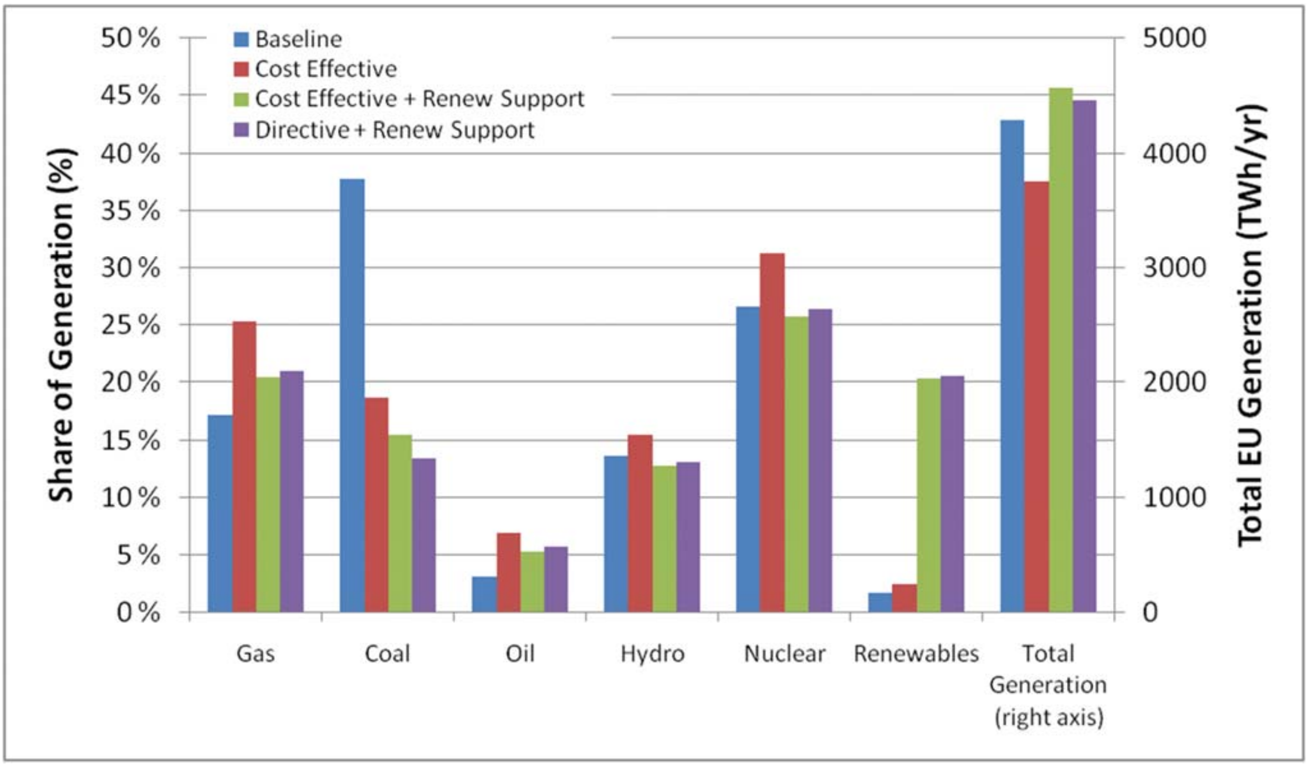

Figure 2: Total electricity generation in 2020 under alternative scenarios, and share of generation by technology.

The effect of the electricity sector's substantial contribution to abatement is manifested in changes in the price of electricity faced by consumers in each region. Even consumers in regions with carbon-lean electricity supply (such as the Nordics and France & Switzerland) will see a notable increase in the price of electricity. The reason is that transmission and energy market integration brings the abatement-induced electricity tariff increases home to all European countries.

In Figure 3, we plot the pattern of electricity price increases in each region against the fossil share in the region's electricity generation. To some extent, our expectations are confirmed: with Eastern European states on the top right-hand corner, and Nordics and France & Switzerland at the bottom left. The price impact in Eastern Europe is exacerbated by their (see Table 5) carbon intensity and export of permits, and the lack of access (due simply to geography) to cheaper non-fossil electricity from the Nordics and France. Among other countries, a greater tendency is seen – and this is efficient, in fact – that price increases will be similar across countries, and not generally greater for countries with a greater fossil share. This pattern implies that emission reduction policies carry with them potential to deliver price increases also in markets with low fossil shares in the baseline, raising profits for non-fossil generators whether quotas are auctioned or not.

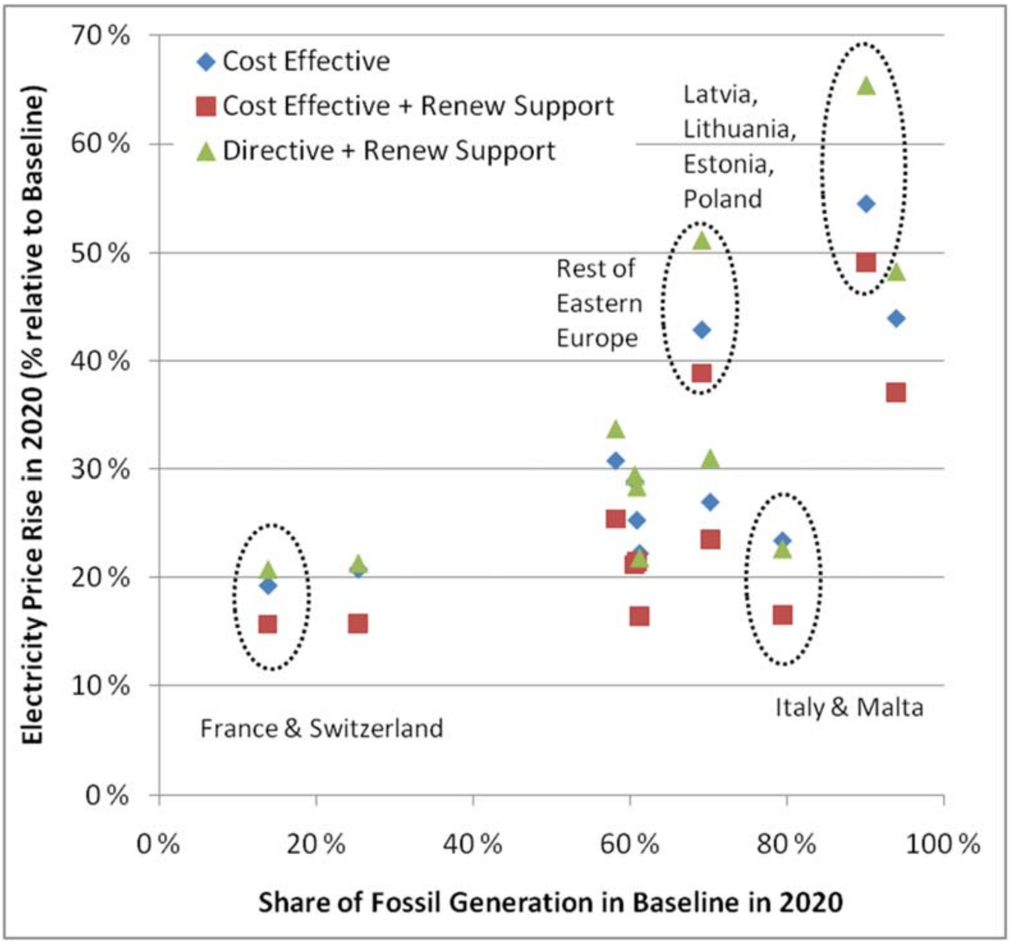

Figure 3: Change in electricity price (% relative to Baseline) under alternative scenarios compared to the fossil share in total generation in baseline in 2020. Results for a selection of GRACE-EL regions are labelled.

4.3 Robustness and sensitivity analysis

In this section, we report on sensitivity to assumptions. In particular we test alternative assumptions for the elasticity of transformation of existing capital (see Section 2), and limits to expansion in non-nuclear and non-hydro generation (see Section 3.2). All other parameters are held the same as those indicated in Section 3. An examination of the impact of alternative GDP growth assumptions can be found in similar literature elsewhere (Böhringer et al., 2009a), and results for our model would be similar. An important feature is that the costs of a given emission goal will be higher the higher is the assumed growth in our model incorporating vintages. Arguably, though, the tolerance for such costs is also higher when incomes are higher, in addition costs are held down under higher growth by new capital being more flexible than old.

In the above default scenarios, the capital elasticity of transformation is set to unity, and we assess the impact of switching to low and high values of 0.1 and 5. These respective values make it more and less expensive to move capital away from a less-profitable sector/technology. In the default scenarios, the growth of each non-nuclear and non-hydro technology is capped at 2x the levels in 2000. For the sensitivity analysis, we remove the caps completely.

		Base Results	Capital CET		Limit for capacity expansion of nuclear and -hydro
			High (5)	Low (0.5)	No Limit
Gross Abatement (GtCO2)		1.56	1.54	1.56	1.57
ETS Permit Price ($/tCO2eq)		48	53	45	46
Electricity Contribution to Total	Baseline Emissions	31 %	31 %	31 %	31 %
	Abatement	42 %	39 %	42 %	42 %
Share of Total Generation	Gas	25 %	23 %	26 %	28 %
	Renewables	2.50 %	2.40 %	2.50 %	2.40 %

Table 7: Comparison of *Cost Effective* scenario result under alternative model parameters in 2020. High capital elasticity of transformation (CET) raises (and Low reduces) the elasticity with which existing (vintage) capital may be transformed to move between sectors and/or generation technologies. Base value is unity. Remove limits for hydro generation and nuclear allow unconstrained expansion in these technologies relative to the year 2000. The base value is 2, allowing an expansion of hundred percent growth (linearly) from 2000-2020.

The results are presented in Table 7. We find that while particular values change, they do not change significantly, lending confidence to our results and conclusions. Increasing the elasticity of transformation of capital and removing the expansion limit increases the use of gas generation under the *Cost Effective* scenario and reduces the permit price, as is expected. The permit price is shifted up and down by about 7% if capital is assumed very inflexible or very flexible. Such a shift is not dramatic but would be greater if the time frame was shorter, since this makes inflexible capital more important. For the exogenous constraints on expanding nuclear or hydro, the reverse holds: removing these would have greater potential effect if the time horizon were longer.

Also other sensitivity analyses and robustness checks yield results one may intuitively expect: greater scarcity of fossil fuels slims emissions in the business as usual scenario and thus reduces the welfare costs of emission reductions, but not if the scarcity applies to gas more than to coal. Reductions or tighter limits on nuclear (as now decided in Germany) raises costs of emissions goals and reduces the additional costs of renewable support. Greater (or lower) substitutability between intermittent and non-intermittent electricity expands (reduces) intermittent electricity relative to presented results, but not much, since what holds intermittent electricity back partly is higher costs (as seen by its response to renewable support).

4.4 The results in light of other studies

Model based analysis of climate policy is important, but perhaps more in communicating effects than in exact numerical estimates. Some theoretical results that are clear (that multiple goals raise costs) may be better evaluated through model based analysis. In annex table 3, we have included a very brief comparison of studies. We emphasise those evaluating EU's 2020 goals, but also include an important model comparison study for global stabilization (Edenhofer et al., 2010) and one for US mitigation with diverse goals and settings (Rose and Dormady, 2011). EU 2020 studies agree on such general points that sectoral differentiation is costly, that the electricity sector is a large contributor to emission reductions, with gas and wind playing a major role and that carbon leakage is significant but not a problem jeopardizing achievements globally in the current time frame.

In numerical results, findings will differ, and they do. The 2020 studies for the EU, Bohringer et al 1009; Bohringer et al 2009b; Bernard and Veille, 2009, and our study find 2020 costs between a third of a percent and one percent for cost effective strategies, rising by 100 to 200 percent under various combinations of goals and instruments reflecting EU policies. Our study's findings is in the middle to lower range of these estimates. We believe our detailed treatments of the electricity sector and its links in the economy gives us confidence in the relevance of the results, but would not want to highlight the difference in numerical results from those of others. Rather, the studies agree that costs are moderate, that they can be influenced, and different studies allow different nuances of policy lessons to be explored. We emphasize our readings of these lessons below.

5 Concluding Discussion

Our purpose is to study how Europe will be affected by its climate policy targets for the fairly near term of 2020. What it will cost to reduce emissions by 20% relative to 1990, assuming a cost effective approach? Similarly: what additional costs come with alternative policies? There are also questions related to technology, real capital and different sectors.

Having refined the GRACE computable general equilibrium model with an emphasis on representing rigor and flexibility in the electricity sector, we simulate alternative climate policy approaches to the EU's climate goals for 2020. The model allows us to estimate aggregate costs and their distribution between regions. Since changes in consumption – substituting emission intensive goods and services with carbon-leaner ones – is a way to reduce emissions, we need a model that both allows for this and estimates its costs. Our welfare cost measure includes the costs to consumers of such consumption adjustments.

Under the policy scenario *Cost Effective* – a single cap for emissions from all sectors, all European countries – we estimate a welfare cost of the 20% emission goal to be about a third of a percent of total consumption in Europe. The permit price rises from \$10/tCO_2eq in 2010 to about \$ 50/tCO_2eq in 2020, electricity prices rise by 15 to 50%, and the electricity sector abates more than its proportional share in baseline emissions.

Under our *Directive + Renewable Support* scenario, which represents the EU's current plans for targets and burden sharing to 2020, we find that emission permit prices under the ETS rise to approximately \$60 per ton of CO_2 equivalents. EU-wide total welfare cost of the emission reduction program amounts to about 1%, three times the cost of the same emission reductions under the *Cost effective* scenario. The welfare cost thus depends heavily on the implementation of policy. Where trading flexibility is allowed, Eastern European regions will seek to abate and sell permits, allowing Europe to exploit the lowest cost abatement potentials through trade.

A key finding is the electricity sector's important potential and role. Our results from the *Directive + Renewable Support* scenario suggest that the electricity sector will contribute approximately half of the EU's emission reductions, much more than its forty percent of emissions in the baseline. Our results point out the electricity generation has low cost abatement opportunities, but also that *Renewable Support* pushes the sector beyond these and in a special direction, raising total welfare costs of emission reductions.

Of particular interest is the apparent and significant trade-off between the cost-effectiveness of achieving the emission reduction targets and ensuring longer-term solutions to emission reduction. As indicated above, our benchmark scenario of *Cost Effectiveness* highlights the added cost incurred by the EU through sectoral differentiation (i.e. the *Directive* approach). The expansion of the ETS to comprise additional sectors after the Kyoto period of 2008 to 2012 is thus a step towards cost reductions, building on the present ETS achievements. Under the *Cost Effective* approach, we see that the electricity sector is a dominant source of emission reductions, primarily via substitution away from coal to gas generation. This simply means that it has great value to try to minimize costs by equalizing marginal abatement costs across sectors, across alternatives. While it might be for administrative or other reasons that not all sources be included under the ETS or an ETS like mechanism, policies towards other sectors can still aim for cost effectiveness through shooting for similar abatement costs. If for instance transport is to be covered by emission presumptive fuel taxes, the gains emphasized in *Cost effective* are preserved if fuel taxes are held at similar levels per unit of GHG emitted.

Beyond the points of cost effectiveness, let us highlight two important implications. Firstly, in the near-term, renewables will likely play only a small part in abating emissions under an economically optimal scenario. Associated with this finding and the moderate resulting price rises for carbon and electricity, climate policy will do very little for the prospect for long-term technological change (Figure 2). Thus, prices for electricity and emissions that are held down by free quotas and support for renewables make it more urgent to discuss expanded government subsidies for R&D into far-reaching technological change.

It is only under *Renewable Support* that the share of renewables increases significantly, but this shift in abatement method is accompanied by a significant increase in the welfare cost of emission reductions. Including *Renewable support* doubles welfare costs relative to the *Cost Effective* scenario from 0.3% to

0.7%. One may interpret this as a trade-off of undertaking cheap near-term reductions compared to ensuring medium-term reductions, since renewables' support reduces the reliance on natural gas in emission reductions. However, there are two important concerns regarding this favourable reading: First, it is 'picking winners' and one that is potentially (and surely presently) a costly one, perhaps ignoring other candidates. Second, in supporting renewables with subsidies, the prices of electricity and of emissions are held down, reducing the prospects for such obvious avenues for emission reductions as energy efficiency improvements. The problems of renewables' support are in part seen in the higher total electricity consumption than in the *Cost effective* scenario.

It is natural to also focus on the impact of climate policy on the electricity price. Because of a market in electricity, electricity prices increase significantly even in regions will low fossil shares in generation (Nordics, France & Switzerland). It is indeed efficient that the higher costs of generating electricity in some countries is transmitted to users in all countries, communicating both the need to economize on use and the need for other responses, such as investments in new technology, in energy efficiency, etc. But this effect may also be politically unpopular, and policies such as renewables support may be interpreted as attempts by politicians to meet climate policy goals while shying away from the unpleasant but natural consequences of higher user costs for energy, including electricity tariffs.

It is worthwhile, too, to cover some possible shortcomings of our analysis. We have mentioned that we believe instruments such as renewables' support are driven in part by belief in the learning by doing hypothesis (windmills' costs will fall as more mills are installed)[7], but also by politicians hesitant to confront consumers with the higher electricity tariffs that abatement without support would imply. We do not offer a more in depth analysis of the issues of political feasibility here (See, for instance, Skodvin et al., 2010, focusing in how industry opposition is overcome), but there are ways these are treated 'gently' in a framework such as a computable general equilibrium model. An example of this is the models' neutrality with respect to whether quotas are auctioned or handed out for free. This is 'merely' an income distribution concern in a CGE model, typically cancelled typically through lump sum redistributions. Examples of treatment of pre-existing distortions exist in the literature (n Bohringer et al, 1990b, for instance), but the fact that gratis quotas may act as distortionary subsidies in emitting industries is often neglected or treated superficially. Harstad and Eskeland (2010) offers analysis demonstrating that the distortionary effects of gratis quotas to an industry like electricity generation may be substantial.

Policymakers should be aware of these challenges, and note that measures to make mitigation more politically feasible also carry with them real costs. In the context we have analysed here, our main result is that both a focus on (rather short term) cost effectiveness and the additions of renewables' support will result in only moderate price increases both for electricity and for emissions towards 2020. This is in itself a pleasant consequence, but it carries risks for the long term if it leads to too much gas reliance, and too low incentives for investing in energy efficiency. IPCC finds, for instance, that the building sector is the sector with the highest potential for emission reductions in this century (IPCC, 2007). There is certainly a

[7] The «learning by doing» justification for supportive policies may be exaggerated as recently argued by Nordhaus (2009).

risk that in the first decades of this millennium, if energy prices are low, important long term investments both in buildings and in far reaching technological change are not made.

Acknowledgment

This paper has benefited from comments of many people including seminar participants of the GTAP Eleventh Annual Conference on Global Economic Analysis in Helsinki and the 18th Ph.D. Student Workshop on International Climate Policy at Columbia University in New York. It has benefited also from the technical assistance from Ian Sue Wing. Anonymous referees have provided very useful comments. The authors are responsible for all remaining mistakes or omissions. The study has been conducted with the financial support from ADAM, CELECT, ICEPS, and CenSES projects financed by the European Union and Norwegian Research Council.

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Annex

GRACE-EL Region	Non-ETS Reduction
Nordics	18 %
Rest of Eastern Europe	-13 %
Latvia, Lithuania, Estonia, Poland	-14 %
France & Switzerland	14 %
Germany & Austria	14 %
UK & Ireland	16 %
Belgium, Netherlands & Luxembourg	16 %
Greece	4 %
Italy & Malta	13 %
Spain & Portugal	8 %
EU Average	9 %

Table A 1: Reductions required in Non-ETS emissions in 2020 (relative to 2005 level) in GRACE-EL regions. Negative value indicates allowed increase. Source: European Commission (2008a)

Study	Main question asked	Theoretical result a priori	Finding	Means of analysis
Bohringer et al, 2009	Costs of supplementing ETS with carbon taxes within ETS	Positive cost except if CO2 tax high enough to compete with ETS	Positive costs except for high CO2 tax	Quantitative model, partial equilibrium
Bohringer Rutherford, and Tol, 2009	Cost of 2020 goals and differentiated instruments	Likely positive, could be negative	2020 goals cost ½ to 2 percent of consumption + 50 to 100% with differentiation and renewables standards	CGE model model comparisons
Bernard, Vielle, 2009	Costs of 2020 goals, and directive	Likely positive costs	Emission target costs 3/5% of consumption, reaching 1% with differentiated targets and renewable support	CGE model
Eskeland, Mideksa and Rive, 2011	Costs of meeting EU 2020 goals, various instruments	Multiple goals, differentiation and renewable support will add costs to emission goal	Cost of meeting emission goal, 1/3% of consumption, rising to 2/3% with renewables support and to 1% under directive	Hybrid CGE model with technology detail for electricity sector
Edenhofer et al, 2010	Cost of 2 degree target, world, century	Likely positive costs	4/5% to 2 ½% of GDP	Model comparison
Rose and Dormady, 2011	Costs of climate policy proposals in USA	Likely positive costs, could be negative	Mean cost estimate, ¾% of GDP	Meta-analysis of various models and analyses

Table A 2: Summary of comparable papers in the literature in light of the research questions, method, and findings.