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Energy Security: An Impact Assessment of the EU Climate and Energy Package

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1. Introduction

In June 2009 the Climate and Energy Package entered into force committing the European Union to transform itself into a highly energy-efficient, low carbon economy over the next decade. The package includes three major objectives collectively known as the 20-20-20 targets to be achieved in 2020:

- To reduce EU greenhouse gas emissions by at least 20% below 1990 levels,[1]
- To reach 20% of renewable energy in EU gross final consumption of energy, and
- To increase energy efficiency by 20% (as compared to business-as-usual in 2020).

The main driving force behind the Climate and Energy Package was the EU's ambition to play a leading role in the battle against anthropogenic climate change. More specifically, the EU had hoped to push an international greenhouse gas emission reduction agreement during the Copenhagen climate change conference in December 2009 as a follow-up to Kyoto which is to expire in 2012.[2] Beyond climate change, energy security has been put forward by the EU as another justification for launching the Climate and Energy Package. Energy security ranks high on the policy agenda of many OECD countries with the popular notion that reduced dependency on fossil fuel imports will be good for the society.

EU policy makers have celebrated the EU Climate and Energy Package as a milestone for Europe's ability "to act for the benefit of its citizens" (European Commission 2009). The political self-appraisal may however be questioned from an economic perspective: Not only should there be a clear efficiency rationale for policy interference as such but also for target levels as well as the choice of regulatory instruments.

Regarding the climate protection objective of the EU package, at least the reasoning for policy interference is straightforward. On unregulated markets greenhouse gas emissions would be considered for free thereby causing a market failure as the social costs of emission use are not taken into account by private agents. Whether the EU should go ahead with unilateral emission reduction pledges at all and why the mid-term EU cutback target should amount to 20% can be debated given the global public good nature of climate protection and the large uncertainties in external cost estimates for climate change. Yet, the 20% target for the EU reflects the need for substantial global greenhouse gas reductions over the next decades in order to limit the rise in global average temperature to no more than 2° Celsius above pre-industrial levels. Likewise, it can be argued that unilateral action may increase public pressure for other industrialized countries and possibly also the developing world to follow suit in the battle against climate change. Fundamental economic concerns on the climate policy part of

1 The EU confirmed its commitment to moving to a 30% reduction as part of a comprehensive international agreement on condition that other major emitting countries in the developed and developing worlds will undertake "comparable efforts".

2 As a matter of fact, the United Nations climate change conference of parties (COP 15) at Copenhagen turned out to be a severe backslash to the EU's aspiration: Instead of binding emission reduction commitments for major industrialized and developing regions, Copenhagen brought about only a voluntary system of pledge-and-review.

the EU package therefore "only" arise from the actual policy implementation which makes emission reduction much more costly than needed. Cost-effectiveness postulates that the marginal cost (price) to each use of greenhouse gas emissions should be equalized, thereby assuring that the cheapest abatement options are realized. This could be achieved through a comprehensive EU-wide cap-and-trade system where emission markets work out the least-cost solution by establishing a uniform emission price. To achieve a single policy target only one policy instrument is required – an insight which has been established in more general terms through the seminal work of Tinbergen (1952) calling for the equalization of the number of instruments with the number of policy targets.[3]

EU climate policy practice, however, violates basic principles of cost-effectiveness. Firstly, the EU Climate and Energy Package which is the central piece of legislation to achieve the overall EU emission reduction target does not accommodate comprehensive EU-wide emissions trading. The EU foresees explicit emissions trading only between energy-intensive installations (sectors) under the EU Emissions Trading Scheme (EU ETS), which covers just around 40% of EU greenhouse gas emissions. Each EU Member State must therefore specify additional domestic abatement policies for the sectors outside the EU ETS in order to comply with the overall EU emission reduction objective through mandated country-specific targets for the non-ETS segments of its domestic economy. Since there are no tight links between the ETS emission market on the one hand and the non-ETS emission "markets" on the other hand, marginal abatement costs across these segments will typically not be equalized and substantial excess costs of market segmentation are likely to occur (Böhringer et al. 2005). Secondly – and not at least because of the fragmentation into one ETS market and twenty-seven domestic policy regimes for the non-ETS sectors – the EU employs a broader policy mix instead of one single instrument to meet its climate policy target. Beyond emissions trading the EU builds upon the explicit promotion of renewable energy production and energy efficiency both in ETS as well as non-ETS segments of the economy.[4] Efficiency and renewable targets have triggered a wide variety of policy measures across the 27 EU Member States including implicit or explicit subsidies to renewables, efficiency standards for buildings, and specific product policies such as banning incandescent light bulbs or patio heaters. From the sole perspective of climate policy the myriad of instruments used in the EU to curb greenhouse gas emissions is doomed to generate excess costs due to overlapping counterproductive regulation. If targets for renewable energy and energy efficiency become binding, they give an outcome different from the cost-effective solution generated by comprehensive emissions trading and thereby create additional costs (Böhringer et al. 2010).

Regarding the energy security objective of the EU package a rigorous economic assessment is tricky. In first place it is unclear of what "energy security" is supposed to be. Colloquially, energy security is often portrayed as reduced dependence on imported energy, most notably

3 While more targets than instruments make targets incompatible, more instruments than targets make instruments alternative, i.e., one instrument may be used instead of another or a combination of others.

4 The EU Climate and Energy Package includes a 20% target share of renewable energy sources in gross final energy consumption and a mandated increase of energy efficiency of 20% by 2020 along with the 20% greenhouse gas emission reduction target.

oil. Dependence on foreign energy imports is viewed as critical since the domestic economy becomes more vulnerable to international energy price spikes and strategic action from energy supply regions. It is therefore argued in policy circles that countries should rely less on imported energy or at least on energy from less reliable sources. The objective of energy security is then "to assure adequate, reliable supplies of energy at reasonable prices and in ways that do not jeopardize major national values and objectives" (Yergin 1988). From an economic perspective, Bohi and Toman (1996) link energy (in-)security to "the loss of economic welfare that may occur as a result of a change in the price or availability of energy". Yet, the public and scientific debate is hampered by a missing operational definition of energy security. The lack in definition directly translates into the lack of clear-cut indicators for energy security. An issue that can not be adequately measured is difficult to improve. Nevertheless, the catchword of energy security persists as a policy driver of great rhetorical and practical importance serving as a common rationale for government actions. Economists as practical minimalists set out three reasons why government should intervene in the marketplace: to improve allocational efficiency, to achieve distributional equity, and to ensure macro stability. The efficiency rationale is all about correcting for market failures. With respect to energy markets, failures may stem from market power of energy exporting countries, insufficient hedging by private actors, or macroeconomic adjustment costs in the case of energy disruptions. It is arguable if such market failures are substantial and – if so – whether they can be cured efficiently through government intervention (Bohi and Toman 1996).[5]

The European Union started to take (narrowly defined) action on energy security in the late 1960s by obliging the Member States to maintain strategic oil reserves, followed up additional regulations specifically on oil use in case of supply disruptions. With the green paper "Towards a European strategy for the security of energy supply" (European Commission 2000) the European Commission intended to trigger the development of a long-term strategy for energy supply security and intensify cooperation between the Member States. The major concern was the growing dependence of the European energy supply on imports, foremost from the Middle East and Russia. Given the fuzziness of the energy security notion it does not come as a surprise that the EU Climate and Energy Package misses a clear metric for energy security as well as a conclusive efficiency rationale for market intervention. With the ambiguity on energy security it is impossible from a scientific perspective to derive pinpoint measures. Nevertheless, policy makers exploit the energy security argument to justify a myriad of measures for promoting renewable energy or improving energy efficiency.[6] This becomes apparent in the EU Energy Security and Solidarity Action Plan (European Commission 2008) where the adoption of the 20-20-20-package is praised as an important step forward to provide future energy security in the European Union through a reduction of energy imports. More specifically, the Action Plan embraces:

5 For example, diversification strategies for energy supply to hedge against market power or unexpected physical disruptions are part of the daily business in private energy companies.

6 Such measures include bans on light bulbs or patio heaters, tax breaks for bicycle owners, standards for tyre pressure, or and tests for fuel efficient driving.

- energy efficiency because "[…] consuming less through energy efficiency is the most durable way to reduce dependence on fossil fuels and imports. […] Energy efficiency has to be at the heart of the EU's Energy Security and Solidarity Action Plan."
- renewable energies because "All cost-effective measures that can be taken to promote the development and use of indigenous resources should form an important element of an EU Energy Security and Solidarity Action Plan. The development of renewable energy such as wind, solar, hydro, biomass energy and marine resources has to be seen as the EU's greatest potential source of indigenous energy."

Overall, the EU Climate and Energy Package sets a tangle of targets and instruments which reflects a multi-dimensional policy process. At the same time the package runs the risk of counterproductive overlapping regulation because policy does not become sufficiently explicit on the economic rationale and even definition of targets. Policy implementation of multiple targets furthermore calls for a careful assessment of spillover and inter-linkages effects of regulatory measures in order to improve the coherence of policy initiatives.

Against this background, our objective is to shed some light on the complex interactions between the multiple targets and policy instruments of the EU Climate and Energy Package. We are furthermore interested in assessing the implications of EU regulation on widespread energy security indicators to highlight the difficulties of the energy security notion from an economic perspective.

The remainder of this article is organized as follows. In section 2, we survey indicators for energy security. In section 3, we lay out the numerical framework for the quantitative impact assessment of the EU Climate and Energy Package. In section 4, we discuss results. In section 5, we summarize and conclude.

2. Energy Security Indicators

The pertinent literature on energy security suggests a variety of indicators to reflect the vulnerability of a country's energy supply. Lefèvre (2010) describes the causal links from energy supply insecurity to a potential welfare loss in four stages: When the demand for a specific fuel (stage I) is met by a supply from dominant or politically unstable exporters (stage II), there is a higher risk of price increase or price disruption for this fuel (stage III). This in turn will lead to welfare losses of the importing economy (stage IV). Many energy security indicators (e.g. IEA 2007; Frondel and Schmidt 2008; Lefèvre 2010; Löschel et al. 2010) refer to stage II and focus on supply-side characteristics such as the diversity of a country's energy sources or the diversity of energy suppliers. These indicators partly include risk profiles of exporting countries or the geological resource base of the energy source. The energy security price index (ESPI), as a prominent example (Lefèvre 2010), evaluates the situation on global export markets for the three fossil fuels crude oil, natural gas and coal, and relates them to the importance of the three fuels in the energy mix of an economy. Other indicators put the emphasis on the energy import dependency of a country. The argument behind is that in emergency situations a country may still be able to control the indigenous extraction of energy resources but has no direct control over the energy imports. Therefore, the degree of import dependency (separately for each fuel or aggregated for all energy carriers) is viewed as an important indicator for energy security (ESMI – energy security import index). Another policy-relevant indicator, which captures at least part of the magnitude of the impact of energy price shocks on welfare (stage IV of the scheme above), is the energy intensity of an economy, i.e., the physical energy inputs needed to generate one unit of economic output (EI – energy intensity). In case of an energy price increase, economies with high energy intensity must spend more of their resources for energy and will thus face a greater welfare loss than economies with low energy intensity. The three indicators – ESPI, ESMI, and EI – can be combined towards a composite energy security index (ESI).

2. 1 Energy Security Price Index (ESPI)

The energy security price index (ESPI) developed by Lefèvre (2010; see also IEA 2007) is based on a political risk assessment of energy exporters and the market share of energy exporting countries in the global export potential for each fuel. The resulting (global) price risk for each fossil fuel *f* is expressed in a single index, the so-called $ESMC_{pol\text{-}f}$ (energy security market concentration index amended by a political risk rating). These fuel-specific indices are then multiplied by the share of each fuel in the examined country's total primary energy supply and added up to obtain one single number:

$$ESPI = \sum_f \frac{E_f}{TPES} ESMC_{pol-f} \text{ with } ESMC_{pol-f} = \sum_c r_c \; {}_{cf}{}^{2} \,,$$

where $\frac{E_f}{TPES}$ is the share of fuel *f* in total primary energy supply in the observed country, ω_{cf} denotes the share of export country *c*'s net export potential in global export potential of fuel *f* (in percentage points) and r_c is the political risk rating of export country *c* ranging from 1 (low risk) to 3 (high risk). The risk rating scales up Herfindahl's concentration index whenever countries are perceived as politically unstable: $ESMC_{pol\text{-}f}$ is large when few high-risk exporters dominate the world market (the maximum of $ESMC_{pol\text{-}f}$ is 30000 points). Note that $ESMC_{pol\text{-}f}$ is independent of the country for which the energy security index is calculated since ω_{cf} only considers export potentials in a truly globalized market. The fuel-specific concentration indices $ESMC_{pol\text{-}f}$ are then weighted by the share of each fuel in total primary energy supply of the country under consideration in order to obtain the aggregate ESPI indicator.[7]

7 In various regions, such as continental Europe, most gas contracts are still directly linked to oil prices. As a consequence the share of gas consumption subject to price formation on gas spot markets is multiplied by the concentration measure ESMCpol-GAS while the remaining share of gas consumption subject to prices directly linked to the oil price is multiplied with the concentration measure ESMCpol-OIL. For our ESPI calculation we adopt the ratings for ESMCpol-f used by IEA (2007) and Lefèvre (2010). For the projected magnitude of oil-based gas pricing in the European Union in 2020 we use a share of 50%, which is in accordance with IEA assumptions (2009).

2. 2 Energy Security Import Index (ESMI)

Another common indicator for energy security is a region's share of net energy imports in its total energy consumption. Since imports defy the control of a country, they are potentially insecure in times of crises. For the calculation of the energy security import index (ESMI), we add up the shares of (positive) net imports across the fossil fuels *f* (coal, natural gas and oil) in total primary energy supply[8]:

$$ESMI = \sum_f \frac{M_f - X_f}{TPES} \cdot 100 \quad \text{for all } f \text{ where } M_f > X_f .$$

The indicator ranges between 0 (no net imports of fossil fuels) and 100 (complete import dependency).

2. 3 Energy Intensity (EI)

The energy intensity of an economy is a demand-side indicator which measures the ratio of total primary energy supply over GDP[9]:

$$EI = \frac{TPES}{GDP} .$$

We report the numbers for energy intensity in tons of oil equivalent over million $US. Values in 2005 for OECD countries vary between 100 and 200.

2. 4 Composite Energy Security Index (ESI)

The three indicators – ESPI, ESMI, and EI – can be combined towards a composite energy security index (ESI) capturing three different energy security aspects: the price risks to specific fuels, the import dependency on specific fuels, and the importance of energy in the economy:

$$ESI = \sum_f \frac{M_f - X_f}{GDP} ESMC_{pol-f} \quad \text{for all } f \text{ where } M_f > X_f$$

The ESI indicator thus represents an aggregation of the fuel-specific energy security market concentrations (including political risks) weighted by the shares of (positive) net imports of the respective fuels in GDP.

3. Method of Assessment: Computable General Equilibrium Analysis

The quantification of trade-offs between different policy targets and the impacts triggered by overlapping regulatory measures calls for the use of numerical model techniques in order to assess systematically the interference of the many forces that interact in the economy. Obviously, models of complex socio-economic systems require simplifying assumptions on system boundaries and system relationships. These assumptions drive the model results and

8 Note that no import risk is attached to the use of nuclear energy and renewable energies.

9 Higher energy intensities are viewed as indication for higher vulnerability to energy price shocks as GDP formation is more dependent on energy inputs.

thus the policy conclusions. Since there is considerable ambiguity in the choice of model assumptions and even in the selection of data, quantitative model results need to be treated with caution. While models are no truth machines, they can nevertheless help to put decision making on an informed basis rather than on fuzzy or contradictory hunches. The informational value of numerical analysis comes from robust insights and not from precise numbers: What is the sign and the rough magnitude of economic impacts and how can we rank alternative policy designs to reach some given policy target?

In general, there is no specific model, which fits all requirements for comprehensive impact assessment, but rather a suite of models or methods depending on the policy measure or issue to be assessed and the availability of data. However, when it comes to economy-wide analysis of policy interferences a strong case can be made for computable general equilibrium (CGE) models that have become a standard tool for economic impact assessment employed by various national and international organizations, research centers, and universities (Böhringer and Löschel 2006). CGE models build upon general equilibrium theory that combines behavioral assumptions on rational economic agents with the analysis of equilibrium conditions. They provide counterfactual ex-ante comparisons, assessing the outcomes with a reform in place with what would have happened had it not been undertaken. The main virtue of the CGE approach is its comprehensive micro-consistent representation of price-dependent market interactions. The simultaneous explanation of the origin and spending of the agents' income makes it possible to address both economy-wide efficiency as well as distributional impacts of policy interference.

3.1 Non-Technical Model Summary

In order to quantify the impacts of the EU Climate and Energy Package on economic performance and energy security indicators we build on a generic multi-region, multi-sector CGE model of global trade and energy use established by Böhringer and Rutherford for the economy-wide analysis of greenhouse gas emission control strategies (see Böhringer and Rutherford 2010 for a recent application and detailed algebraic description). A multi-region setting is indispensable for the economic impact analysis of climate policy regimes: In a world that is increasingly integrated through trade, policy interference in larger open economies not only causes adjustment of domestic production and consumption patterns but also influences international prices via changes in exports and imports. The changes in international prices, i.e., the terms of trade, imply secondary effects that can significantly alter the impacts of the primary domestic policy. In addition to the consistent representation of trade links, a detailed tracking of energy flows as the main source for CO_2 emissions is a pre-requisite for the assessment of climate policies.

The static CGE model used for our numerical analysis features a representative agent in each region that receives income from three primary factors: labour, capital, and fossil-fuel resources (i.e. coal, gas and crude oil). Labour and capital are intersectorally mobile within a region but immobile between regions. Fossil-fuel resources are specific to fossil fuel production sectors in each region. Production of commodities, other than primary fossil fuels is captured by three-level constant elasticity of substitution (CES) cost functions describing the price-dependent use of capital, labour, energy, and material in production. At the top level, a CES composite of intermediate material demands trades off with an aggregate of energy, capital, and labour subject to a constant elasticity of substitution. At the second level, a CES function describes the substitution possibilities between intermediate demand for the energy aggregate and a value-added composite of labour and capital. At the third level, capital and labour substitution possibilities within the value-added composite are captured by a CES function whereas different energy inputs (coal, gas, oil, and electricity) enter the energy composite subject to a constant elasticity of substitution. In the production of fossil fuels, all inputs, except for the sector-specific fossil fuel resource, are aggregated in fixed proportions. This aggregate trades off with the sector-specific fossil fuel resource at a constant elasticity of substitution. The latter is calibrated in consistency with empirical estimates for the supply elasticity of the specific fossil fuel.

Final consumption demand in each region is determined by the representative agent who maximizes utility subject to a budget constraint with fixed investment (i.e. given demand for the savings good) and exogenous government provision of public goods and services. Total income of the representative household consists of net factor income and tax revenues. Consumption demand of the representative agent is given as a CES composite that combines consumption of non-electric energy and composite of other consumption goods. Substitution patterns within the non-electric energy bundle are reflected by means of a CES function; other consumption goods trade off with each other subject to at a unitary elasticity of substitution, i.e. a Cobb-Douglas relationship.

Bilateral trade is specified following the Armington approach of product heterogeneity, domestic and foreign goods are thereby distinguished by origin.[10] All goods used on the domestic market in intermediate and final demand correspond to a CES composite A_{igr} that combines the domestically produced good and the imported good from other regions differentiated by demand category (i.e., the composition of the Armington good differs across sectors and final demand components). Domestic production is split between input to the formation of the Armington good and export to other regions subject to a constant elasticity of transformation (CET). The balance of payment constraint, which is warranted through flexible exchange rates, incorporates the base-year trade deficit or surplus for each region.

Due to the limited data availability on non-CO_2 abatement options the current model version only tracks CO_2 which is by far the most important greenhouse gas in the EU. CO_2 emissions are linked in fixed proportions to the use of fossil fuels, with CO_2 coefficients differentiated by the specific carbon content of fuels.[11] Restrictions to the use of CO_2 emissions in production and consumption are typically implemented through exogenous emission constraints that keep CO_2 emissions to a specified limit or through CO_2 taxes. CO_2 emission abatement then takes

10 The only exception is crude oil, where we assume product homogeneity.

11 Emissions of non-CO_2 greenhouse gases can in general not be tied in fixed proportions to production activities – there are many technical possibilities to reduce emissions per unit of activity which makes the inclusion of explicit or implicit marginal abatement costs to non-CO_2 gases within an economy-wide CGE framework a more subtle challenge (see e.g. Böhringer et al. 2006).

place by fuel switching (inter-fuel substitution) or energy savings (either by fuel-non-fuel substitution or by a scale reduction of production and final demand activities).[12]

Given the paramount importance of the electricity sector as the major source of CO_2 emissions in the EU, the standard representation of power production through a single CES production (cost) function is replaced by a bottom-up activity analysis characterization where several discrete generation technologies compete to supply electricity to regional markets. The price of electricity then is determined by the production costs of the marginal supplier. Power generation technologies respond to changes in electricity prices according to technology-specific supply elasticities. In addition, lower and upper bounds on production capacities can set explicit limits to the decline and the expansion of technologies.

3.2 Data

The model builds on the most recent GTAP dataset (version 7) with detailed accounts of regional production, regional consumption, bilateral trade flows as well as energy flows and CO_2 emissions for the base year 2004 (Badri and Walmsley, 2008). The dataset also features a variety of initial taxes. As is customary in applied general equilibrium analysis, base year data together with exogenous elasticities determine the free parameters of the functional forms. Elasticities in international trade and sectoral value-added are based on empirical estimates reported in the GTAP database. Substitution elasticities between production factors capital, labor, energy inputs and non-energy inputs (material) are taken from Okagawa and Ban (2008) who use most recent panel data across sectors and industries for the period 1995 to 2004.

As to sectoral and regional model resolution, the GTAP database is aggregated towards a composite dataset that accounts for the specific requirements of international climate policy analysis (see Table 1).

Table 1: Model sectors and regions

Sectors and commodities	Countries and regions
Energy	*Industrialized regions*
Coal (COL)	EU-27 (EU)
Crude oil (CRU)	USA
Natural gas (GAS)	Japan
Refined oil products (OIL)	Russia
Electricity (ELE)	Other OECD countries
Non-energy	*Developing regions*
Energy-intensive Industries (EIS)	China
Transport (TRN)	India
Rest of Industry (ROI)	Brazil
	OPEC
	Rest of the developing world

12 Revenues from emission regulation accrue either from CO_2 taxes or from the auctioning of emission allowances (in the case of a grandfathering regime) and are recycled lump-sum to the representative agent in the respective region.

At the sectoral level, the model captures details on sector-specific differences in factor intensities, degrees of factor substitutability, and price elasticities of output demand, in order to trace the structural change in production induced by policy interference. The energy goods identified in the model are coal, crude oil, natural gas, refined oil products, and electricity. This disaggregation is essential in order to distinguish energy goods by CO_2 intensity and the degree of substitutability. In addition, we consider explicitly an aggregate of energy- and emission-intensive industries which – within Europe – is subject to regulations of an EU-wide emissions trading system. All remaining industries and services are represented through a composite sector. Regarding regional coverage, the EU is treated as one aggregate region which dismisses the heterogeneity of economies across its 27 Member States but substantially relaxes data problems with respect to baseline calibration and details of regulatory practice. In order to capture terms-of-trade effects from international markets the model includes all major trading partners of the EU. All remaining regions are summarized within two rest-of-the-world composites.

The economic impacts of meeting the EU 20-20-20 targets in 2020 critically depend on the structural characteristics of the EU economy exhibited in a hypothetical business-as-usual situation without policy constraints. A simple forward projection of the model from the 2004 base year to some target year with regional emission abatement pledges (2020 in the case of the EU Climate and Energy Package) involves calibration to a steady-state where all physical quantities (including CO_2 emissions) grow at an exogenous uniform rate while relative prices remain unchanged. The virtue of a steady-state baseline is that it provides a transparent reference path for the evaluation of policy interference. Any structural change in the counterfactual can be attributed to the new policy. Such a steady-state forward calibration, however, lacks policy appeal since it does not comply with official business-as-usual projections although the assumptions behind the latter are often controversial or opaque. In applied policy analysis we are, however, typically confronted with projections for non-uniform growth rates and heterogeneous structural dynamics. Off-the-steady-state baseline projections may run against the high degree of endogeneity in economic variables CGE models stand for. The key challenge is to reconcile disparate and possibly contradicting values: For example, GDP growth estimates may be much higher than the projected increase in CO_2 emission. A plausible reconciliation under business as usual then requires the assumption of "autonomous" energy efficiency improvements triggered by baseline capital investments. Our model forward projection builds on recent projections by the US Energy Information Agency (International Energy Outlook – EIA 2010). The business-as-usual structure of model regions (i.e. the reference situation without exogenous emissions constraints) in 2020 is based on projected energy input demands across sectors, future GDP levels, the international price trajectory for crude oil and the assumed structure of electricity generation.[13] We furthermore account for the abolishment of the subsidies to indigenous coal production in the European Union, which are to be phased out by 2018.

13 The calibration procedure thereby solves for a revised baseline equilibrium in which energy demands and energy prices match the baseline projection while sectoral productivities adjust such that all sectors remain on the benchmark iso-cost line. This keeps the cost and expenditure functions as close as possible to the initial static technologies and preferences underlying the base-year calibration.

4. Policy Scenarios and Simulation Results

We quantify the effects of policy measures with respect to a hypothetical reference situation without these measures in place – the so-called business-as-usual (*BaU*) scenario. Policy impact assessment then involves (i) changes in parameters or exogenous variables that mimic alternative policy regulations, (ii) simulation of the new counterfactual equilibrium, and (iii) comparison of the counterfactual and the *BaU* equilibrium to derive information on policy-induced economic effects. Our primary interest is to investigate how the objectives of the EU Climate and Energy Package – i.e. emission reduction, renewable promotion, and energy efficiency improvements – interact with each other and thereby affect the economic costs of policy interference. If we keep with emission reduction as the only tangible objective under economic efficiency consideration, how do the additional targets and associated measures affect cost-effectiveness? Our secondary interest is to monitor the changes in energy security indicators induced by the EU Climate and Energy Package. While we do not attempt to provide any cost-benefit analysis on energy security, our quantitative analysis can provide price tags to changes in energy security indicators – irrespective of a more rigorous welfare interpretation.

4.1 Business-as-Usual Scenario

The targets of the EU Climate and Energy Package must be achieved in 2020, i.e., a decade from now. Impact assessment requires a business-as-usual evolution of the economy in the absence of the package. The critical importance of baseline projections is hardly addressed in the public climate policy debate. Baseline projections do not only determine the magnitude of reduction requirements but also the ease of adjustment. For example, the 20% emission reduction target of the EU Climate and Energy Package – stated with respect to historical 1990 emission levels – will translate in a higher effective reduction requirement from 2020 *BaU* emission levels should the EU economy have positive emission growth along the baseline.[14] Table 2 reports historical data and projected *BaU* values for CO_2 emissions, total primary energy use, renewable share in power production and energy security indicators at the EU-wide level.

Table 2: Historical and *BaU* values of key variables (*BaU* values stem from model simulations based on the GTAP database in 2004 and EIA projections up to 2020)

	2004	*BaU* in 2020
CO_2 emissions (in Mt)	3965.0	4167.6
Total primary energy use (in Mtoe)	1838.2	1976.0
Renewable share in power production (%)	14.8	24.8
ESPI (price risk)	5560.9	6106.5
ESMI (import index)	50.0	50.9
EI (energy intensity)	142.1	103.7
ESI (composite index)	527.4	453.5

14 Also the ease of emission abatement is determined through the *BaU* value shares of inputs to production and consumption together with the underlying substitution elasticities (in partial equilibrium analysis the ease of abatement is graphically indicated by the curvature/steepness of marginal abatement cost curves).

It becomes obvious that the *BaU* stands out for a strong ("autonomous") decline in energy intensity which explains the rather moderated increase of CO_2 emissions by 5.1% between 2004 and 2020. In other words: Despite a projected substantial growth in economic activity the EU emission reduction target does not become much more restrictive along the baseline. According to IEO baseline projections the renewables' share in power production goes up by 10 percentage points which greatly relaxes the stringency of the respective 2020 targets. Compliance to all three targets – emission reduction, renewables' energy share increase, and energy efficiency improvement – can become much more difficult (costly) should the optimistic baseline projection not materialize.

The *BaU* evolution of energy security indicators between 2004 and 2020 show a heterogeneous picture. The ESPI which measures the price risk of total energy consumption rises by roughly 10% to 6106.5 points.[15] The ESMI has a value of 50 in 2004, meaning that EU-27 imported half of its energy consumption in that year from abroad. According to *BaU* projections the energy import share increases slightly to 50.9% in 2020. As mentioned above the baseline development until 2020 stands out for substantial energy efficiency improvements such that EU energy intensity declines from 142.1 (toe / million $US) in 2004 to 103.7 in 2020. The decline in energy intensity is the main driver for the improvement of the energy security composite index which decreases from 527.4 points in 2004 to 453.5 points in 2020.

4.2 EU-20-20-20 Scenarios

Table 3: Nominal and effective emission reduction requirements for ETS and non-ETS

	Nominal CO_2 reduction pledges (% vis-à-vis 2005)	Effective CO_2 reduction pledges (% vis-à-vis 2020)
EU-27 (Total)	15.5	19.6
ETS	21.0	28.8
Non-ETS	10.0	9.25

The EU Climate and Energy Package does not only set binding EU-wide targets for greenhouse gas emission reduction, renewable energy promotion and energy efficiency improvements but also prescribes to a larger extent how targets are shared across countries and segments of the EU economy. This is in particular relevant for EU emission reduction where the aggregate EU pledge is split down into a reduction target of 21% for energy-intensive industries covered under the EU ETS and a 10% emission reduction requirement for the non-ETS segment (taking 2005 as the reference year in each case).[16] Table 3 indicates how baseline emission growth in ETS and non-ETS sectors translates into effective reduction requirements from 2020 *BaU* emission levels. Note that due to the lack of detailed data on

15 Note that the exogenous changes in fuel-specific price risks are taken from Lefèvre 2010 who expects the price risk for gas to decrease substantially due to the expected transition from a regional to a global market and the declining share of oil-indexed gas prices. Likewise, the expected price risk for oil increases due to the continued exhaustion of oil reserves in the industrialized countries.

16 The aggregate emission reduction adds up to a 20% cut vis-à-vis 1990 emission levels.

non-CO_2 emissions and non-CO_2 abatement costs we take CO_2 emissions as a *pars pro toto* for all greenhouse gas emissions in our model simulations. The effective emission reduction requirement for the ETS rises (as emissions in the ETS sector increase between 2005 and 2020) whereas the effective emission reduction requirement for the non-ETS sector remains almost constant.

The emission ceiling for the ETS sectors is implemented centrally through an EU-wide cap while the reduction target for emissions outside the EU ETS is distributed according to an allocation scheme that reflects differences in economic performance –measured in terms of GDP per capita – across Member States.[17] The policy regulation for meeting the domestic non-ETS targets can be chosen by each Member State. There is no tradability or so-called "where-flexibility" in abatement between the ETS and the non-ETS sectors, which – as mentioned before – is likely to increase costs of EU climate policy. The excess costs might be ameliorated for ETS and non-ETS sectors through the access to CDM emission offsets although the latter has been restricted by the EU to enforce primarily domestic abatement efforts: The EU ETS can offset up to 50% of its overall emission reduction requirement from 2005; the non-ETS sectors are allowed to buy up to 3% of their 2005 base-year emissions. In our simulations, scenario *CO2* picks up the differential targets for the ETS and non-ETS sectors as well as their respective CDM provisions. The default policy instrument for EU Member States to achieve emission reduction in the non-ETS sectors is a domestic CO_2 tax which equalizes marginal abatement costs across domestic non-ETS emission sources.[18] Revenues from emission taxation and auctioning of emission allowances are recycled lump-sum to the representative EU household.

Beyond emission reduction targets the Climate and Energy Package sets national targets for renewable energy which collectively will lift the average renewable share across the EU to 20% by 2020 (roughly double the 2008 level of 10.3%). The national targets range from a renewables share of 10% in Malta to 49% in Sweden. Scenario *REN* mimics the promotion of renewable energy. As we do not distinguish between EU Member States and do not cover renewable energy use comprehensively, we impose a single EU-wide renewable target of 35% on the electricity generation sector. The higher target for power generation reflects policy demands for a substantially higher contribution in this sector compared to other segments of the economy. The target is achieved through subsidies to renewable power generation technologies; subsidies are financed lump-sum.

The mandated energy efficiency improvements under the EU Climate and Energy Package are taken up in scenario *EFF* where we demand that total primary energy consumption must decline by 20% as compared to the *BaU* level. Technically, the target is met through the imposition of a sufficiently high tax on primary energy use.

17 Targets range from 20% decrease of emissions for high income regions such as Ireland, Luxemburg or Denmark to a 20% increase of emissions for low income regions such as Bulgaria.

18 This assumption is rather optimistic with respect to cost-effectiveness of climate policy action. In EU practice, Member States are rather going for a bundle of command-and-control measures. Furthermore, we do not differentiated in our analysis between EU Member States such that the non-ETS CO_2 prices are implicitly the same across all twenty-seven EU Member States.

Apart from the policy scenarios *CO2*, *REN*, and *EFF* that capture the different targets of the EU Climate and Energy Package in isolation, we combine these scenarios to assess the overall impact of the Climate and Energy Package and to gain insights into the implications of overlapping regulation. For the sake of brevity, we limit the combined scenarios to the subsequent imposition of the renewable target and the efficiency target on top of the emission target rendering two composite scenarios *CO2-REN* and *CO2-REN-EFF*. We furthermore consider a comprehensive emissions trading scenario *TRD* where marginal abatement costs are equalized across all EU emission sources. While the *TRD* scenario is still off from global where-flexibility (CDM limits apply and there is no extra-EU emissions trading with other industrialized regions) it provides some guidance on the magnitude of excess costs induced by the emission market segmentation under the current EU climate policy regime.

Table 4 summarizes the scenarios with their key assumptions.[19]

Table 4: Summary of scenario characteristics

Scenario	Basic assumptions
BaU	Business-as-usual assumptions on economic growth, energy (emission) demand and electricity generation shares
CO2	• 20% CO2 emission reduction target for the EU (as compared to 1990 levels • Segmented CO2 emission regulation with EU-wide emissions trading for energy-intensive industries (EU ETS) and cost-efficient emission regulation for non-ETS sectors within each Member State • Limits to CDM offsets for ETS and non-ETS sectors • Lump-sum recycling of revenues from CO2 emission regulation
REN	Renewable target share of 35% in EU power production (implemented via subsidies for renewable power technologies)
EFF	20% reduction in primary energy use from BaU levels (implemented via a tax on primary energy use)
CO2-REN	Combination of CO2 and REN
CO2-REN-EFF	Combination of CO2, REN, and EFF
TRD	As CO2 but without emission market segmentation

4.3 Results

We first discuss the impacts of meeting the single EU 20-20-20 targets through specific policy measures captured by policy scenarios *CO2, REN,* and *EFF*. We then investigate the implications of overlapping regulation in scenarios *CO2-REN* and *CO2-REN-EFF* as we subsequently impose the additional targets of renewable promotion and primary energy reduction (energy efficiency improvements) on top of the CO_2 emission reduction target. Finally, we discuss how the various policy measures affect energy security indicators.

The economic implications of alternative EU 20-20-20 scenarios are reported in terms of percentage changes in key economic variables from their *BaU* levels. The central welfare indicator is the so-called Hicksian equivalent variation in income which denotes the amount

19 The use of nuclear power in the EU is limited to the *BaU* level throughout all simulations reflecting public concerns on the operation of nuclear power plants and the unresolved issue of long-term nuclear waste management.

which is necessary to add to (or deduct from) the benchmark income of the representative consumer so that she enjoys a utility level equal to the one in the counterfactual policy scenario on the basis of ex-ante relative prices. In our framework, the welfare change can be readily interpreted as a change in real consumption. For scenarios with binding CO_2 emission constraints, marginal costs of abatement are stated as CO_2 values in $US per ton of CO_2. Differences in marginal abatement costs across regions and sectors (e.g. ETS versus non-ETS) indicate scope for direct cost savings through increased where-flexibility.

Table 5 provides a condensed report on how the individual or combined implementation of the EU-20-20-20 targets affects economic welfare, CO_2 values in ETS and non-ETS sectors, and the performance on the three objectives of the Energy and Climate Package, i.e. CO_2 reduction, renewables promotion and efficiency improvements.

We start the interpretation of results with scenario *TRD* as a hypothetical reference for efficient EU climate policy design where marginal abatement costs across all EU sectors are equalized. The economic costs of meeting the 20% emission reduction target by 2020 are moderate. While baseline emissions in 2020 have to be reduced by 19.6%, a significant share of this reduction can be generated in the CDM market (around one third). This represents the maximum of CDM credits that is officially acknowledged as emission reduction by EU legislation, since CDM credits can be imported at low costs from abroad (in particular from China as the major CDM host country).

When we turn to scenario *CO2*, which reflects the actual climate policy regime, we can identify a difference between CO_2 prices in ETS and non-ETS sectors. For non-ETS sectors where abatement is rather costly (in other words the non-ETS marginal abatement cost curve is relatively steep) the maximum amount of CDM offsets depresses the CO_2 price to 33.5 $US and there is no possibility for further cost reduction through trade with ETS (opposite to scenario *TRD*), where the CO_2 price is almost 10 $US lower. The overall excess costs of emission market segmentation are small for our reference baseline assumptions.

As expected, part of the CO_2 mitigation is achieved through energy savings (efficiency improvement) – total primary energy use goes down by 7.2% (scenario *CO2*) and 7.1% respectively (*TRD*). The renewables' share in power production goes up from 24.8% in the *BaU* to 29.4% in the *CO2* scenario. The reasoning behind is twofold. Firstly, the CO_2 value for power production which is covered under the ETS leads to a substantial decline in coal power generation together with a drop in overall electricity production. Secondly, the absolute level of the CO_2-free renewable power production increases by around 10%. Both effects are slightly stronger in the *TRD* scenario due to the higher price for CO_2 emissions in the electricity sector.

Table 5: Summary of main results of the scenarios for 2020

	TRD	*CO2*	*REN*	*EFF*	*CO2-REN*	*CO2-REN-EFF*
Welfare (% vis-à-vis *BaU*)						
Consumption	-0.17	-0.18	-0.17	-0.71	-0.20	-0.82
CO_2 Values (in $US) and Emissions (% vis-à-vis *BaU*)						
CO2 value ETS	25.5	24.4			9.4	15.5
CO2 value non-ETS	25.5	33.5			32.4	
CO2 emissions ETS	-20.5	-19.4	-11.6	3.4	-19.4	-19.4
CO2 emissions non-ETS	-5.0	-6.2	-0.1	-10.6	-6.2	-11.3
CO2 emissions total domestic	-13.2	-13.2	-6.2	-3.2	-13.2	-15.6
CO2 emissions CDM countries	-6.4	-6.4			-6.4	-5.0
20-20-20 Targets						
CO_2 (% vis-à-vis *BaU*)	-19.6	-19.6	-6.2	-3.2	-19.6	-20.6
Renewables share in electricity (%)	29.8	29.4	35.0	33.5	35.0	35.0
Energy use (% vis-à-vis *BaU*)	-7.1	-7.2	-0.8	-20.0	-5.6	-20.0
Energy Security Indicators (% vis-à-vis *BaU*)						
ESPI (price risk)	1.0	0.9	-1.7	15.9	-0.8	8.1
ESMI (import index)	-3.6	-3.8	-3.7	14.5	-5.6	2.9
EI (energy intensity)	-6.7	-6.9	-0.8	-19.1	-5.4	-18.9
ESI (composite index)	-5.6	-6.1	-2.5	-8.4	-6.3	-13.6

Next, we discuss the implications of pushing the renewables' share in power production which reflects the second target within the EU-20-20-20 package. The costs of achieving the renewable target in power production are in the same range like the costs for compliance with the CO_2 target. Renewable subsidies have a distinct impact on economy-wide CO_2 emissions which decline by 6.2%. This is about half of the domestic CO_2 reduction under *CO2* (13.2%) where a significant share of emission reduction requirements is offset through CDM. Note that the CO_2 reduction in scenario *REN* stems almost exclusively from the decrease of CO_2 emissions in the ETS sector through the targeted share of 35% renewables in power production together with the distinct decline in coal power production. Compliance to the renewable energy target involves a moderate decrease of primary energy use.

The reduction of primary energy use by 20% (from *BaU* levels) as mandated in scenario *EFF* through the imposition of a comprehensive primary energy tax is by far the most expensive 2020 target to reach. It works as a blunt restriction to the use of energy which exerts a downward pressure on wages and capital rents (align with decreased factor productivity) translating in a substantial loss of real income, i.e., reduced welfare from consumption. While CO_2 emissions decrease together with energy use in the non-ETS sector, it comes at first glance at a surprise that CO_2 emissions in the ETS sector increase. The reason for this is the phase-out of nuclear power production in scenario *EFF*. Since nuclear power plants have the lowest energy conversion efficiency of all electricity generation technologies they are hit hardest by the tax on primary energy. Despite the decrease in gross electricity production the phase-out of nuclear power plants implies an increase in output of CO_2-emitting coal and gas power generation. The renewable energy share in power production increases to 33.5% and thus comes close to the renewable target.

Scenario *CO2-REN* investigates the economic consequences when a renewable target share (35%) in power production is imposed on top of the explicit emission reduction constraints for ETS and non-ETS sectors. Subsidization of green power technologies induces excess costs if we only value the CO_2 target. With the CO_2 target stand-alone the share of renewable power production increases by five percentage points (see scenario *CO2*) to roughly 30%. An additional five percentage points increase towards 35% as mandated by scenario *CO2-REN* makes power production greener than necessary. The restrictive renewables' target drives down the CO_2 price in the ETS sector by more than 50% (compared to scenario *CO2*) as the CO_2 quota becomes less binding. Joint implementation of the CO_2 and renewables' targets decreases primary energy use by less than the compliance to the CO_2 target alone. The reason is that a larger share of emission reductions is achieved by a substitution across energy sources (fuel switching) compared to improvements in energy efficiency.

The simultaneous imposition of the three 20-20-20 targets (scenario *CO2-REN-EFF*) increases economic costs relative to the imposition of the energy efficiency target alone. While the renewables target is almost achieved by the efficiency target alone, CO_2 emissions in the ETS sector still must be decreased substantially. Although nuclear power production "only" drops by around 50% in this scenario and is not phased out completely since nuclear power contributes to achieving the emission reduction target. The CO_2 reduction target for the non-ETS sectors is already met through the efficiency target such that the price for CO_2 emissions in these sectors drops to zero. The additional welfare costs of the triple 20-20-20 scenario are relatively small as compared to the efficiency scenario *EFF* alone while the cost increase is substantial vis-à-vis compliance to the double targets of CO_2 emission reduction and renewable energy promotion. The cost gap widens further compared to fulfillment of the single CO_2 reduction target (and likewise the single renewable energy target).

We now turn to the implications of 20-20-20 policy regulation on energy security in the European Union. Section two introduced three indicators that can be used to measure three different aspects of energy security: the price risk to the fuel mix (ESPI), the importance of imports in fossil fuels (ESMI) and overall energy intensity of the economy (EI). Furthermore, the three indicators can be combined to a single composite indicator (ESI). While this allows monitoring a single number, the aggregation goes along with a loss of information – also in this case. Note that for each of the four indicators, a decrease in the value means an improvement in energy security.

The energy security price index (ESPI) takes up a value of 6106.5 points in the *BaU* scenario (see Table 2). In principle, the indicator can range between 0 (no price risk attached to the fuel mix) and 30000 (highest possible price risk attached to the fuel mix). Obviously, such an indicator on potential risks cannot be an objective assessment as it relies on subjective judgments concerning the classification of risks. Nevertheless, it can be informative to track changes of the indicator across the different scenarios and identify the reasons for these changes. The energy security import index (ESMI) in the *BaU* scenario reports that 50.9% of the primary energy used in the European Union are imported fossil fuels from abroad. The energy intensity takes up a value of 103.7. The composite energy security index (ESI) then yields as the value of 453.5 in the *BaU* scenario.

With the implementation of the CO_2 target alone (scenarios *TRD* and *CO2*), the ESPI increases slightly by around 1%. There are some favorable effects on energy security compared to the *BaU* due to the increase in the use of renewables (no price risk) and the decrease in the use of gas (medium price risk) in the non-ETS sectors. However, these effects are not enough to fully compensate the increase in the overall price risk from the significant reduction of coal use (low price risk). In power generation, the output of coal power plants decreases by almost 40% while the output of the other non-renewable generation technologies stays roughly constant. These effects together lead to a higher share of oil and a lower share of coal in the fuel mix of the CO_2 constrained scenarios and therefore to a higher ESPI. The other energy security indicators show an improvement compared to the *BaU*. The import index ESMI decreases by almost 4%, reflecting lower imports of gas and coal due to depressed fossil fuel demand. Energy efficiency improvements that lead to lower CO_2 emissions reduce energy intensity (EI) by around 7%. The composite ESI which combines the three former indicators drops by roughly 6%. Overall, the beneficial effects from CO_2 reduction on energy security appear rather modest.

In scenario *REN*, energy security measured by ESPI slightly improves compared to scenarios *BaU* or *CO2*. Since renewable energy gains at the expense of fossil fuels, the price risk of the energy mix decreases. Similarly, imports are reduced, leading to a decrease of the ESMI comparable to scenario *CO2*. The effect on energy intensity is negligible since there are no strong incentives to implement energy efficiency measures. In sum this leads to a smaller reduction of the composite indicator ESI as compared to the *CO2* scenario.

The strongest effect on energy security indicators results from the implementation of the energy efficiency target. Scenario *EFF* leads to an increase of the ESPI by 16.9% and of the ESMI by 14.5%. While the absolute levels of all fossil fuels go down, the relative shares of coal, gas and oil in total energy consumption increase, most notably gas with a share of 19% in total primary energy supply compared to 11% in the *BaU* scenario. The reason is the phase-out of nuclear power generation in this scenario which is mainly substituted by gas and partly by coal power generation. On the contrary, the energy intensity indicator EI decreases strongly by 19.1% as a consequence of the primary energy tax. The latter effect dominates the reverse implications in the other indicators within he composite ESI, leading to a reduction by 8.4%.

For scenario *CO2-REN*, i.e., the combination of the CO_2 target and the renewable energy target, the effects on the single indicators are more balanced than if only one of the two targets is implemented. Energy intensity is decreased somewhat less than in the *CO2* scenario alone since energy efficiency improvements are partly replaced by fuel switching. The composite effects is modest with ESI falling by 6.3%. The effects for scenario *CO2-REN-EFF* are less pronounced than for scenario *EFF* alone but still ESPI and ESMI increase due to strong decline in nuclear power generation. Together with the decrease in energy intensity, the ESI drops by 13.6%:

Overall, we find that the implementation of the CO_2 and the renewables targets of the 20-20-20 package leads to a decrease in the value of most of the various energy security indicators, implying a positive impact on energy security. However, the decrease of the indicators is very modest and the scenario outcomes are far off from EU energy autarky which might be regarded as the highest possible degree of energy security. The implementation of the efficiency target surprising leads to increased energy imports as well as increased price risks of the energy mix due to the phase-out of domestic nuclear power generation.

While the increase in energy security for most indicators and scenarios might be viewed as a desirable outcome by policy makers such a judgment is severely flawed. It is by no means clear how changes in energy security indicators should be valued by society or how it can be translated into welfare effects.

4.4 Sensitivity Analysis

In computable general equilibrium (CGE) analysis the impacts of policy regulation are quantified as adjustments in production and consumption decisions of rationally behaved firms and households. Technologies and preferences together with endowments thereby determine economic responses. For large-scale applications the lack of data prevents the econometric estimation of functional forms to characterize technologies and preferences. Therefore, CGE analysis builds on the use of sufficiently flexible constant-elasticity-of-substitution (CES) functions whose value shares can be calibrated from a single base-year economic dataset while elasticities are taken from the empirical literature. It should be noted that calibration is a deterministic procedure and does not allow for a statistical test of the model specification. Due to the reliance on a single base-year observation and exogenous elasticities, sensitivity analysis on reference data should be performed before concrete policy recommendations are derived.

Whenever policy measures apply to the future their impact must be measured with respect to a hypothetical business-as-usual (*BaU*) development without policy interference. The EU Climate and Energy Package requires its three major objectives – greenhouse gas emission reduction, renewable energy promotion, and energy efficiency improvements – to be achieved in 2020. Obviously, the costs of policy regulation will depend on the extent to which these 20-20-20 targets constrain the *BaU* development of the EU economy. Exogenous *BaU* assumptions do not only rule how far off the EU is from meeting its targets in 2020 but also the ease of adjustment through implicit changes in productivity and preferences along the baseline. For example, higher GDP growth projections will ceteris paribus lead to higher *BaU* emissions and thereby enforce more stringent emission reductions in order to comply with the 20% emission cutback requirement from historical 1990 emission levels. Likewise, optimistic assumptions on autonomous (costless) energy efficiency improvements can substantially lower the compliance costs to emission reduction or energy efficiency targets. Our central case simulation results in section 4.3 emerge from the reference growth projection by the

International Energy Outlook (IEO). We can perform sensitivity analysis for alternative views on future GDP, emissions and energy demand building on the IEO high economic growth scenario or alternatively on the IEO low economic growth scenario. The high (low) growth scenario implies higher baseline emissions and therefore the effective cutback requirements increases (decreases) vis-à-vis the reference case inducing higher (lower) adjustment costs for the climate policy scenarios. The cost ranking of the different policy scenarios and thus our conclusions on the implications of overlapping regulation and the excess burden of restricted where-flexibility remain robust.

The ease of substituting away from (i) greenhouse gas emissions with respect to the EU's emission reduction target, (ii) fossil fuel use (with respect to the EU's renewable energy target) and (iii) more generally primary energy (with respect to the EU's energy efficiency target) is to a large extent governed through the choice of cross-price elasticities between factors (capital and labor) and intermediate inputs (energy and non-energy inputs) to production. In our model parameterization we adopt sector-specific empirical estimates for cross-price elasticities by Okagawa and Ban (2008). Regarding sensitivity analysis on elasticities we keep with these estimates and focus on the implications of alternative values for so-called Armington trade elasticities which measure how easily imports can substitute for domestically produced goods. In our policy simulations, the trade elasticities affect the extent to which the EU's domestically produced goods is displaced by imports from outside the EU when unilateral EU climate policies raise the costs of EU-produced goods. The Armington elasticities imply product heterogeneity which leads to changes in international prices when a large open economy such as the EU changes domestic policy. As pointed out in the pertinent literature the induced secondary terms-of-trade effects can even dominate the direct (domestic) effects of policy interference: For example, the EU may be able to pass on the costs of emission reduction via higher product prices for energy-intensive goods to trading partners. In the sensitivity analysis we either halve or double the Armington elasticities provided by the GTAP database for traded commodities. In the absence of terms-of-trade effects, the costs of climate policy regulation move inversely with trade elasticities, because countries can more easily substitute away from emission-intensive inputs into production and consumption (as domestic and imported goods are closer substitutes). Depending on a country's initial trade structure, international spillovers may strengthen, weaken or even outweigh the unambiguous domestic policy effect associated with a change in trade elasticities. This is because the trade elasticity determines the extent to which domestic cost increases can be passed further to trading partners. With lower elasticities, a country importing emission-intensive goods from a trading partner with high domestic emission taxes (or likewise quota prices) is less able to substitute away from the more expensive imports to the cheaper domestically produced goods. While the choice of Armington elasticities affect both the calibration of the model to exogenous *BaU* projections as well as the trade responsiveness to climate policy measures all of the qualitative findings from the central case simulations remain robust.

Our assessment of the EU Climate and Energy Package includes "sensitivity analysis" on the additional costs of segmented EU emissions markets (default setting – see scenario *CO2*) compared to EU emissions trading across all segments of the EU economy (scenario *TRD*). Beyond comprehensive where-flexibility within the EU, the costs of emission reduction can be further reduced if the EU cancels supplementarity restrictions on CDM imports. On the other hand, the economic gains from project-based abatement measures may be reduced by transaction costs associated with abatement projects in developing countries. Such transaction costs can arise from a variety of activities associated with market exchange, including search and information acquisition, negotiation, monitoring or enforcement of contracts. In our central case simulations we incorporate country-specific estimates of project-based transaction costs for CDM credits by Wetzelaer et al. (2007). Transaction costs then enter the model calculations as an absolute premium on marginal abatement costs of CDM host countries. In the sensitivity analysis we investigate how the impacts of implementing the EU Climate and Energy Package change with alternative assumptions on the magnitude of transaction costs. As expected, lower values for transaction costs decrease implementation costs for the EU while higher values increase costs – yet for a larger range of transaction cost estimates the changes in results compared to the central case simulations are rather negligible.

5. Conclusions

In 2009 the European Union has launched the Climate and Energy Package. The package includes explicit objectives to curb greenhouse gas emissions, promote the use of renewable energy and increase energy efficiency. All three objectives are stated in 20% metrics to be achieved in 2020: a 20% greenhouse gas emission reduction from 1990 emission levels, a 20% share of renewable energy use in gross final consumption of energy and a 20% reduction of primary energy use vis-à-vis the 2020 business-as-usual level. The objectives are thus colloquially referred to as the EU-20-20-20 targets. The key driving force behind the Climate and Energy Package was the EU's ambition and commitment to play a leading role in the fight against climate change. Another – much more vague – policy justification of the targets and measures endorsed within the package is the pursuit for more energy security.

From an economic perspective policy interference into markets should aim to improve the market outcome – either in terms of allocational efficiency, distributional equity, or macro stability. If the yardstick is allocational efficiency – as put forward by the EU policy makers in the case of the Climate and Energy Package – then there must be a case of market failure and a convincing argument that policy interference can cure market inefficiencies. Regarding the climate policy dimension of the package, the need and effectiveness of appropriate policy measures to internalize the greenhouse gas emission externality is evident. One can debate whether a 20% reduction target by 2020 is a sensible number under marginal cost-benefit considerations but in view of uncertain estimates for climate change damages, the validity of risk aversion (i.e. a precautionary approach) and recent recommendations by natural science on "necessary" emission reduction efforts the EU climate policy target seems to be in place. This judgement though is difficult to maintain for the remaining two targets, i.e. the administered increase of renewable energy use and the decrease of primary energy use. What are the market failures that call directly for an increase of renewable energy and a decrease of primary energy use? Why should an optimal or cost-effective change amount to 20%?

If we focus on the climate policy target alone, then one would expect that efficient policy instruments such as a EU-wide cap-and-trade system will favor the use of "zero-emission" renewable energies and discourage the use of primary energy. But rather than EU bureaucrats prescribing the level of changes in renewable and primary energy use, the markets would endogenously work out cost-effective adjustments to meet the overall emission cap.

Energy security, which is brought forth every so often as another argument for promoting renewable energy and decreasing primary energy use, lacks a clear economic efficiency rationale. There is no unique notion and concept of energy security and there is hardly an attempt to provide some cost-benefit underpinning for claims towards more energy security. Drawing on fundamental economic insights of comparative advantage and gains from trade and specialization, the implicit policy proposition that a move towards more energy autarky would be necessarily beneficial is odd. Clearly, one should be worried about the dependence on foreign energy (notably oil) sources if strategic action or political tensions in other countries can substantially affect the price and availability of energy imports. However, if private action can not hedge at a socially desirable level it must be made clear why and to what extent public policy interference will do better. The energy security indicators presented in this study can at least help to sort out different aspects of energy security and give policy discussions a hint on what might happen when the 20-20-20 targets are implemented. However, the indicators have no direct link to economic welfare, so policy interventions into energy markets need more specific justifications than only improving the energy security indicators.

Apart from missing a comprehensive rationale for the triple EU-20-20-20 targets the problem with the EU Climate and Energy Package is the actual policy implementation. Economics provides some guidance on the cost-effective design of policy interference to meet a given target at least costs. Rules of thumb do not only suggest that market-based regulation usually outperforms command-and-control measures but that the number of instruments should be aligned with the number of targets. Along the example of EU emission reduction, the simple textbook recommendation is to equalize marginal abatement costs across all emission sources which can be easily accomplished through EU-wide emissions trading. Yet, in practice EU emission markets have been segmented and are subject to a myriad of measures which is likely to make EU emission reduction much more costly than necessary. The tangle of policy instruments and (in part unclear) targets endorsed through the EU Climate and Energy Package runs the risk of counterproductive overlapping regulation with substantial excess costs to EU citizens.

In this report, we have used model-based analysis to assess how various policy measures put forward by the EU affect the 20-20-20 targets and energy security indicators. Our quantitative framework allows to put some price tags on the isolated or combined use of policy instruments taking into account important spillover and feedback effect through economic markets. Obviously, models are only a crude approximation of the real world so we caution against too literal an interpretation of the numerical results. Furthermore, the economic focus of our model-based analysis may be much too narrow. In the end, the decisions how to resolve potential trade-offs must be taken on the basis of societal values and political decisions but we believe that consistent and transparent model analysis can contribute to a more informed policy debate and hopefully better regulation.

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