Project Acronym: **ENTRACTE**
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Content

1 Executive summary

Climate policy-making in Europe today is complex. The climate and energy policy in EU and its Member States is characterized by multiple targets and a myriad of instruments. All these targets interact through the energy system and most interactions lead to distortions and increase the costs of reducing GHG emissions. However, additional market failures, policy targets, and policy failures can provide rationales for complementary policy instruments, additional to a carbon price.

The principal aim of **ENTRACTE** was to understand climate and energy policy interactions in Europe, and acknowledging those interactions, to conduct research that would support the identification of a feasible and effective policy mix to achieve Europe's ambitious long-term climate targets. At the core of the project was a coherent assessment of Europe's climate and energy policy instruments.

This assessment shows that the European Emissions Trading Scheme (EU ETS) has reduced European carbon emissions by as much as 15% below what they would otherwise have been in the absence of this mechanism. Although most sustained recession in Europe since decades has been the single largest contributor to reducing the levels of carbon emissions from what they were expected to be at this point in time, novel research approaches show that the EU ETS had a measurable effect on reducing emissions.

Innovation is the key to long-term cost reductions and our research shows that existing climate regulation, of all kinds, has stimulated innovation in emission-reducing technology. There is, however, no evidence from the research that economy-wide productivity has been either increased or decreased by this regulation and the associated innovation that it has triggered within the market.

The **ENTRACTE** research focused in on issues involved in implementing border carbon (or tax) adjustments should they become necessary as EU ambition increases and should major trading partners not take commensurate measures. The research shows that the design requirements for effective border carbon (or tax) adjustments are extremely challenging, and identifies an immediate need to develop the means to track embedded emissions and understand the complex domestic effects of such adjustments.

Policy interactions are numerous and unavoidable. They are a fact of life in policy and no different in effect than market interactions. Our research shows that they can as easily reduce costs, by overcoming market barriers, as they can increase costs, by constraining cheaper options. It shows that there is indeed a rationale for a policy portfolio where its different components address different market failures. However, it also shows that in order to be cost-efficient, those additional policies need to be calibrated very well. The most important intervention is to price GHG emissions correctly. Adding new policy instruments has therefore to be done with the utmost prudence. Otherwise the policy mix risks becoming a policy mess.

2 Description of the project context and the main objectives

The climate and energy policy architecture in the European Union (EU) and its Member States is characterized by several targets and a myriad of instruments. Three main pillars constitute the European policy environment. The so-called 20-20-20 targets, defined in the EU Climate and Energy Package, have been adopted in 2009. They consist of a 20% reduction in EU greenhouse gas (GHG) emissions relative to 1990 levels, a 20% share of renewables in EU energy production, and 20% energy savings by 2020 in comparison to a baseline projection. This triangle of targets has been iterated by the decision of the European Council on the 2030 Framework for climate and energy policy that again defines targets in the these three domains. In 2030, GHG emissions shall be at least reduced by 40% relative to 1990, renewables shall have a share of 27% in EU energy consumption, and there is also an indicative target for energy savings of 27% in 2030.

Additionally, several EU Member States have own targets, somewhat decided independently from the policy processes on the EU-level. The **ENTRACTE** project took stake of the current EU climate policies and targets (Landis et al., 2013). It shows for example that Denmark aims for a 34% GHG reduction in 2020. The UK target a 80% GHG reduction by 2050. Germany has, by 2020, pledged to reduce its GHG emissions by 40% (relative to 1990), boost its share of renewable in electricity generation by 35%, and reduce (relative to 2008) its primary energy supply by 20% and total electricity consumption by 10%. Table 1 gives an overview about the targets by the EU as a whole and of selected member states.

	GHG Emissions	**Renewable Energies**	**Energy Efficiency**
EU	Reduction of 20% by 2020 and 40% by 2030 relative to 1990.	20% in 2020, 27% in 2030.	20% energy savings by 2020 compared to baseline, 27% in 2030.
Denmark	Reduction by 34% in 2020 relative to 1990	35% in 2020, 100% in 2050.	
France	Reduction of 40% (75%) by 2030 (2050) relative to 2005.	40% in 2030.	Reduction in final energy consumption by 50% in 2050.
Germany	Reduction of 40% by 2020 and 80% by 2050 relative to 1990.	18% (35% in electricity generation) by 2020, 30% (50%) by 2030	20% energy savings by 2020 compared to baseline.
UK	Reduction by 80% in 2050, derived from this: -50% by 2025 relative to 1990.		

Table 1: Climate and energy policy targets of the EU and of selected Member States. Source: Landis et al. (2013)

The objective of **ENTRACTE** was to take stock of instruments, assess them with the best available methods, and derive conclusions on policy interaction and the composition of policy portfolios. In a first step, we took in Work Package (WP) 1 stock of the current climate and energy policy landscape in the EU.

2.1 Greenhouse Gas Emission Reduction Targets

In 2009, the EU adopted a plan to reduce its emissions by 20% relative to 1990 in 2020. However, the EU-28 GHG emissions (excl. LULUCF) in 2009 have already decreased by 17.5% relative to 1990, mainly due to the slump and restructuring of the economies in Eastern European Member States and the economic decline due to the global financial crisis (EEA, 2014). Figure 1 shows the GHG emissions of the EU-28 from 1990 to 2012.

In order to achieve this target, actions by individual member states and centralised actions on a pan-European level are foreseen. Thus, the 20% GHG reduction target is broke down into a target for sectors regulated under the pan-European instrument of the EU Emission Trading System (EU ETS). This covers the sectors power and heat generation, energy-intensive industry and commercial flights to and from the EU, Iceland, Liechtenstein and Norway. Currently, the EU ETS covers about 45% of EU’s GHG emissions.

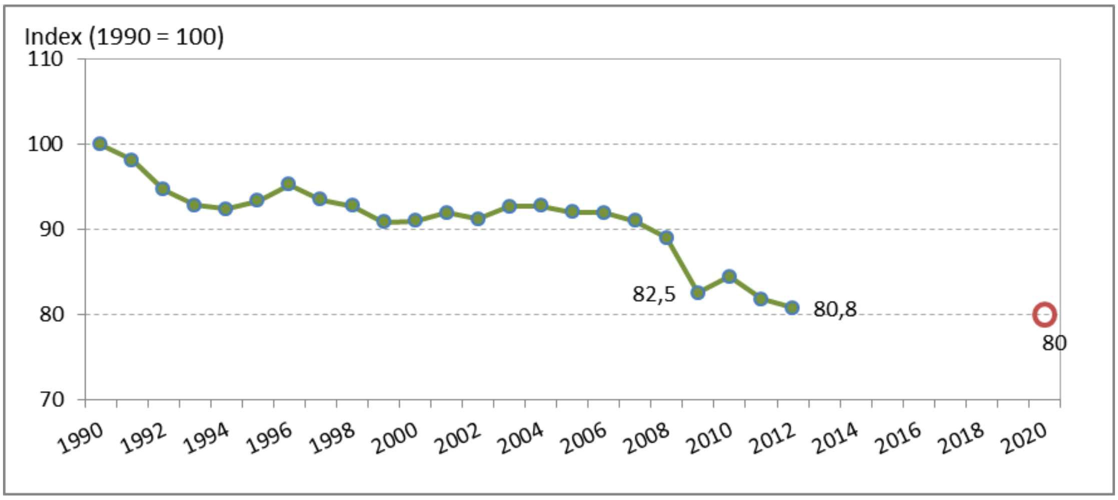

Figure 1: EU-28 GHG emissions 1990–2012 (excl. LULUCF). Source: EEA (2014)

The remaining emissions are subject to individual Member State actions in the remaining sectors of the economy such as transport (without intra-EU civil aviation), buildings, agriculture, and waste. The multiple layers of emission reduction targets are supplemented with additional targets set by some Member States, in some cases legally binding, in some cases indicative. For example, France has the goal to reduce its GHG emissions by 40 % in 2030 and the United Kingdom aims for a 50% reduction until 2025.

This indicates how complicated the policy landscape is just in the domain of GHG emission reduction targets. An analysis of the International Energy Agency's (IEA) Policy and Measures database shows more than 110 active GHG reduction policies in force in the EU and its Member States (Landis et al, 2013). The Member States measures range from energy and fuel taxes to voluntary agreements with certain sectors in the economy. It is understood that a simple counting of policies is *per se* not very informative regarding the stringency of the individual measures. However it underlines the picture of a complex landscape, making it quite obvious that those policies cannot be analysed individually but have to be put in perspective to each other.

2.2 Renewable Policies

There is a broad political and scientific consensus that renewable energy has to play an important role in the pathway to a low-carbon energy system. This materialises in the Renewable Energy Directive 2009/28/EC, which sets binding specific national targets for each EU Member State concerning the share of renewable energy by 2020, ranging from 10% in Malta to 49% in Sweden. Each Member State is also required to have at least 10% of their transport fuels coming from renewable sources by 2020. The achievement of these individual targets shall ensure that the EU as a whole reaches a 20% share of energy from renewable sources by 2020.

The first round of National Renewable Energy Action Plans submitted in 2011 to the European Commission (EC) in order to evaluate the pathway to the target showed a positive development: In 2012, 13% of the European energy consumption stems from renewable sources, rising from 8% in the year 2000. However, the current economic situation might affect these plans negatively. Some countries such as Spain and the Czech Republic cut financial support for renewables.

But decisions are not taken on the EU level only and Member States have their own agenda. We draw again from the German example: The EU Renewables Directive sets for Germany a target of an 18% share of energy from renewable sources in 2020. In addition, the German government aims for a share of renewables in electricity generation of at least 35% in 2020 (and 50% in 2030). Also other member states have their own targets and sub-targets. This is reflected in around 275 policies and measures that are in place, either regulation of the EC or the individual member states and address renewable energy sources (IEA, 2014).

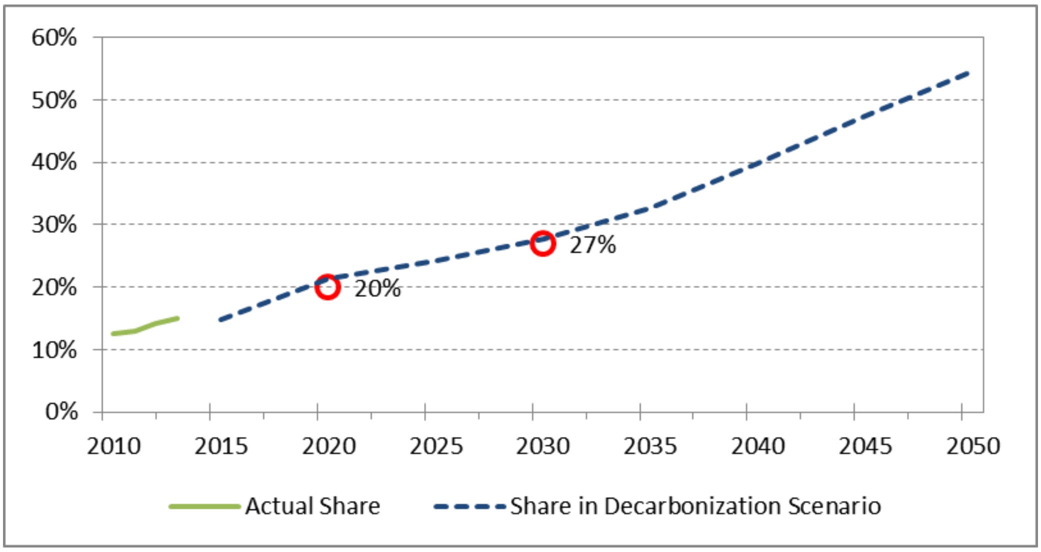

Figure 2: Share of renewables in gross final energy demand. The green line shows actual shares, the dashed blue line shows the cost-efficient share in the Diversified Supply Technologies Scenarios of the EU Energy Roadmap 2050 that is consistent with an 80% GHG emission reduction in the EU by 2050. The red circles indicate legislated EU-wide renewable targets. Sources: EEA (2014), EC (2011).

In the transport sector, almost all Member States implemented a quota for biofuels in total fuel use. Three different types of instruments have been considered to incentivize either directly renewable energy supply in the electricity sector (RES-E) generation or support upstream industries that produce the necessary technologies: feed-in tariffs (FiTs), feed-in premium (FiP) and renewable portfolio standards (RPS).

Most European countries draw on FiTs as the primary instrument in order to promote RES-E production. FiTs provide RES-E producers with long-term contracts that guarantee access to the grid at a fixed price that normally decreases over time. The remuneration generally differs among technologies, with higher payoffs for more expensive technologies such as photovoltaic energy and offshore wind energy. The stability of the cash flow makes it attractive for investors but can also generate huge costs for state budgets or electricity consumers if the scheme is "too" attractive. Since FiTs guarantee a fixed price, producers are immunized against price signals from electricity markets, potentially leading to market distortions from an unresponsive electricity supply.[1]

FiPs induce more responsiveness, but in return give less certainty for investors. FiPs provide an output subsidy per kilowatt hour of electricity produced, often differentiated by technology. Since producers face the wholesale price plus the subsidy, they have generally higher incentives to respond to demand and price changes, making markets more flexible. Denmark, for example, operates with such a scheme.[2]

Renewable portfolio standards (RPS) are similar to non-technology-specific, uniform FiPs. RPSs define quotas for RES-E and create a market where the obligations to generate a certain amount of RES-E can be traded. Energy suppliers must purchase certificates or otherwise generate the necessary amount of RES-E. Such systems are used in several EU Member States, inter alia United Kingdom and Sweden, but the characteristics differ in the details – sometimes for example treat different technologies differently.

FITs, FIPs and RPSs incentivize directly the generation of RES-E by downstream users of technology. Another important component of most policy portfolios is the support of Research and Development (R&D) activities by upstream producers of RES-E technologies. On an EU-wide level, the NER300 program might serve as an example. This program is funded from the sale of

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[1] For example, a typical roof-top PV system in Germany with 10-40 kW installed in July 2015 got about 12 c/kWh in the first month and decreasing by 0.5% each month. At same time average whole sale price for electricity was 3.5 c/kWh.

[2] As an example, under this scheme, a Danish onshore wind plant commissioned after beginning of 2014 received a guaranteed bonus of 0.25 DKK (approx. 3 c) per kWh for certain number of load hours.

300 million emission allowances from the New Entrants' Reserve (NER) set up for the third phase of the EU ETS and aims at selected supporting low-carbon energy demonstration projects. With the implementation of the 2030 Framework for Climate and Energy this program will be updated to NER400, having more allowances in its stock.

2.3 Energy Efficiency Target

The third EU target is known as a 20% improvement in the EU’s energy efficiency. But it is actually defined as a 20% energy savings target compared to the projected use of energy in 2020. Under the 2030 Framework for Climate and Energy, an indicative energy savings target of 27% by 2030 has been enacted. This target will be reviewed in 2020 and perhaps adjusted to a 30% target by 2030.

This EU wide target has not been translated into binding targets for member states yet. The EU implemented so far only a fragmented set of single measures (such as the controversial ban of conventional light bulbs). It seems rather unlikely that this target will be reached as the projections indicate that given the implementation rates of current energy efficiency policies in the Member States only, the EU will achieve energy savings of around 18-19% in 2020 (EC, 2014).

Furthermore, while the economic crisis contributed to this decrease in energy consumption, it has also negatively impacted energy efficiency investment decisions. As a response, the Commission has adopted two new initiatives – the Energy Efficiency Plan and the Directive 2012/27/EU on energy efficiency that establishes a set of binding measures such as a given energy efficient renovation rate for governmental buildings – aiming at stepping up efforts towards the 20% target.

However the target architecture in this domain is also more complicated and contains several layers that include own targets for Member States. Using the same example again, Germany has set a target of -20% primary energy consumption versus 2008, a 10% reduction in total electricity consumption, and a 10% decline in primary energy supply in the transport sector. All European efforts are reflected in more than 440 policies that are tabled as measures directed to improve energy efficiency (IEA, 2014).

2.4 International Competitiveness Measures

The role of the EU as a frontrunner in the implementation of climate and energy policies has always been accompanied by concerns about the consequences for the competitiveness of its industry. Hence, there is a fourth, implicit policy target that in addition shapes EU’s climate and energy policy: The implemented actions shall not endanger the competitiveness of Europe’s industries. Since losses in competitiveness might also reduce the effectiveness of EU climate policy target. So-called “carbon leakage” would compensate to some extent the emissions abatement efforts in Europe by increasing emissions in regions with less stringent or non-existing emission regulations.

To safeguard Europe’s competitiveness, a large fraction of emission allowances in the EU has been given for free to industrial emitters deemed at a larger risk of losing competitiveness from compliance costs with the EU ETS. The third phase of the EU ETS, running from 2013 to 2020, saw a harmonisation of the rules which sectors are entitled to be get free allocation. The EC considers two factors for the valuation of leakage risk: On the one hand cost of carbon as a share of gross value added, on the other hand the trade intensity of the sector with non-EU countries. This results in general to a free allocation of 80% of the necessary allowances for the manufacturing sector, with a decreasing share to 30% in 2020.

2.5 ENTRACTE’s main objectives

This brief assessment indicates how diverse the climate- and energy policy landscape in Europe is. In order to reach the respective targets cost-efficiently policy instruments have to be chosen, implemented and adjusted taking each other into account to minimize distortions. Taking this into account in the assessment of policies is therefore key in order to create an efficient and effective policy portfolio. More specifically, the **ENTRACTE** project has four main objectives:

i) All these targets interact through the energy system. A higher penetration of renewable energy generation and higher energy efficiency reduces the emission of GHG, contributing to the emission reduction achievements. Conversely, stringent policies to meet GHG reduction targ To coherently assess the most important climate policy instruments with the full range of economic research methods. **ENTRACTE** looks at the EU ETS and additional policy instruments like energy efficiency standards, renewable policies, carbon taxes, innovation policies, and trade measures.

ii) To gain a deeper understanding of the interactions between multiple climate policy instruments. **ENTRACTE** provides a deep understanding of how climate policy instruments interact with each other and with related policy instruments. Therefore, interactions of different climate policy instruments are explicitly considered throughout the analysis of the particular policy instruments.

iii) To provide an analysis that takes into account the barriers to the implementation of climate policy instruments. **ENTRACTE** takes the “real-world” and its imperfections comprehensively into account and considers practical barriers in the implementation (like information asymmetry, uncertainty, political and legal constraints, behavioural aspects).

iv) To identify mixes of climate policy instruments that provide an effective, efficient and feasible overall climate policy. The individual findings are taken as basis to identify effective, efficient, and feasible policy instrument mixes.

The figure 3 summarizes the concept of the **ENTRACTE** project. It shows how **ENTRACTE** aims to address our goals, assessing coherently the most important climate policy instruments, understanding their interactions, taking barriers to implementation into account, and identifying efficient, effective, and feasible policy portfolios.

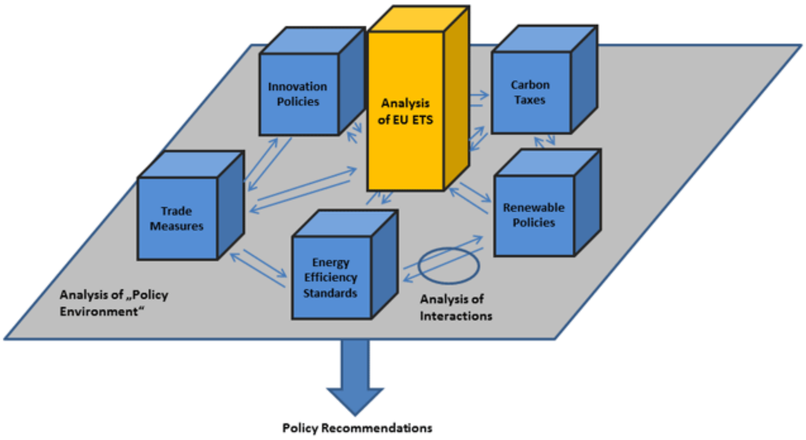

*Figure 3: The structure and idea behind **ENTRACTE***

3 Description of main S&T results / foreground

3.1 Emission Trading

3.1.1 Evaluating the EU ETS

Assessing the performance of the EU ETS has been one of the core tasks of the **ENTRACTE** project. The economic crisis reduced demand and thus emissions. Hence, it is not straight forward to identify the amount of emission reductions due to the implementation of the EU ETS. Using comprehensive firm-level data on companies regulated across Europe as well as French plant-level data for manufacturing firms, Dechezleprêtre (2015) analysed the contribution of the EU ETS to actually realized emission reductions.

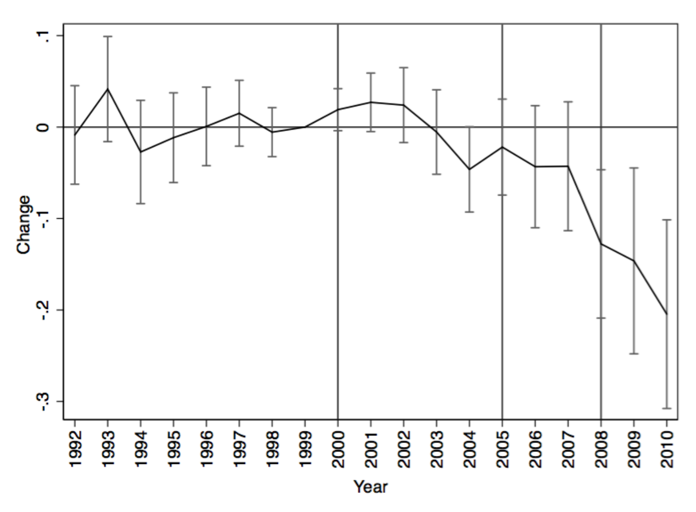

Figure 4: Impact of EU ETS on (log) carbon emissions. Source: Dechezleprêtre (2015)

In order to analyse the impact of the EU ETS on energy consumption and thus on carbon emissions, governmental micro-data has been collected and analysed. The focus was mostly on gathering and analysing data from France, but also on collecting and analysing data from the UK and Belgium. The French data includes the EACEI (Annual survey of energy consumptions in the industry), a survey conducted until 2008 by the Service des études et des statistiques industrielles (SESSI) of the ministry in charge of manufacturing, which provides quantities and values of energy consumed by energy type as well as the different usages of each type of energy. It also includes the Enquete Annuelle des Entreprises, the French annual business surveys data, also conducted by SESSI, which is available for the period 1993 to 2007. This dataset provides balance-sheet data including turnover, employment, capital, and aggregate wages as well as information about firm location and industry classification. The resulting dataset includes 5,957 plants within 4,589 firms. 287 firms and 384 plants are part of the EU ETS. With this data at hand, parametric and non-parametric statistical techniques have been used to analyse the impact of the EU ETS on the energy consumption and competitiveness of French companies.

The analysis of French installations shows that regulated plants reduced emissions by an average of 15.7% between 2005 and 2012. Further the analysis points out that the most important abatement option has been a switch from coal and oil to gas. Moreover, the econometric analysis finds no evidence at the European level that the EU ETS had any impact on turnover or employment level of regulated firms, suggesting that the EU ETS has reduced carbon emissions without jeopardizing the competitiveness of the companies regulated under the EU ETS.

Another important issue are transaction costs. The analysis carried out in **ENTRACTE** by Heindl (2015) reveals that transaction costs have only a moderate impact on marginal permit prices, implying no substantial market distortions. Whereas the study identified substantial impacts on average costs in particular for small and medium enterprises (SMEs), leading to a rather passive and compliance orientated behaviour of these emitters without efforts to improve their carbon efficiency.

3.1.2 Monitoring and Enforcement

However, the integrity and the success of the EU ETS relies upon consistent implementation of monitoring and enforcement across all participating states. Research conducted in **ENTRACTE** by Verschuuren and Fleurke (2014) shows that compliance practice in the different Member States varies greatly due to differences in underlying principles of enforcement strategies, institutional settings and funding. Although it can be concluded that over the years between the enactment of the first legislation establishing the EU ETS in 2003 and today, a wide range of revisions in the regulatory system facilitating the EU ETS have been implemented, all aimed at improving the robustness of the system through centralization and through tightening the rules on monitoring and compliance. Despite these revisions, checking compliance still is mainly in the hands of national institutions of the 28 Member States. The effectiveness and reliability of the ETS, therefore, partly still depends on each of their effort. A lack of compliance in one or a few Member States may harm the functioning of the ETS in the entire EU. It can also be found that the functioning of the ETS compliance practice in the different Member States varies greatly. This is due to differences in underlying principles of enforcement strategies, institutional settings and in funding. While compliance rates are currently high, efforts should be afforded to ensuring more harmonized practice with a view to likely future price increases of allowances.

3.1.3 Structural Reforms

Probably the biggest reform between Phase 3 and 4 of the EU ETS is the implementation of a so-called Market Stability Reserve (MSR). As it stands, the supply of allowances in the EU ETS is determined within a rigid allocation programme. The MSR intends to make the allocation of allowances flexible thus it can adapt to changes, such as economic shocks and technological advancements. The challenge for policymakers is to design a flexible system that helps regulate a market affected by future uncertainty, whilst also limiting the complexity of that system. Taschini et al. (2015) found that only long-term structural reforms – such as the introduction of an MSR – can incorporate the flexibility required by the EU ETS. It is crucial to clarify the specific objectives of such a mechanism. If the MSR is primarily aimed at tackling future extreme and unanticipated variations in allowance demand, the instrument can indeed redistribute abatement efforts across the compliance phase and thus reduce total compliance costs from otherwise delayed abatement decisions.

All MSRs respond to emissions (quantity) shocks, but to a different degree; MSRs based on price-trends are the least active. By withholding or injecting allowances, volume-based and mean-price-based MSRs can re-distribute abatement efforts across the compliance phase and thus help reduce total costs from the otherwise delayed abatement.

All else being equal, total abatement efforts are increasing with the MSR size, which depends on threshold levels and intervention quantities. A higher (lower) volume-based (price-based) withholding threshold reduces the pressure on total abatement required; a lower (higher) volume-based (price-based) injection thresholds increases the pressure on total abatement required. A rise (drop) in the withholding (injection) quantity increases the pressure on the total abatement required. In all MSR sub-cases but one, the reserve permanently withholds some allowances from the market. All else being equal, the higher (lower) the price (volume) injection threshold, the higher the permanent withholding by the price-based (volume-based) MSR. Permanent withholding increases aggregate compliance costs. In the modelling, the highest permanent withholding is observed for the mean-price MSRs. These MSRs also correspond to the highest aggregate compliance costs.

3.1.4 Sectoral and regional expansion

Another area of reform in the EU-ETS could be its possible sectoral and regional expansion. **ENTRACTE** analysed these two issues.

Regarding sectoral expansion, different policy designs to price EU agricultural GHG emissions have been investigated. One of the main insights of the work on the pricing of agricultural emissions is that if these emissions were to be priced, then due to the heterogeneity of the sector and barriers, it would be necessary to implement different policy instruments across actors and emission sources as well as a gradual phase-in.

Regarding regional expansion the linking of REDD+ offsets with carbon markets has been studied. This would be relevant in case of linking between the EU ETS (where REDD+ offsets are not allowed) and ETS schemes where offsets are already traded. The goal of the study was to model the impact of linking REDD+ with carbon markets on low-carbon investments. In a real options analysis of firm-level investment decisions, market linkage designs (e.g. optimal REDD+ quota) that stimulate private investment into low-carbon technology have been identified.

The results on linking to REDD+ illustrate the crowding-out effect of relatively cheap offsets: while investment in wind is increasing over time, wind investments are higher when the firm does not have the option to use REDD+ offsets. Yet, several important insights emerged from these results. First, the strength of the crowding-out effect hinges critically on the volatility of prices of REDD+ offsets and ETS permits. In a nutshell, investors will be more willing to invest into capital-intensive low-carbon technologies if carbon prices are more certain. Second, the results show more wind investment when ETS and REDD+ prices are highly correlated. A high correlation would occur if the REDD+ scheme was integrated in the global carbon market as it is currently the case for CDMs. A low correlation would emerge if REDD+ remains a segmented market, in which REDD+ prices mainly reflect opportunity costs of other land use (i.e. forgone agricultural returns). The intuition is that under a low price correlation offset usage becomes more attractive because it offers risk diversification opportunities. As a consequence, the crowding-out of wind power investment is more pronounced. The policy implication from this observation is that a market-based (rather than based on opportunity costs) REDD+ mechanism is more likely to be effective in inducing low-carbon investments.

To achieve ambitious climate policy objectives, economic analyses strongly suggest that regional flexibility in reducing emissions is vital to ensure low mitigation costs. Hence, linking of the EU ETS with other emission trading systems is an important building block in any long-term evolution of regional climate policy. An important aspect that has so far been neglected in the literature is the question how the linking of the EU ETS with a potential Chinese ETS would affect the co-benefits of CO2 mitigation, the abatement of local pollutants such as SO2, N2O and particulate matter (PM). To this end, the computable general equilibrium model PACE was applied. PACE is a multi-sector, multi-region computable general equilibrium (CGE) model of global production, consumption, trade and energy use.

Reductions in Chinese CO2 emissions by means of an emissions trading scheme can provide co-benefits with respect to declining emissions of other greenhouse gases and local pollutants. Linking the Chinese ETS with the EU ETS even increases these co-benefits depending on the amount of allowances that are traded between the EU and China. Due to lower marginal abatement costs in China, a link between the EU ETS and the Chinese ETS further reduces CO2, and hence SO2, N2O and PM emissions. This result is of particular importance for China since local pollutants such as SO2 and PM, which causes tremendous health problems, can be reduced through the change of the energy mix induced by the introduction of binding CO2 reduction targets and even more through the linkage with other ETSs due to relatively low marginal abatement costs.

3.2 Energy Policy

3.2.1 Energy efficiency policies

The effectiveness of energy efficiency policies in saving energy and greenhouse gas emissions has been in the focus of **ENTRACTE** as well. The results from three different approaches to energy efficiency improvements find support for the hypothesis that energy efficiency obtained in some processes has considerable *rebound effects*, i.e., that the final energy and emission reductions are smaller than immediate, technical potentials.

This is related to a variety of behavioural and systemic responses to the efficiency improvements. For example, energy efficiency improvement in residential heating means that less energy is used for obtaining the same indoor temperatures. The money saved can be used for increased consumption, and part of this can include consuming more comfort in terms of higher indoor temperatures; particularly so since this good has become less expensive because of the efficiency improvement. These effects will counteract the immediate energy saving of the efficiency improvement and represent a *rebound effect*. If the net energy use of households nevertheless falls, rebound effects may also occur outside of the residential sector, because the market price of energy will tend to drop. That will stimulate energy use in other sectors of the economy.

Bye et al. (2015) analyse energy use in five European countries (Germany, Spain, Italy, France, the UK) in the period 1995-2009, identifies rebound effects related to energy efficiency in a large variety of industries, as well as transportation and heating in households. It shows that rebound effects emerge for all the five EU economies considered and are in the range of 40-70%, with higher estimates for production sectors than for the households. In other words, more than half of the technical potential was counteracted by income and substitution effects which shifted the input mix in production towards energy and increased the actual economic output of the industry.

The results are obtained by comparing factual energy use with a counterfactual situation without any (direct) energy technology improvements, thus identifying the magnitude of rebound. The study is also performed for industries when assuming a counterfactual unchanged productivity for other factors of production, as well. For example, all factor productivity improvements serve to decrease unit production costs, thereby stimulating output and increasing energy demand as a rebound effect. In our European cases we find these effects to be strong; adding them lead to more than 100% energy rebound (so-called *back-fire*).

The rebound effects vary somewhat among the five European countries in the study. The table below shows the energy technology rebound and the all factor rebound for each country:

Country	Energy, only	All factors
UK	70	150
Spain	60	180
France	60	100
Germany	50	120
Italy	40	180

While much of these differences are explained by different industry patterns, there also seems to be differences among the countries when comes to the industry-specific energy use and rebound effects.

The analysis presented here shows that energy use may not decrease as a result of technological efficiency gains. Further, as long as large part of the energy use is based on fossil sources, rebound effects will counteract greenhouse gas mitigation efforts. Decarbonisation of the energy system needs to be pursued along with energy efficiency effort in order to obtain climate goals.

ENTRACTE looked also at economy-wide rebound effects of regulating energy efficiency in residents. This is done by applying a large-scale macroeconomic model that is able to track a variety of indirect effects on energy use in the wake of energy efficiency regulations in order to decompose the rebound effects into various mechanisms at play. In contrast to most studies of rebound effects, the study accounts for the costs borne by the households when facing energy efficiency regulations. The costs are estimated from bottom-up information on technological options.

The case is the Norwegian economy by 2030. Norway has climate policy targets corresponding to the EU and aspires for a joint implementation with the EU. The intention is to keep costs of greenhouse gas mitigation as low as possible by participating in the EU ETS and other flexible mechanisms for the non-ETS emissions. We have assumed full flexibility across borders, so that the EU ETS price applies in all countries, as do a common marginal cost of abatement for the non-ETS sectors. While the EU has announced a 27% energy efficiency target, the interpretation of this target is not yet settled. In this study two alternative interpretations are used: (i) a cap on energy use (ii) a cap on energy use per housing service, both corresponding to a 27% reduction from business as usual.

The rebound effect of setting a cap on residential energy use is found to be 37%. One factor that contributes to lower the rebound effect is that the study accounts for costs of improving energy efficiency for the households. The estimated costs of the caps are equivalent to introducing energy tax rates of around 175%. This means that households themselves face a significant income reduction and a large boost in housing costs, both contributing to decrease rebound. The reason for the substantial rebound still obtained is that energy prices fall by 16%. So do prices of labour and capital, first of all due to lower demand for dwellings. The result is a vast expansion of the electricity-intensive process manufacturing, which increases their electricity demand by 35%.

Even if clean hydropower is the main energy source in Norwegian households, national greenhouse gas emissions increase by 2.4%. The reason is that lower electricity demand reduces electricity prices for manufacturing industries. They respond by are expanding their output and increasing process emissions that cannot be abated by substituting with electricity.

If the 27% cap is rather set for the energy intensity than for the energy use, results are not much affected. However, capping energy intensity excludes the possibility of reducing energy by reducing housing services, i.e., reducing the number or sizes of the rooms in the dwelling. This makes the energy intensity regulation somewhat more costly, and all changes increase slightly, including the economy-wide welfare reduction (1.3% versus 1%) and rebound effect (40% versus 37%).

ENTRACTE also investigates the interaction between the 2030 carbon policy and energy efficiency regulation. Findings indicate that the higher carbon prices caused by the simultaneous tightening the European emissions targets from the 2020 to the 2030 level, serve to increase the welfare costs of the energy efficiency policies by 10-15%, since they render a substitution of fossil fuels for electricity less attractive. Electricity prices will need to drop more, reinforcing the expansion of the process industries. The simultaneous carbon price increases are found to explain 38% of the rebound effects and 20-30% of the rise in domestic emissions. Note, however, that the *European* emissions would be virtually unaffected by the energy efficiency policies in Norway, since most of the rise in domestic emissions takes place in the ETS sector, which ensures a reduction elsewhere in the system.

To sum up, energy efficiency policies introduced in dwellings without simultaneous capping in all parts of the economy will generate rebound effects of around 40%. Moreover, the study supports conclusions from earlier studies that energy saving and energy efficiency policies are ineffective instruments for reducing carbon emissions. This study has the even more pessimistic finding that domestic emissions increase. Moreover, when energy efficiency policy is introduced simultaneously with rising carbon prices, both rebound and emission problems intensify.

An additional study in **ENTRACTE** looked at fuel efficiency in transport. It widens the perspective compared to the two previous by introducing global aspects. Different scenarios for improved fuel efficiency are simulated by a model of the global oil market. There are four main conclusions to draw from this analysis. First, large rebound effects are identified. They are global and work through a drop in the oil price. If a 50% fuel efficiency is obtained globally, rebound effects are found to bisect the total oil savings in transportation to about 25%. Further, rebound occurs through demand from other sectors like electricity generation, manufacturing industries and heating. In total, global oil consumption in 2050 declines by 10%. A second conclusion is that expectations of stricter energy efficiency measures in the future shifts oil extraction to earlier periods. This is consistent with the hypothesis of *the green paradox*. However, the effect is found to be small. It is first of all seen for the OPEC countries.

Third, if fuel efficiency is promoted only is some regions (OECD and China), the carbon reductions obtained in these regions will be severely counteracted by increased emissions in rest of the world. This phenomenon, coined carbon leakage, is related to the rebound effects that occur in other regions. Measured by the carbon leakage rate, i.e., the emission increase outside the regulating regions relative to the emission reduction within the regions, the leakage is 35-50% in the period 2020-2050, but much higher in earlier periods, due to the "green paradox" discussed above. Thus, if fuel efficiency is stimulated mostly to curb climate change, there is a strong unintended counteracting effect through carbon leakage unless regulations are broadly implemented. However, increased fuel efficiency may have other additional beneficial effects in the regulated regions, such as reduced local air pollution and reduced dependence on imported oil.

Finally, the study investigates the global distributional implications of increased fuel efficiency. As expected, producers will suffer from lower demand. OPEC will suffer the least, due to low production costs and exploitation of market power.

3.2.2 Renewable energy policies

In **ENTRACTE** coordinated simulations of two models of the European energy markets are performed for a variety of scenarios (Golombek et al, 2015). The models complement each other nicely, as the electricity system model *LIMES-EU* is detailed in terms of technologies and temporal resolution, while the model *LIBEMOD* has its advantage in covering more behavioural responses, for instance, capturing how fuel market prices adjust and how demand responds to changes in policies and other conditions. Altogether, this task constitutes an extensive sensitivity analysis of how technological, institutional and political conditions affect renewable shares, costs and market responses for the decades ahead. The reference scenario accounts for the 2030 announced climate policy targets, i.e., a 40% reduction of greenhouse gas emissions from the 1990 level. While *LIMES-EU* focuses on the EU power system, *LIBEMOD* also covers non-ETS sectors.

The *LIMES-EU* model exercises show that the ETS climate policy scenarios translated to the power system generates a cost-effective renewable supply share of electricity of 50%. This is very close to 49 %, which was attained by the Impact Assessment of the European Commission and which is consistent with the 27% renewable energy share target of the EU. Sensitivity analyses of several underlying plausible technological and institutional assumptions show a variation in the renewable share between 43% and 56% in 2030 given the 40% abatement target. The sensitivity tests cover (amongst others) different assumptions on fuel prices, on future investment cost developments, on CCS and nuclear policies as well as on transmission expansion possibilities. As expected implementation costs of wind, solar and biomass are decisive for the renewable share outcomes. Furthermore, renewable shares in the lowest range are realised if electricity demand decreases due to progress in energy efficiency programs. The highest shares are attained if CCS technology does not become available or a nuclear phase-out is pursued all over Europe.

The task had a particular focus on the latter point. The *LIBEMOD* study has largely been devoted to the impact of phasing out European nuclear power. Already in the reference path a decrease in nuclear capacity of 20% within 2030 has been accounted for in line with announced policies.

As opposed to the simulations described above, the LIBEMOD model accounts for possible total supply reductions as a response to demand and other energy supply effects. Total capacity increases slightly – by 2% - from the reference scenario if nuclear is completely phased out. The corresponding increases in wind and solar capacity are 18 and 11%, respectively. Total electricity generation decreases by only 4% when nuclear power is phased out, but the composition of technologies changes radically; gas power increases by more than 50 %, whereas bio power production increases by 20%.

We have also investigated the effects of a nuclear phase-out in the case of no EU-wide energy and climate policy. Then, there is a substantial production of coal power – its market share is roughly one third. The main implication of introducing a nuclear phase-out in the absence of a climate and energy policy is that nuclear production is replaced by fossil-fuel-based production.

By means of the *LIMES-EU* model we have studied the cost-optimal *regional* distribution of providing the European market with the necessary renewable capacity. The conclusion is that the investments in renewable capacity towards 2030 would be uneven – with renewable shares varying between 15 and 93% among the EU member states. We have also calculated the EU system-wide excess cost of implementing a RES target *above* the cost-optimal. The economic costs of setting RES targets higher than cost-effective levels are moderate in the long-run (less than 2% of total system costs). However, the costs increase non-linearly with the renewable target.

Finally, how does the climate and renewable policies interact under different business-cycle stages? This has been addressed this in a setting where not only the energy markets, but the whole European economy, are modelled. One conclusion is that carbon prices are more sensitive to changes in economic activity if they are applied in combination with renewable energy targets. Unintended, adverse consequences of the policy interaction may be particularly severe and costly when aggregate demand is low.

An important methodological achievement from the project is also worth mentioning: A novel approach to select representative model for *LIMES-EU* is far more computationally efficient than common previous approaches and allows for a high degree of geographical and technological detail, besides an appropriate representation of RES fluctuations.

3.2.3 Distributional impacts of energy policies

Landis et al. (2015) analysed implications of a combined emission and renewable policy on distribution across and within member states. It revealed that revenues from permit auctioning in the EU ETS are of such magnitude that their distribution among member states has important consequences for the distribution of the overall policy cost. Current emission targets and distribution of auctioning over-compensate the abatement cost of the poorest member states if permit prices within the ETS are high. For instance, households in low-income Eastern countries like Bulgaria Romania, and Slovakia tend to profit from EU climate policy. This is not the case for Poland, however, which belongs to the more impacted member states.

The introduction of ambitious renewable targets in several member states will reduce permit prices in the ETS and, thus, dampen the distributive effects of auction permit allocation among member states. The distribution of costs across member states will not be significantly different from the case of an emission cap, alone, if an ancillary renewable energy target is introduced. Only the eastern EU member states are pronouncedly affected by introducing the renewable policy. The reason for this outcome is that eastern EU member states are relatively CO_2 intensive and receive a relatively large amount of emission permits under the existing burden sharing rules. Thus, eastern member states are particularly vulnerable to changes in permit prices so that policy interaction with a renewable target tends to affect these member states the most.

The model analysis goes on by focussing on distributional impacts *within* member states among consumers with different levels of income. Given factual consumption and income patterns, the results show that the combination of capping emissions in the ETS and taxing fuel demand in final consumption has *regressive* distributional impacts within member states, i.e., the poorest households bear, proportional to their income, more of the costs than do households with higher income. If member states want to counteract this regressivity, they can do so by recycling back the revenues from the carbon pricing in ways that benefit households with low incomes. Among analysed schemes, recycling via the existing tax and transfer schemes is the most favourable for low-income households.

The model exercises show that the revenue from pricing emissions is large enough to effectively eliminate the regressive impacts of the carbon pricing, itself. In most member states, revenues from non-ETS carbon tax on fuel demand, alone, would suffice. In some member states, revenues of ETS permit auctioning should be added in order to alleviate the distributional regressivity. The same applies if for some reason carbon taxes are lower than stipulated by our study. Reduced auctioning is already suggested EU climate policy. We conclude that member states have the necessary degrees of freedom to avoid regressive impacts of climate policy at the country level without having to raise additional revenues.

The last part of this task on distribution involves a detailed microeconomic analysis of one specific policy in one specific member state, namely the profit-neutral promotion of renewable energy sources in Italy during the years 2000 to 2010. The results from this study indicate that not all energy policies necessarily need to have regressive distributional impacts. Unlike the EU-wide macroeconomic study presented above, this microeconomic study focuses on a policy that directly affects electricity prices. The price increases from more stringent environmental targets do not impact poor households disproportionally.

The findings from this case highlight the importance of analysing country-specific circumstances when detailed distributional impacts of any given policy bundle need to be assessed or predicted.

The distributional effects of climate policy are case dependent and need to be analysed within their specific political and economic circumstances.

This becomes easier as EU member states collect comparable data about household expenditures. But unlike household *income* surveys, where the Statistics on Income and Living Conditions (SILC) provide a unified access to the data, access to data from *expenditure* surveys across EU member states is more tedious. These data would, however, be more suitable for distributional analysis, as consumption can also be based on already collected wealth.

3.3 Innovation Policies

In order to decarbonise the economy with maintainable costs, new and improved technologies are necessary. However innovation is not like any other good, its characteristics indicate that Pigouvian policies, which add a price tag to environmental externalities, might not be sufficient to exploit the full cost-reduction potential of low-carbon technologies. Additional market failures can be attributed to the knowledge generation in low-carbon technology industries need to be addressed for an efficient market outcome.

3.3.1 The Interaction between environmental and innovation policy

The research of **ENTRACTE** provided solid evidence that complementing market-based environmental regulation with non market regulation further increases innovation activities at the firm level. These insights emerged from an analysis which empirically estimated the effects of direct and indirect environmental regulations on innovation at the firm level in Norway between the years 1993-2011 (Klemetsen et al. 2013). The analysis was based on a very detailed firm level database that was compiled using a number of sources[3] and provided solid results that non-market based instruments have an additional effect on innovation above and beyond what is induced by the use of market-based policy instruments. The combination of several policy instruments addressing the climate change and innovation externalities can be beneficial. The authors,

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[3] Patent data from the Norwegian Patent Office was used to proxy for innovation at the firm level, while direct environmental regulations as emission permits, inspections and violations were collected from the Norwegian Environment Agency (NEA), other registers at Statistics Norway were used to collect information on firms' accounts, employers and employees, and national education and data on electricity prices, environmental taxes, and tradable carbon emission quotas

however, conclude with a word of caution: the key element to keep in mind when analysing the interaction of market and non-market policy instruments relates to the design of the non-market instruments. Specifically, bans on inferior technologies seem to have brought about further innovation incentives. This conclusion does not necessarily extend to the specific case of governments “picking” winning technologies ex-ante through specific and targeted support.

The research carried out under **ENTRACTE** also provided evidence that so far environmental policy was not a drag on (nor a boost for) firms’ productivity in Europe. These insights emerged from an empirical analysis of sector level innovation in several EU members (Rubashkina et al. 2015). Specifically, the paper shows that increased environmental policy stringency in European countries (which is measured using pollution abatement costs and expenditures, PACE) are associated with a positive effect on overall (i.e. not only “green”) patenting, but do not affect positively or negatively either R&D efforts or TFP. These findings are robust to proper accounting for the endogeneity of policy stringency, namely by cleaning the estimated impact of PACE expenditures on innovation and competiveness from any bidirectional effect.

Furthermore, Verdolini (2014) provides evidence that so far no environmental multiplier effect emerges in the case of European countries. Specifically, the analysis tests whether the availability of cleaner and superior technology did indeed provide more incentives to further increase the stringency of environmental policy between the years 1995-2009. Using a different proxy for environmental policy stringency, the results presented in Verdolini (2014) confirm the positive link between environmental policy and overall innovation found in Rubashkina et al. (2015), but fail to support the hypothesis higher level of innovation act as springboards to further tightening environmental standards.

Taken together, Rubashkina et al. (2015) and Verdolini (2014) provide evidence that overall innovation levels do not decrease as a result of more stringent environmental policies. Across all economic sectors, a 10% increase in pollution abatement spending is associated with up to a 1% increase in innovation. This can either indicate the absence of crowding out effects (namely, non-green innovation does not decrease as a result of more green innovation) or that the presence of crowding out is more than compensated by the increase in green innovation levels. While being unable to discriminate between these two hypotheses, these two contributions provide strong evidence that environmental policy can increase the overall innovativeness of a given country or sector.

3.3.2 Policy instruments to address market failures in the innovation process

Two sets of findings emerged. First, Smulders et al. (2015) and Witajewski et al. (2015) analyse that combining carbon pricing with R&D subsidy lowers costs of climate mitigation. Smulders et al. (2015) focuses on the case of reneweable energy generation and explored to what extent emission policy creates the right incentives for directed technical change. They set up a model which distinguishes between innovation targeted at reducing the cost of renewable energy and innovation targeted at reducing the cost of investment goods. The model is used to explore different policy scenarios in line with the 2 Degree target: a tax on fossil, a subsidy to renewables, or a subsidy to R&D in renewables or a combination thereof.

The analysis estimates that in absence of carbon pricing, the R&D subsidy required to reach an optimal innovation level around 1400%: 1 euro of private R&D should be matched with 14 euros of public spending. Conversely, the use of optimal carbon pricing brings the optimal subsidy down to around 75%. Most importantly, the analysis shows that the R&D subsidy needs only be a temporary policy: after transition to renewable, the subsidy will not be necessary anymore. Witajewski et al (2015) focuses instead on the case of energy efficiency improvements in industrial technologies and develop an analytical model which helps to (1) understand how different types of innovation can reduce energy demand, (2) highlight the drivers of this type of innovative activity, and (3) evaluate the role of R&D subsidies and carbon prices in shaping the pattern of energy efficiency dynamics. The key parameters of such analytical model where then estimated using information on patent as proxy of innovation activity and a host of other control variables, as suggested by the model set-up. Such estimates were used to calibrate a new module for the WITCH mode lwhich improves the representation of technical change by endogeneizing the key parameter of autonomous energy efficiency improvements. The results provided in this case of energy efficiency are strikingly similar to those of the renewable energy case: first, to support innovation in energy-efficiency both the carbon tax and the R&D subsidy are substantial in magnitude. Second, the R&D subsidy decreases fast over time, disappearing after roughly 40 years.

Hübler et al. (2015) enlarge the analysis beyond the combination of just carbon pricing and R&D subsidies. Specifically, they consider the use (and combination) of carbon price, output subsidy on renewables, R&D subsidies on renewable and energy efficiency subsidy in a multiple market failures setting to reach GHG emissions trajectories in line with a 20-20-20 target. To this end, they set up a stylized model of the power sector that includes the knowledge externalities which charachterize innovation in climate change technologies and the market failure in the investment decision of energy efficiency measures. This model, which was carefully calibrated to European power sector based on the “EU Energy Trends to 2030” of the European Commission (2009), was used to analyse different policy mixes, in particular 2nd best policy mixes (i.e. when one of the optimal policy instruments is not available and the remaining ones have to be adjusted). These allowed to simulate the policy costs associated with several policy mixes. The calibrated numerical model revealed that the first best policy portfolio reduces the climate policy costs by one third compared to policy that only uses a carbon price._ In line with the analyses above, Hübler et al. (2015) show that if the first best policy option is not available, using a combination of policies can significantly reduce costs with respect to using only a carbon price.

The simulations show that the combination of all instruments can reduce costs up to 30% compared to a scenario with only carbon price. The key result of the analysis shows that the two most crucial instruments to lower mitigation costs are (1) carbon price and (2) energy efficiency subsidies.

3.3.3 Innovation policy design

The third theme analyzed within the WP was linked with the analysis of possible designs of prospective policy instruments. Specifically, Golombek et al. (2015) focus on the role of prizes in (environmental) innovation. These instruments have not been implemented or largely considered to date, but they provide important advantages with respect to other types of policy intervention such as targeted R&D subsidies or government R&D investments. The use of prize awards for R&D is first studied in an analytical model which allows to compare the performance of innovation prizes in market goods R&D and in emission abatement R&D. The analysis shows that the optimal innovation prize is higher for environmental innovation than for other market goods under several circumstances.

3.4 Trade Measures

In order to ascertain the effectiveness of domestic emission reduction policies in a globalized world, policy makers have to minimize the efficiency losses arising from carbon leakage. Currently, the preferred instrument of the EU is the free allocation of emission permits. As we discussed above, this instrument has probably being used too imprecise and needs to being better targeted.
Another instrument that could be complementing the current policy measures would be so-called Border Carbon Adjustments (BCA). Such a border measure could materialize as a tax on imported carbon-intensive products, as a rebate and reimbursement of the carbon costs for EU exporters (similar to the distribution of free allowances today) or a requirement for the exporting country to buy domestic emission permits to offset the carbon emissions coupled with the production of the imported good.

3.4.1 Basic economics and current empirical evidence of trade measures

In **ENTRACTE**, several topics related to the design and implementation of such border polices have been assessed. Estimates of leakage rates vary substantially across studies as these estimates are sensitive to model specifications. Estimates of the impact of unilateral GHG emissions regulation on global emissions mostly rely on computable general equilibrium (CGE) models. Although energy accounts for a small fraction of total costs in most industries, and hence, leakage could be expected to be not important CGE models' simulation results indicate that leakage can substantially hinder unilateral climate policies. One possible explanation for this result is the observation that not 'specialization leakage' (industry reallocation) but 'energy-market leakage' (via changes in fossil fuel prices) accounts for the largest share of emission leakage. The leakage rate is defined as the increase in emissions in unregulated countries, divided by the reduction in emissions in regulated countries. CGE models find leakage rates between 5% and 130%. i.e. unilateral GHG emissions regulation could even increase global emissions. These figures, however, are sensitive to the model's structure and assumptions, for example, leakage rates significantly increase if not only energy-related, but also process emissions are taken into account. Other research has found *negative* leakage rates, for example due to a fuel switch (from fossil to renewable sources) in countries implementing emission policies. At the sectoral level, a number of studies have assessed the impact of the EU Emissions Trading System (ETS) on particular industries. The ex-ante analyses studying the impact of the EU ETS on EU firms find a substantial cost increase due to carbon pricing among carbon intensive sectors. However, the ex-post literature finds no statistically significant evidence that the EU ETS had an impact on production, employment or exports during its first and second phases. This result is not surprising, for two main reasons: first EU-ETS carbon prices were low, at least during the first phase of the EU ETS, and second the allocation of free allowances would have ameliorated, to a large extent, possible cost increases. Some of the most recent contributions point out that the criteria for granting free carbon allowances under the EU ETS may have been too generous.

Since the most common policy suggested to reduce carbon leakage is to introduce a BTA on imports from unregulated countries, a literature review conducted in this regard indicates that it is necessary to take into account the general equilibrium effects that determine how international patterns of production and consumption change as a response to climate policy. In particular, it is important to take into account how production patterns of foreign suppliers will change if BTAs are imposed on their exports. Empirical analyses suggest that border tax adjustments would, at least moderately, reduce leakage. However, there is a variety of policies that would also reduce leakage that might be preferable to a BTA from a welfare perspective. In particular, a tariff on imports, of highly traded emission-intensive industries, is likely to reduce leakage and would be relatively easy to implement and administer.

Regarding GATT-WTO compatibility, it has been pointed out that there seem to be ways to impose a BTA without violating GATT's stipulations. This requires that measures are adopted in a way that does not discriminate against importers, either in favor of domestic or third-countries firms. To this end the so-called "best-available technology" approach would stand the highest plausibility to be regarded as non-discriminatory. This approach consists of calculating embedded emission by assuming that the country to whose exports the BTA is applied uses environmental standards and production technologies equivalent to those used within the area in which the BTA is applied.

A theoretical model of trade that includes the main policy options suggested to reduce carbon leakage was one of the models developed within WP5. The model is a two region model of international trade in which one region implements optimal climate policy. Using this model, three scenarios were considered: non-policy, carbon pricing, and carbon pricing with a border tax adjustment and export rebates (full BTA). The model includes intermediate inputs in production, which have been previously omitted by the theoretical literature on carbon leakage. Including intermediate inputs in production is important due to the large size of intermediate inputs observed in international-trade data (intermediate goods account for more than half of the total internationally traded goods). Using this model it was possible to find analytical results of the effects of policies on patters of leakage and competition. The main findings indicate that when intermediate goods are considered, a full BTA restores competitiveness in intermediate goods. However, a BTA increases the cost of imported intermediate goods and hence, decreases competitiveness in the regulated region final-good sector. In other words: Once intermediate goods are considered, a BTA is not a silver bullet that restores competitiveness to all sectors.

The analysis also indicates that carbon pricing as well a BTA have income distributional effects. These effects go beyond the focus of the study, but analyzing the distributional effects of carbon pricing and BTAs deserves a study on its own.

3.4.2 Feasibility and practicability of competing designs

WP5 also studied how different practical implementations of trade policy instruments perform under ‘real-world’ conditions such as informational constraints with regard to the carbon intensity of foreign production. In particular, the objective was to consider more targeted tariffs than in most previous studies, which generally have considered country-/region-specific tariffs. While region-specific tariffs are easier to implement than firm-targeted tariffs, recent development of standards designed for tracking carbon contents suggests that firm-specific tariffs may be feasible. Moreover, from a WTO perspective, firm-targeted tariffs may be preferable to region-specific tariffs. Whereas the region-specific tariffs do not give foreign producers incentives to reduce their carbon intensities, firm-targeted tariffs give such incentives to foreign producers that export to the EU. Thus, the hypothesis is that targeted tariffs should lead to lower carbon leakage and a more cost-effective reduction of global emissions.

To perform this analysis a multi-regional and multi-sectoral CGE model for the world economy (SNoW) based on GTAP-data was employed. For this project a version of SNoW was developed allowing for analysis of firm-specific carbon tariffs that respond to the embodied emissions, both direct and indirect, in the exported goods to the EU. A brief theoretical analysis was performed, deriving optimality conditions for the firms exporting to the EU under different tariff designs. The analysis shows how the different types of tariffs give different incentives for those firms. For instance, region-specific tariffs reduce the incentives to export emission-intensive goods to the EU, but do not give any incentives to alter the input mix in the production. Firm-targeted tariffs give the firm incentives to reduce their emissions at the plant – hence such tariffs function like an implicit carbon price on those emissions. If the tariffs also take into account indirect emissions from electricity generation, the emission-intensive firms are also incentivized to buy electricity generated with little emissions. Simulations results indicates that firm-specific carbon tariffs, which target embodied emissions in exported goods to the EU with an emissions price equal to that in the EU, can enhance cost-effectiveness.

The benchmark scenario with uniform carbon pricing in the EU leads to a lower output in emission intensive goods compared to the scenario without policy. The output of carbon intensive goods declines due to a relocation of production within the EU towards less carbon intensive production and also because production shifts from the EU to non-EU countries. There are significant differences across carbon intensive sectors, due to differences in emission-intensities and differences in trade exposure, which also depend on transport costs and substitutability between imported and domestically produced goods. Supplementing carbon pricing with carbon tariffs moderates the cutbacks in EU outputs. This is found irrespectively of the tariff scenario and across all emission intensive and trade exposed sectors. However, it is not possible to rank the impact of region-specific tariffs and firm-targeted tariffs due to mixed results across sectors. As expected energy intensive goods exports from non EU countries to the EU are reduced in all tariff scenarios when compared to the benchmark scenario.

Regarding leakage a benchmark scenario with uniform carbon pricing in the EU leads to a leakage rate of about *18%.* Introducing tariffs leads to a decline in leakage. In particular, when the tariffs are based on *direct* embodied emissions, only, the tariffs yield a modest reduction in leakage rates. In the case of region-specific tariffs the leakage rate is 16.4%, whereas for the case of firm-targeted tariffs the leakage rate is 14.7%. The drop is considerably larger when the tariffs are based on *indirect* emissions from electricity use, leakage drops to 14.5% under region-specific tariffs and 8.3% under firm-targeted tariffs.

3.4.3 Identify EU sectors 'at risk'

WP5 explored the risk to international competitiveness due to EU unilateral climate policy by looking at the effect of past differences in energy prices between countries on competitiveness. There is no commonly accepted definition of competitiveness. In turn, the idea was operationalized by looking at the employment level of affected firms. Alternatively firm level output, investment or survival could be considered. Specifically, the impact of energy price disparities on firm level employment was studied by performing an econometric analysis using a global firm level panel database (ORBIS). Firm level regressions of employment on sector and country specific energy prices as well as other control variables were conducted. The most general conventional regression model does not find any evidence of a negative impact of energy prices on firm level employment. However, the estimates found are highly sensitive to specific model assumptions. This is dealt with by using a new kind of estimator – the worst case scenario estimator (WOCASCE) that systematically tries to find the most dramatic impact of energy price gaps on firm level employment from a wide range of possible model specifications. The WOCASCE estimator leads to moderately negative energy price elasticities ranging from -0.17 for the Chemical sector to -0.09 for the Iron&Steel sector; i.e. a 10% increase of energy prices in Chemicals relative to competitors would lead to a 1.7% reduction of employment in the worst case. The energy price elasticities found for paper and minerals are -0.16 and -0.13, respectively. In terms of the relevance of these findings for policy making, the use of WOCASCE implies that risk averse policy makers could then base any decision on these estimates in an effort to be on the "safe side.

3.4.4 Long-run effects

WP5 also analyzed how BCA would interact with domestic and foreign firms' R&D investment. In order to assess the dynamic efficiency of BCA measures a multi-country multi-sector model with endogenous R&D investment and endogenous market structure was developed. The endogeneity of the market structure is crucial in order to embed the effect of changes in market concentration as a consequence of trade measures on innovation incentives. The model was calibrated to the multi-regional input-output data of the World Input-Output Database (WIOD) that maps trade flows between sectors and regions. The calibration of the R&D function was performed using data on sectoral R&D intensity from the OECD's ANBERD database, using data for year 2007. This dataset contains information for industrial R&D expenditures and has a high degree of international comparability. With this model at hand the effects of BCA have then been examined. The model differentiates between two sectors, emission-intensive and trade-exposed (EITE) and a composite of other sectors that are not prone to carbon leakage, i.e. services, but particular attention was paid to the performance of EITE industries. In the model developed each firm has the possibility to invest in process innovation and increase its efficiency of production, which also reduces the emission intensity of each unit of output. The stock of internal knowledge is firm-specific and it is produced through internal R&D activities.

The analysis shows that endogenous R&D investments have significant effects on carbon leakage rates and also increase the effectiveness of BCA schemes. Assuming firms are not able to respond with process innovation to the implementation of an ETS, a leakage rate of 42 percent can be observed. BCA are quite successful in reducing these leakage rates and bring down the carbon leakage rate to 10 percent. Adding R&D investments to the firm's response menu has significant effects on trade responses to climate policy. Allowing for R&D responses by individual firms increases carbon leakage to over -100 percent. However, BCA becomes much more effective and cause even positive mitigation effects by firms not directly involved in the ETS. The analysis performed also indicates that understanding the competition-innovation nexus is crucial for a better design of unilateral climate policies.

BCAs also affect the market structure. Unilateral climate policy measures lead to a significant reduction in the number of active European EITE firms. New firms enter the market for EITE goods but are located abroad. Hence, the so called extensive margin is an important driver of carbon leakage in this analysis. If the unilateral implementation of an ETS in the EU is supplemented with a BCA on imports, we observe entry in all markets even in the EU. This has also important effects on aggregate R&D investments since the majority of the aggregate R&D effect is caused by product innovation (i.e. the entry of new firms). This study with a relatively simple calibrated model at hand shows that innovation and competition closely interact with each other. This has significant effects on the effectiveness of unilateral climate policies and may give another justification of complementing unilateral climate policies with R&D subsidies.

3.5 Policy Interactions: Synthesis - Commitment and coordination for policies

While it is generally perceived that the transition to a cleaner economy not necessarily restricts long-run growth – various studies point to economic benefits of a clean environment – the biggest concerns comes from the costs in the short run. In particular, firms and households may be reluctant to enact changes if they are not sure that other firms will make similar investment. Since a successful transition requires coordinated action among energy users, the fear of coordination failures and free riding threatens Europe’s climate policy at various levels of decision making.

Commitment is central to the story. The role of commitment can be illustrated by a simple example: if key energy users can commit now to reduce their energy use in the future, this makes it easier for other players to trust that they will operate in an economy that makes serious work of the transition, and this makes them more eager to also reduce their energy use today and in the future. The question is to what extent commitment is possible and what increases the incentives to commit to future climate action.

More generally, coordination and cooperation during transition processes are difficult and behaviours and performances may be hampered by commitment problems. A coordinated cooperation to implement such a transition process is difficult. Agents are uncertain about future rewards for current investments as there is no commitment to present future behaviour and performance.

An experimental approach has been used to study the effectiveness of different instrument of climate policy in the transition to a cleaner economy. To address these issues we followed a two-stage approach. First we developed a framework for analysis and evaluation. We developed a model that contained commitment problems, while it is general enough to allow us to study the effects of several instruments. The general idea of the dynamic model is to describe a situation where transitions (away from the status quo) may be desirable because of better long-run outcomes, but at the same time transitions are problematic and costly during the transition period. Second, we used lab experiments to explore the behavioural economics aspects of these instruments. In particular, we investigated in the lab how subjects respond to technology subsidies and to several policies when they know that regulators cannot commit to future policies. In addition, we studied the impact of legitimacy by comparing the results (effectiveness) of several instruments, some of which may be perceived as fairer than others.

To study how coordination and commitment can be useful instruments in climate policy, we have developed a new game, which we believe includes some key elements of the transition processes described above and we study how people behave in his game in a laboratory experiment. The game combines features of a coordination game with features of a public good game (including free-rider incentives) and because it captures some important elements of a transition from a dirty economy to a green economy we will refer to it as a ‘green transition game’. The green transition game consists of seven rounds and is inherently dynamic in nature. In the game, group members have to choose whether they want to transit from the benchmark (initial) state to an alternative state, where states in the game are determined by chips that can take two different colours. Conceptually, the benchmark state refers to an economy based on dirty (brown) technologies, whereas the alternative state is one based on ‘green’ technologies. But, in the basic treatment, we do not want to frame the game as ‘environmental’, so that we avoid references to green and brown. Instead we used purple chips to indicate dirty technologies and blue chips to indicate clean technologies. The distinction between ‘dirty’ and ‘clean’ materializes only through the private and public payoff structure.

In particular, players can change to green technology privately (by changing one purple chip into a blue chip), but this is costly to the individual and only becomes beneficial after some time and if a sufficient number of other players also changes to green technology (by changing their chips from purple to blue). This makes that individual player support for the transition is risky.

The game is set up in such a way that both the benchmark (initial) state (with only purple chips) and the alternative (green) state (with only blue chips) are stable; if everybody chooses for the alternative state (full transition), each has a higher payoff, but it it costly to transit, and it requires coordination. The first aim was to see what decision subjects make in this game. Do they manage to make the green transition or not? Secondly, we wanted to test whether interventions may help improve coordination and group performance. If so, which instruments or institutions work and why? We study the effect of several interventions, namely communication, commitment, and leadership. In total 342 subjects (114 groups of three) have participated in one of nine treatments. In each of the 19 experimental session, subjects played five times the green transition game (of seven rounds).

A first main result of the experiment is that we see a clear lock-in pattern. Over all sessions, all games, we find 81 groups that successfully converge to the alternative state that is interpreted as a transition to a green economy, while 99 groups do not transit. Figure 1 shows how the total number of purple and blue chips in a group develops over the seven rounds of a game. The figure presents a clear dichotomy. The 81 groups that transit make a full transition. The 99 groups that do not transit, keep close to the steady state. The figure thus shows the lock-in effect: because it it costly to transit, some groups do not collect enough support from the group members, and those groups remain in the status quo. Figure 6A shows for the baseline (control) treatment the share of groups that manage to make the full transition to the alternative green state (blue bars), the share of groups that stay in the initial state (purple bars), and the share of groups that experience a costly transition (i.e. they transit to the alternative state but payoffs are lower than in the status quo situation, grey bars).

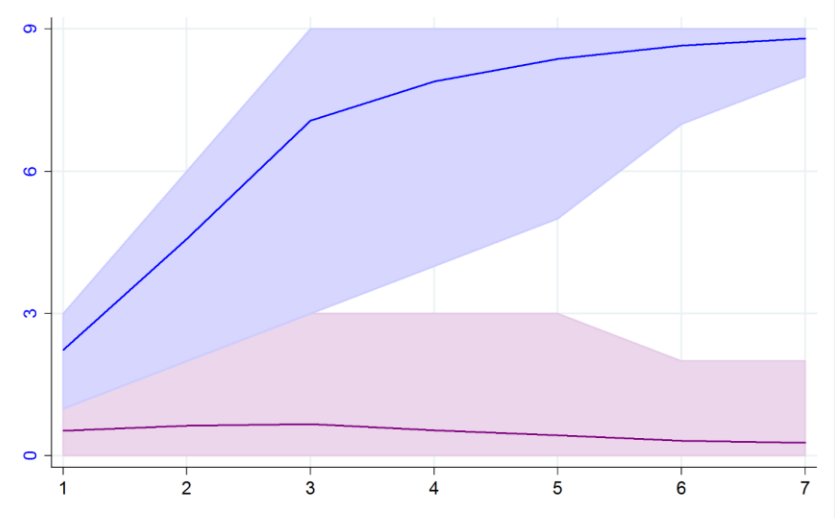


Figure 5. Development of purple and blue chips in a game. Horizontal axis: 7 rounds of a game. Vertical axis: average total number of purple and blue chips in a group at the end of a round. The population has been divided in two sub-populations, those with more less than 5 blue and those with 5 or more blue chips. Lines show the averages for both populations, Shaded areas show the 10-90% interval. The chart shows the lock-in effect. Populations either succeed to transit, or don’t transit. No groups remain in the middle area.

A second important outcome of the experiment is that communication helps to implement the transition. In some of the treatments of the experiment, one or more subjects are once (before game 3 starts) given the opportunity to “communicate” with their group members about their strategy to invest in the alternative technology or not. While the message sent does not bind the actions by other subjects, nevertheless communication stimulates actual investment, as can be seen from 6B. The number of successful transitions is much higher than in the baseline treatments. Communication has a strong effect and can be seen as an effective instrument. The legitimacy of the instrument seems to play only a minor role. We compared a treatment where all group members can communicate with one where only one randomly selected member can send a message; both inclusive and exclusive communication work equally well.

A third important result regards the instrument of commitment. Also commitment helps stimulating the transition, as can be seen in Figure 6C. Whereas in the baseline, the payoff from an investment depends on the decisions by all other group members, commitment in the game means that subjects can pre-set the future payoff that they will receive from a particular invest decision. Specifically, if subjects can vote to commit, the majority will do so, and this will implement the transition. After commitment in one game (game 3), further commitment is not needed (and also not possible), but coordination remains and thus better outcomes are obtained. Also here the legitimacy or justification of the (commitment) instrument seems not very important: results are very similar, independently of whether commitment is endogenously selected by means of voting, or alternatively that it is exogenously imposed.

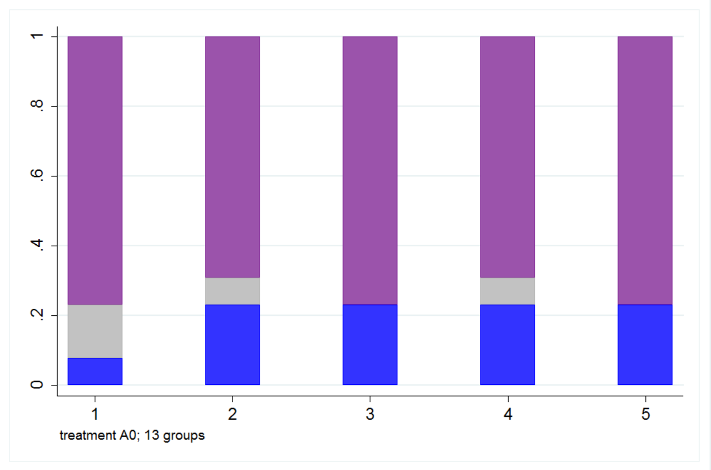


Figure 6A. Game coordination outcome types per game, baseline treatment. Horizontal axis: 5 games. Vertical axis: share of outcomes with profitable transitions to the alternative equilibrium, costly transition, or no transition.

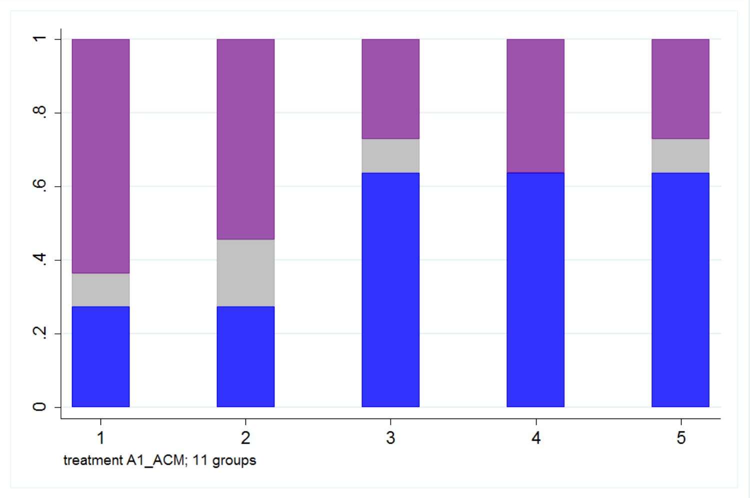


Figure 6B. Game coordination outcome types per game, treatment with communication between subjects before game 3. Horizontal axis: 5 games. Vertical axis: share of outcomes with profitable transitions to the alternative equilibrium, costly transition, or no transition.

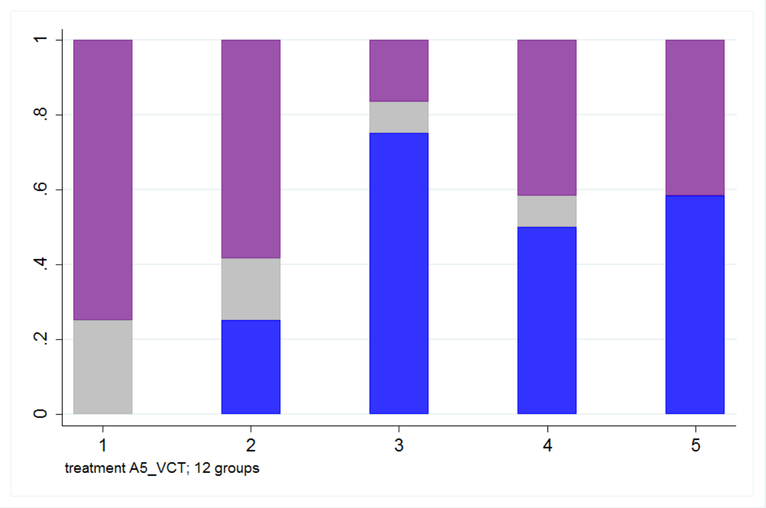


Figure 6c. Game coordination outcome types per game, treatment with commitment to blue payoff in game 3, round of commitment through vote by all players. Horizontal axis: 5 games. Vertical axis: share of outcomes with profitable transitions to the alternative equilibrium, costly transition, or no transition.

4 Description of the potential impact

ENTRACTE shows that there is indeed a positive rationale for using a portfolio of policies. The policy mix has to address the specific market failures beyond the climate externality.

- It is essential to stress the most important policy instrument to deal with GHG emissions: a price on carbon, mediating mitigation actions economy wide that reflects the damages emissions provoke.
- However, other instruments are also advisable to address additional market failures. These complementary instruments might reduce the long-term costs of decarbonisation. Two market failures in the knowledge generation process hamper the market economy from realizing the full benefits from innovations.

First, learning-by-doing and learning-by-using externalities need to be addressed. Experiences gain in the production and usage have a public good component because also other technology users profit from the generated knowledge. This market failure can be addressed with a market premium (or a renewable portfolio standard) on top of the whole sale electricity price that compensates RES-E producers for their contribution to the cost reduction. Such a FiP scheme has clear advantages over a FiT scheme since it forces producers to response to prices as signal for scarcity. In any case, diffusion externalities might be small and learning-by-doing and probably even more learning-by-using externalities are difficult to target.

Second, a learning-by-searching externality has to be considered, since the generation of knowledge through R&D is partly a public good. There is some empirical evidence that substantial spillovers exist. Moreover, R&D subsidies seem to be far more efficient in bringing down costs relative to learning-by-doing subsidies. However, the current public spending addressing the two market failures is the direct opposite. Public spending on diffusion of wind and PV has been two orders of magnitude larger than on R&D support. Spending that addresses these two market failures needs to be better balanced, reducing substantially the amount of subsidies for technology diffusion and shifting substantial resources to R&D support. When analysing the demand side carefully, **ENTRACTE** also identified market failures that hamper the uptake of energy efficient technologies. However, these market failures are very specific and have particular effects on different consumers. Thus, successful policies need to be calibrated very well in order to reduce distortions. The risk of doing more harm than good is certainly high.

The same holds for competitiveness policies such as BCA but also the grandfathering of allowances to certain sectors. The distortions and potential welfare losses due to an imprecise allocation scheme are a relevant policy risk. This is also true for border carbon adjustment policies: For example the repercussions on supply chains and R&D investments are difficult to estimate. More efficient designs that take firm specific carbon intensities into account have potentially high administrative costs. Further, its wider implications for the current world trade system are hard to assess. As the threat with trade retaliations from China and the US has shown after the proposed unilateral inclusion of Non-EU airlines in the EU ETS, they could have significant costs.

When it would be possible to calibrate policies such that they are able to address the market failures precisely according their first-best configuration, they would not cause distortions but would be part of the first best instrument portfolio. However, policy makers often lack the information necessary to implement these first best policy portfolios. This obtains even more importance as renewable and energy efficiency policies operate in a world where a broad range of policy targets exists. These targets might be legitimate, but addressing these further goals cause distortions due to the interaction with existing instruments. Economists need to take this n-th-best world into account in their assessments. The (societal) benefits from reaching additional goals have to dominate the distortions from additional and interacting policy measures. Since this implicitly assumes that reaching one goal is more important than another, a societal defined ranking of goals is needed.

The **ENTRACTE** project presented rationales, founded in economic theory, for utilizing a policy portfolio that contains several measures, each addressing a worthwhile goal. But in such a complex environment, policy interactions are not easily to be predicted, rather surprising and unintended interactions might emerge. Adding new policy instruments has therefore to be done with the utmost prudence because policy failures are a constant risk when designing extended policy portfolios. Otherwise the policy mix risks becoming a policy mess.

ENTRACTE has been discussing this message with other researchers, stakeholders and policy makers using several channels and at various occasions and events.

The research plans and its findings have been presented and discussed at several workshops. *Inter alia*, the consortium organized jointly with its sister project CECILIA2050 a workshop in Dublin in September 2013. The two-day event focused on recent developments in European Climate Policy and a contemporary review of the EU Emissions Trading System (EU ETS) performance and prospects. Discussions on the EU ETS and Non-EU ETS sectors at member state level were also among the main topics. During presentations, panel discussions and round table sessions, the participants exchanged their views and opinions on climate policies and engaged with different perspectives.

The two consortia also teamed up to present findings at a side e event at the UN Climate Conference in Warsaw, Poland, on November 20, 2013. The side event, titled “Triggering innovation for decarbonisation”, aimed at presenting scientific findings of both research projects to policy makers and other stakeholders. Discussions at the side event focused on which policies would be most effective and efficient in decarbonising Europe and the world.

On March 18, 2014, Andreas Löschel, co-coordinator of **ENTRACTE** discussed the pros and cons of the 2030 Policy Framework for Climate and Energy with Günther H. Oettinger, the former European Commissioner for Energy, and two Members of the European Parliament. Andreas Löschel gave a short overview about the **ENTRACTE** project and its core themes, namely the interaction of climate and energy policy targets and instruments, arguing that the EC proposal has to be assessed in the light of these core themes.

ENTRACTE convened a policy session at the Fifth World Congress of Environmental and Resource Economists in Istanbul on 30 June 2014. The policy session brought together leading scholars from Australia, the United States, the European Union, and China who discussed lessons learned and upcoming challenges in their respective jurisdiction concerning the design, as well as the political embedding of emissions trading schemes.

On February 17, 2015 the **ENTRACTE** consortium held a fruitful “Workshop on Policy Interactions and Overlapping Policies” in Milan. During the one day workshop it was discussed how climate and energy policies interact and how policy portfolios which comprehensively address these complexities need to be designed. Key outcomes of the workshop on lessons learned from theoretical and empirical analysis in the past 2.5 years were extensively discussed and they framed further project steps towards the final conference hold in Brussels on September 25, 2015.

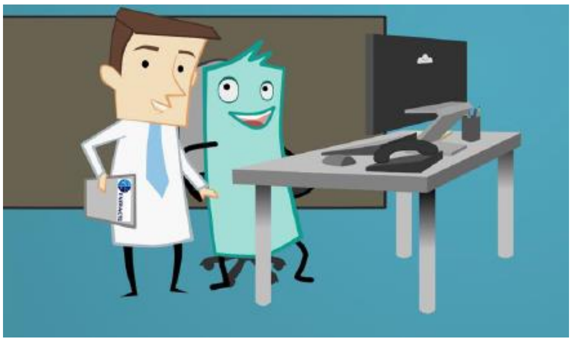
At the **ENTRACTE** final conference in Brussels, provided policy insights generated from the research work and to discuss them with an excellent line-up of internationally recognised leaders in climate policy and climate research. The one day event focused upon presenting concise policy relevant messages and evidence from the completed research project, and thereby facilitating discussion and networking amongst high-level stakeholders and policy makers across a range of clearly defined subjects.

The first policy brief of the **ENTRACTE** project considered three fundamental challenges for the future of European climate policy. Specifically, 1) responding to the low EU ETS price, 2) addressing innovation and multiple policy instruments in the market, and 3) the issue of market linkages and maintaining competitiveness. In each case decisions are required that will shape the future of European and international climate policy.

As an outcome of the **ENTRACTE** final conference the second policy brief offered insights relating to the future of European climate policy, including the following selected headline messages from the **ENTRACTE** research:

- Policy interactions are numerous and unavoidable. They are a fact of life in policy and no different in effect than market interactions. Our research shows that they can as easily reduce costs, by overcoming market barriers, as they can increase costs, by constraining cheaper options.
- The most sustained recession since the 1930s has been the single largest contributor to reducing the levels of carbon emissions from what they were expected to be at this point in time, and this has in turn lowered the cost of meeting the European Emissions Trading Scheme (EU ETS) cap. However, our research, like that of others, shows that the ETS has reduced European carbon emissions even farther, perhaps by as much as 15% below what they would otherwise have been in the absence of this mechanism.
- Innovation is the key to long-term cost reductions and our research shows that existing climate regulation, of all kinds, has stimulated innovation in emission-reducing technology. There is, however, no evidence from the research that economy-wide productivity has been either increased or decreased by this regulation and the associated innovation that it has triggered within the market.
- Given the consensus in the literature that the EU ETS has had little to no effect on competitiveness, the ENTRACTE research focused in on issues involved in implementing border carbon (or tax) adjustments should they become necessary as EU ambition increases and should major trading partners not take commensurate measures. The research shows that the design requirements for effective border carbon (or tax) adjustments are extremely challenging, and identifies an immediate need to develop the means to track embedded emissions and understand the complex domestic effects of such adjustments.

ENTRACTE also reached out to the wider public by using an animation movie. The **ENTRACTE** consortium produced an animated short film to provide the public with a better understanding of its research work and raising awareness on the topic.



The project film is available on the project website and on YouTube. Responsible for the concept and implementation of the film was the **ENTRACTE** partner Eurice in cooperation with the coordinating institution ZEW and the Filmakademie Baden-Wuerttemberg, Institute for Animation, Visual Effects and Digital Postproduction.

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