Taran Fæhn[*^], *Karl Jacobsen*[*], *and*
Brita Bye[*]

Diffusion of climate technologies in presence of an emissions cap

PRELIMINARY VERSION
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Abstract:

The EU and other selected jurisdictions have independently expressed high ambitions for greenhouse gas (GHG) control. In absence of international, binding agreements the reliance in such proclamations by individual governments can, however, suffer. A uniform GHG pricing scheme, that would otherwise be a first-best strategy for meeting a national cap, may not be optimal if the agents perceive the durability of the scheme as uncertain. Given this assumption, this paper compares a uniform GHG pricing system with two second-best options, one which combines emissions pricing with subsidies to upfront investments in climate technologies, and one with a public guarantee arrangement that places the political risk on the shoulders of the government. We use a technology-rich, dynamic CGE model that accounts for abatement both within and beyond existing technologies, the latter through investments in alternative, climate-friendly technologies. We find that domestic climate policies unable to stimulate investments in new technological solutions will triple the costs of a uniform GHG pricing system. Subsidising investments is a remedy, though costly compared to a system that ensures commitment from the government.

Keywords: Abatement costs, Climate technologies, Computable general equilibrium model, Technological change, Hybrid modelling

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[*] Affiliation: Statistics, Norway.

[^] Presenting author.

1 Introduction

In the wake of the Copenhagen negotiations in December 2009, several jurisdictions have reported unilateral climate policy ambitions to the UN. The main purpose of this study is to compare costs of mitigating national greenhouse gas (GHG) emissions under different policy designs. The costs of imposing a domestic cap will critically depend on whether the domestic policy design releases the most cost effective projects within the jurisdiction. Even though the usual recommendation for optimal abatement is uniform emissions pricing, market failures or other inefficiencies can cause second-best situations and increase the abatement costs. This paper looks at market failures in the process of technology diffusion.

While the literature on market failures related to technology *development* is relatively rich both in theoretical and empirical contributions, the reasons for inefficiencies in technology *diffusion* are less covered. Network externalities, information insufficiencies, and public good features related to several new climate technologies are potential arguments. A special situation that can impede up-front investments in climate technologies occurs if agents mistrust that the unilateral policy efforts will last. We investigate the situation where up-front investments in climate technologies are hampered by the inability of policy makers to signal a trustworthy future climate policy. In face of a *perceived* short-lived emission price, up-front investments in climate technologies will not appear profitable; firms will rather reduce their variable costs and scale down output, and consumers will respond by substituting other consumer goods for energy and leisure for consumption.

It is reasonable to suspect that a confidence problem will be more or less present in market economies. A related problem of the trustworthiness of global climate agreements is discussed Bosetti and Victor (2011). They argue that from the perspective of powerful states, inherent confidence problems of international agreements can be even more serious than that of domestic policies, due to lack of legal institutions. Our study does not distinguish between the credibility of future GHG prices that follow an international agreement from that of unilaterally decided prices. Domestic governments have restricted power to commit future governments to a particular climate policy. Given the global nature of climate change, there are reasons to question the effectiveness of unilateral action of small countries, and this will add to the risk of the next government abandoning the policy announced and initiated by the present.

We use a CGE model that allows for abatements both within and beyond existing technologies. The latter take place through investments in alternative climate-friendly technological solutions. The technology richness of the model enables us to account for potential endogenous changes in climate technologies and is a necessary tool in order to study possible impacts of an uncertain climate policy.

The methodological approach to abatement cost analyses varies in the literature, as do abatement cost estimates. The Stern Report (2007) does, for instance, sum up a wide range of estimates of global costs related to stabilisation of the atmospheric concentration in 2050 at 550 ppm CO_2-equivalents. Traditionally, two main model approaches have dominated. The *bottom-up* tradition describes the competing energy technologies available, irrespective of whether they are currently in use or at present only known on paper. These models can describe technological scenarios radically different from today. The MARKAL models[1] are widely used examples. However, bottom-up models tend to suffer from applying a partial perspective of the energy system that fails to count in macroeconomic feedbacks and shows little attention to the endogeneity of demand and factor prices.

The *top-down* approach to climate policy analyses mostly use computable general equilibrium (CGE) models. CGE models predict the development of the economy, energy use, and emissions based on micro-economic behaviour and the resource constraints and long-run conditions that restrict the opportunity set of agents and economies. They are empirically pinned down by use of historical data on the responsiveness of agents, and by use of current information on the technology specifications of production and consumption. Thus, their technological responses do not exceed observed practice.

Conventional analyses, top-down as well as bottom-up, tend to underestimate the potential for emission reductions. While top-down analyses exclude important profitable technology substitutions and systemic shifts, bottom-up analyses exclude important flexibility of economies by neglecting profitable down-scaling of supply and demand and shifting of costs among market agents. This dilemma has inspired analysts to develop synthesis models. Several amendments of the MARKAL model has been made, aimed at introducing main macroeconomic characteristics; among pioneering works, see Hamilton et al. (1992) and Loulou and Lavigne (1996). An impressively ambitious, recent approach departing from a bottom-up basis is that of Bataille et al. (2006).

Other recent contributors have used CGE modelling as a point of departure and supplemented it with technology details; see e.g. Böhringer et al. (2003), Laitner and Hanson (2006), and Bosetti et al. (2009). This enables a good representation of technological richness, while simultaneously ensuring advanced status quo characteristics of CGE models like intertemporal dynamic behaviour and the facilitation of a consistent welfare measure.

Our approach follows this latter strategy. We expand the scope compared to other contributions in the field by not restricting the technological adaptation possibilities to the energy supply side, but also allowing for investments in climate technologies within energy-demanding sectors. Energy-intensive manufacturing industries have several technological options, as have a large range of households, firms and public service sectors when comes to e.g. transportation technologies. Our modelling procedure is relatively simple, but at the same time capable of representing, with good approximation, a variety of potential technological measures.

We find that in a trustworthy, long-lasting, uniform emissions price scheme the loss in economy-wide welfare (total discounted utility of households) compared to a reference scenario without capping of emissions, amounts to ¼ per cent, or about 100€ per capita as a yearly average. In this cost-effective regime about one half of the necessary reductions take place by choosing other technological solutions and the other half by scaling down relatively emission-intensive industries and consumption activities. Given this, the results indicate that costs of ambitious domestic abatement goals are, indeed, not overwhelming. Failing to conduct a reliable, enduring climate policy does, however, more than triple the abatement costs, and regional employment in traditional manufacturing tend to suffer the most. Subsidising up-front investments in climate technologies is a remedy, though costly compared to a system that ensures commitment from the government and eliminates the political risk. The case where technological barriers are prohibitive also serves to illustrate the outcome of a traditional CGE analysis as compared to our hybrid approach.

2 The model

2.1 General

This analysis is based on simulations of a CGE model for the Norwegian economy. It is an integrated economy-energy-emission model designed for studies of economic and environmental impacts of climate policy (Bye, 2008; Heide et al. (2004). In the particular model version employed – MSG-TECH – we have integrated data on technological substitution opportunities today and for the next decades. Technological adaptations are induced to the extent that the optimising agents find the opportunities profitable. The modelling of technological opportunities is based on data from bottom-up approaches to energy and abatement technologies. The technology model consists of industry-specific combinations of additional *costs* in terms of investments, operation and maintenance, and *benefits* in terms of reduced unit emissions. The result is a model which is fundamentally a so-called top-down model, but with technological flexibility that goes beyond current practice, as for traditional bottom-up models.

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[1] See ETSAP (2004) for a central documentation.

The top-down CGE features of the model ensure a consistent economy-wide framework that captures how behavioural effects of a policy instrument in one market induce changes in adjacent factor and output markets, and so forth. Macroeconomic constraints, like sustainability conditions imposed on the current account, as well as labour and other factor market equilibrium conditions, will be reflected in market prices and eventually feed back into the behavioural responses. Furthermore, as we consider welfare implications for the entire economy, an explicit social welfare measure is a crucial aspect of our model. The top-down CGE approach enables us to account for welfare implications of a wide range of market reallocations taking place. The model gives a detailed description of the empirical tax, production, and final consumption structures. Several second-best features through market or policy distortions are modelled, including taxation of labour and existing industrial policies. In addition, barriers to technological investments can be represented.

The modelling of emissions to air, including the six GHGs in the Kyoto protocol[2], links them closely to detailed economic activities, including the production, input and consumption of various energy goods. It specifies 60 commodities and 40 industries, and these are classified with particular respect to capturing important substitution possibilities with environmental implications.

2.2 Behaviour

Consumers are represented by a single average consumer whose utility in every period depends on their consumption of leisure and 26 different consumer goods. The representative consumer determines consumption of leisure and the different goods so that welfare is maximised, defined as the present value of utility. The welfare of the consumers defines economic welfare. Consumer goods are specified at a detailed level with a view to capture important substitution possibilities. Energy goods transport fuel, heating oil and electricity are specified and different polluting and environmentally friendly forms of transport can replace own car use. Own car use can also avoid climate emissions by investing in new vehicle types with alternative technologies. The modelling of these choices is explained in the next section. Households can borrow from and save in the international finance markets where they, by assumption, face a given interest rate, reflecting that the economy is small and open.

The production side of the model specifies about 40 firms and 60 products which are classified with a view to displaying differences in emissions and substitution possibilities among goods. Each firm produces its own product variety different form others; this implies a certain degree of market power in separated domestic market niches. Firms maximise the current value of the cash flow in setting production levels and composition of factor inputs, including one type of labour, different types of capital, goods, services and energy goods, among them fossil fuels. As for households, firms may also choose to invest in different climate technologies; see below. Increasing production increases unit costs (diminishing returns to scale). Production within an industry can also expand through entry of new firms and varieties. A wider variety range increases utility and productivity of the goods (love of variety).

The model provides a detailed description of electricity supply, distinguishing between hydro power and natural gas power, transmission and distribution. Gas power producers can invest in carbon capture and storage (CCS) technology. Norway's trade in the Nordic market is modelled. Due to policy and resource restrictions, the following activities are exogenously determined: Production of public goods and services, oil and gas, and hydroelectric power and output from agriculture, forestry, fishery, and hunting.

Norwegian firms compete with foreign suppliers in the domestic market and abroad. As the Norwegian economy is small, the prices are set by the global markets. In the case of most commodities there is room for different price developments of Norwegian and foreign commodities on the domestic market (Armington hypothesis). There is also room for domestic market prices to develop differently from export prices, modelled by the cost to firms of switching between the domestic and export markets within a Contant Elasticity of Transformation model.

2.3 Technology adaptations

A distinct feature of this version of the model, MSG-TECH, is that households, firms and public institutions can choose to invest in completely new technologies with lower emission intensities. This applies to the process industries (sector 27, 34, 37, and 43 in Table A1 in the appendix), the petroleum industry (sector 66), as well as the road transportation activities of firms, households and the public sector. Along with households, the service industries land transportation (sector 75) and other private servicing (sector 85) are the largest users of road transport. By adding into the model realistic emission reduction possibilities through technology investments and their associated economic costs, agents will have a wider range of possibilities than traditional equilibrium models allow for. We have exploited information on emission reduction potentials and costs of different specified, more or less developed technology options. The data, estimations and results are accounted for below and in greater detail in Fæhn et al. (2010).

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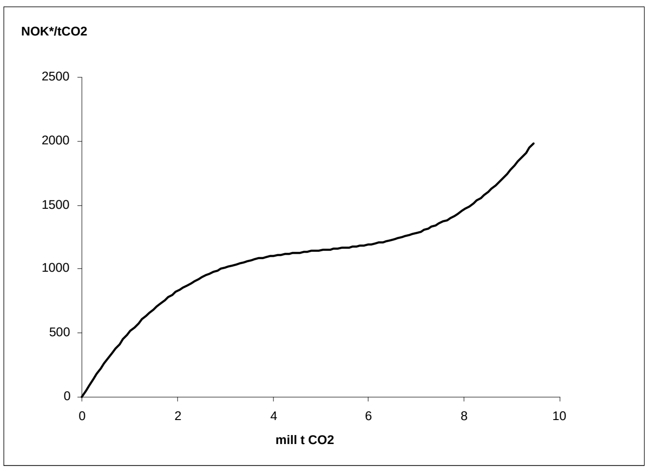
[2] These include carbon dioxide (CO_2), methane (CH_4), laughing gas (N_2O), and the fluorine compounds SF6, CFC and HFC.

Process industries

We estimated the costs for the following industrial processes: cement production (in sector 27 in Table A1 in the appendix), production of chemical commodities (in sector 37); aluminium production (in sector 43); iron/steel/ferroalloys (sector 43), and oil refining (sector 40). The technological adaptations investigated include different ways of converting to bio-energy, process optimisation, as well as sequestering of GHG emissions, which includes CCS. The following sources were used to estimate abatement costs: SFT (2007) and SINTEF (2009); SFT (2009); TELTEK (2009); and Climate Cure 2020 (2010).[3] If we arrange the measures by cost annuities and position them in an (X-Y) diagram where accumulated emission reductions are plotted along the X axis and costs of the marginal technology measure along the Y axis, we can estimate a marginal abatement cost curve. We have estimated the following curve for the process industry as a whole:

Figure 1: Marginal abatement cost curve, process industry



[*] 100 NOK = 12.5€

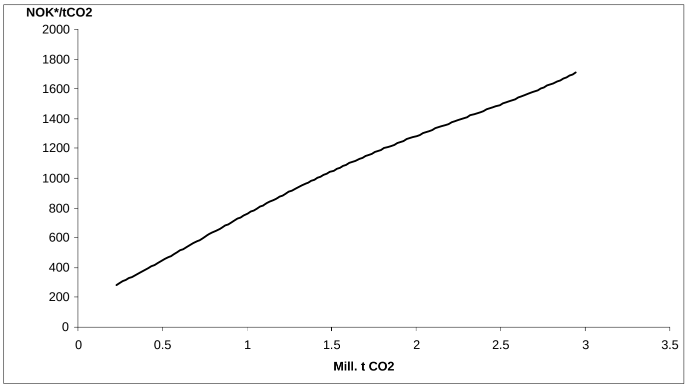
Road transport

The sources of information on reduction potentials and costs in road transportation are SFT (2007) and Kanenergi/INSA (2009). In addition to improving efficiency of passenger cars and commercial vehicles, the measures within road transportation comprise private and public zero-emission vehicles, fuel intermixture of ethanol and biodiesel, and measures to coordinate land planning. Our sources assess sensitivity to costs and potentials for the sequence in which the measures are phased in. In our assumptions, the medium estimates are used and the cheapest measures are assumed to be introduced first.

The emissions are all measured in CO_2 equivalents according to their global warming potentials (GWP).

[3] Climate Cure 2020 was a government-appointed commission tasked with preparing the ground for an evaluation of Norway's climate policy.

Figure 2: Marginal abatement cost curve, road transport

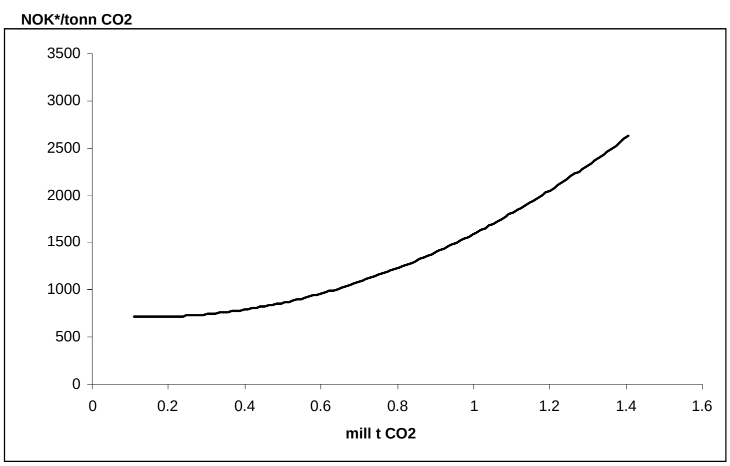


* 100 NOK = 12.5€

Petroleum sector

Measures for the petroleum sector were quantified by the Norwegian Petroleum Directorate (NPD, 2010). They include various forms of alternative power supply to the offshore sector (electrification, wind power), power efficiency improvements and CCS.

Figure 3: Marginal abatement cost curve,



* 100 NOK = 12.5€

2.4 Emissions and climate policy instruments

The model’s production and consumption activities are linked to coefficients for emissions to air as projected by the emissions inventory of Statistics Norway. The emission-generating activities include intermediate goods, energy goods, consumption activity, processes and waste disposal sites. There is a relatively detailed modelling of climate policy instruments, allowing for differentiated and uniform GHG taxes, national and international allowance systems, free allowances, and investment subsidies for climate technologies. It is assumed that the authorities' budget balance is always maintained. In the version of the model used here, this is accomplished by adjusting employers' social security contribution.

3 Design of the analysis and main assumptions

In section 4, we analyse and compare three different policy strategies, all aimed at the same unilateral ambitions for 2020, exemplified by the climate ambitions of Norway reported to the United Nations in the wake of the Climate Change Conference in Copenhagen in 2009. These include continued participation in the European emissions trading system (EU-ETS), contributions to global abatement, and a cap on domestic emissions.

The three scenarios differ with respect to how the domestic cap is met. In all scenarios a uniform emission price is imposed on all Norwegian GHG sources. The difference between scenario I and II is that the government succeeds to commit to the future policy in scenario I, while the policy lacks confidence in scenario II. In scenario III, commitment is not ensured, but the emissions pricing scheme is supplemented by subsidies to up-front investments as a second best approach to encouraging up-front investments in abatement technologies.

Scenario I is analysed in section 4.1, compared to a reference scenario without the climate policy ambitions for 2020. For the reference scenario, see section 3.1. In section 4.2 policy scenario II is compared with scenario I to reveal the importance of conducting a policy that encourages long-term dispositions within firms and households. In addition, scenario II replicates how abatement challenges are traditionally modelled in the CGE literature, where all measures are defined within existing technologies. Thus, it helps identifying the difference between applying a hybrid model approach and a traditional CGE method. The costs of the second-best subsidy policy is identified by comparing scenario III with scenario I in section 4.3.

3.1 The reference path

The reference path coincides with the reference scenario published in Climate Cure 2020 (2010). It is based on realistic developments in economic variables and technologies for the next decades. Main driving forces are the demographic development, natural resources forecasts, where a continuing growth in oil and gas production is anticipated, as well as a projected productivity growth of between 1 and 1½ per cent yearly.

Policy assumptions are based on current practice. When comes to the climate policy, in particular, the Norwegian differentiated system of CO2 taxes in 2004 is included and prolonged throughout the reference path. The rates vary between 0 and 50€/tonne, with petrol and emissions from offshore production of oil and gas at the highest rates; see table 1. Norway's international commitments in the Kyoto Protocol and the EU-ETS since 2008 are not included in the reference, but introduced in the policy scenarios. Only the impact of these multinational arrangements abroad is reflected in the exogenous estimates for world market prices.

Table 1: CO_2 tax rates in the reference scenario, €/ tonne (2004 prices)

	Rate
Maximum taxes by fuels	
- Gasoline	50
- Coal for energy purposes	24
- Auto diesel and light fuel oils	22
- Heavy fuel oils	19
- Coke for energy purposes	18
Taxes by sectors and fuels	
North Sea petroleum extraction	
- Oil for burning	42
- Natural gas for burning	48
Pulp and paper industry, herring flour industry	10
Ferro alloys, carbide, and aluminum industries, production of cement and LECA, air transport, foreign carriage, fishing and catching by sea, domestic fishing, and goods traffic by sea	0

Source: Statistics Norway

In the gas power industry, CCS is assumed installed already in the reference path from 2014, in accordance with the plans of the Government.[4] Figure 1 depicts the development of overall GHG emissions in the reference path from 2008 to 2020. Except for a small downward movement in domestic GHG emissions from 2013 to 2014 because of the CCS instalment, the emissions increase steadily in the reference path until they reach 59 million tonnes in 2020.

3.2 The targets in the policy scenarios

All the scenarios account for international contribution targets of the Norwegian government within the frameworks of the EU-ETS and UNFCCC[5] until 2020, as well as a domestic target in 2020. All these targets are reported to the UN in January 2010 in the wake of the Copenhagen negotiations.

[4] After the construction of the reference path, these plans have been postponed until 2018.
[5] United Nations Framework Convention of Climate Change

For the period 2008 – 2012 the EU ETS participation implies that oil and gas producers, manufacturers of chemical and mineral products (including cement), pulp and paper commodities, chemical raw materials (including fertilizer), refined oil products, gas power generation and parts of the metallurgical industries are quota regulated, embracing about 40 per cent of current Norwegian climate gas emissions. From 2013 the rest of the metallurgical industries are also included.[6]

It is assumed that the European allowance price is determined abroad independent of domestic actions. Total Norwegian allowances amount to 75.2 million metric tonnes, capped at 15 million metric tonnes annually over the first five years, while it gradually declines until 2020, when it reach 79 per cent of the 2005 emissions, according to the EU ETS specifications. In the first period 87 per cent of the allowances allocated to the firms affected are free of charge with the exception of the offshore sector which has no free allowances. Since the size of the subsidy follows from historical emissions, it is introduced as a lumpsum transfer to the firms from the public budgets. Firms will be allocated up to 100 per cent of their allowances free of charge when production competes with manufacturers outside EU ETS. This, we assume, will apply to two-thirds of the firms' operations.[7]

The global contribution targets within the UNFCCC framework includes an over-fulfilment of the Kyoto commitments by 10 per cent. Norway has also reported to UN a self-imposed ambition of contributing to global mitigation corresponding to a 30 percent reduction from the national 1990 emission level. In order to meet these targets it is assumed that the government can supplement the EU-ETS instruments and the remaining CO2 tax system with use of the flexible Kyoto mechanisms. The most prevalent mechanism to date is the Clean Development Mechanism (CDM), which permits the purchase of emission reductions from projects in developing countries.

The over-fulfilment of the Kyoto Agreement implies a total emissions ceiling of 225 million metric tonnes CO_2 equivalents in the five years 2008−12 or a maximum annual global emission contribution of 45 million metric tonnes CO_2 equivalents for each of the five years. The self-imposed global target for 2020 is equivalent to a ceiling of 35 million metric tonnes CO_2 equivalents from 2020. In the period between 2012 and 2020, we assume the annual Kyoto ceiling is kept constant.

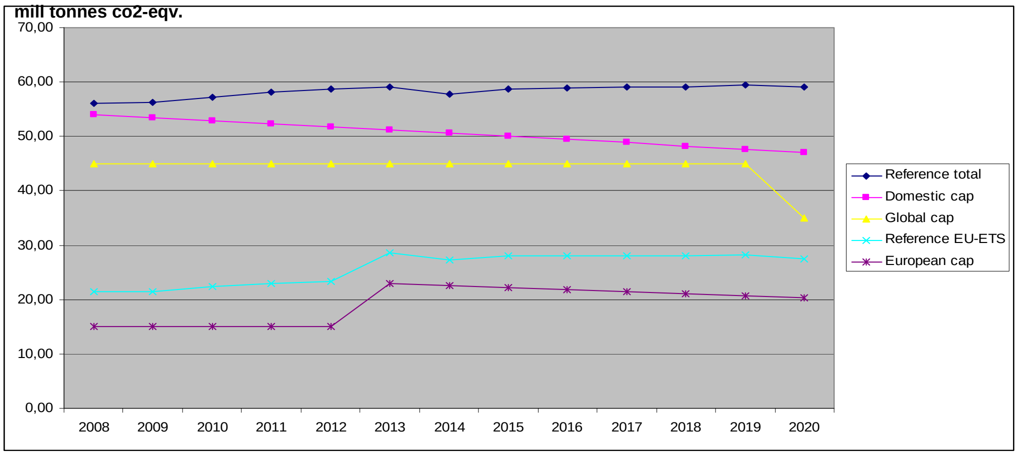
The domestic emission target comes on top of these international aspirations. It corresponds to reserving at least half of the global reduction ambition in 2020 for domestic measures. We assume that this 2020 goal is approached gradually from the 2008 level. The reference emissions for the economy

[6] These include sector 27, 34, 37, 43, 40, 66 and 70 in Table A1 in the appendix.

[7] In addition, a separate market connected to EU−ETS will be introduced for emissions from European air traffic from 2012. The calculations do not include the aviation market.

as a whole and for the EU ETS industries are depicted in figure 4, along with the over-all domestic cap, the global target and the committed emission cap for the EU ETS industries. As reflected, in every period the domestic cap lies higher than the annual global targets. It means that the country as a whole will have to buy allowances abroad in addition to making national cuts.

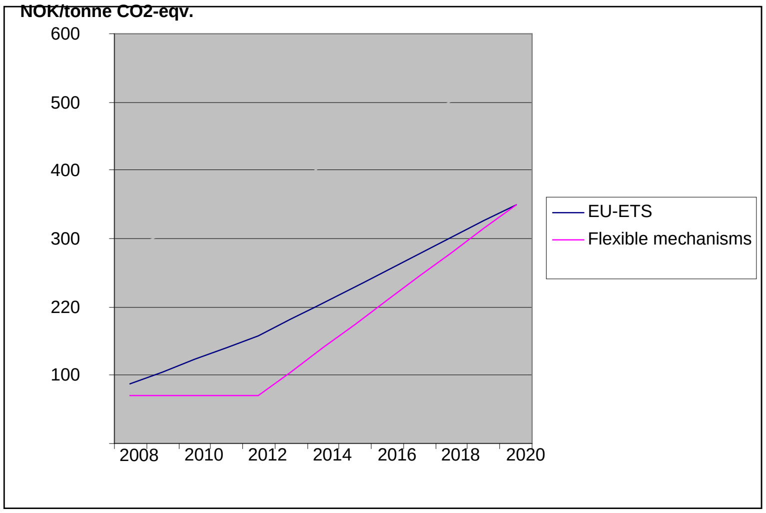
Figure 4: Reference path emissions (total and in EU ETS sector), and domestic, European, and global caps; million tonnes CO_2 equivalents



3.3 Emission prices and policy instruments

The exogenous, internationally determined emission prices in scenario I, II and III are assumed to develop as shown in Figure 5, in accordance with the medium estimates from Climate Cure 2020 (2010). The EU ETS price increases to 40€ within 2020, while the flexible mechanisms have so far remained significantly below the EU–ETS price and is assumed to stay below until 2020.

Figure 5: Allowance prices in scenario I, NOK/tonne CO_2 equivalents, 2004 prices



100 NOK = 12.5 €

In order to keep emissions below the cap, an endogenous, uniform price on all GHG emission sources is imposed on all emission sources. A national emission price will require the EU ETS sector to pay an additional price over and above the European allowance price to the Norwegian authorities, exactly sufficient to reach the domestic target.

In scenario I the private risk related to future costs of emitting is neutralised by a legal assurance arrangement between the private agents undertaking emission reductions and the government. Hoel (2008) sketches an alternative with allowance sales options. An agent undertaking investments based on the future price forecast of the government, receives sales options for each forthcoming year corresponding to the emission reductions he realises. The sales options guarantee that the government purchases the allowances at the forecasted price. If the price in a given year falls short of the forecast, the agent can buy relatively cheap allowances in the market and use his sales options to earn the difference between the market price and the forecasted price. The allowance trading will exactly compensate for the costs in excess of the expenditure savings on allowances caused by his abatement efforts. If the price reaches the forecasted level, the undertaken abatement efforts are profitable without allowance sales. There will be nothing to earn on the sales options, and they will not be used. We assume that scenario I is characterised by an assurance arrangement similar or equivalent to sales options, which perfectly compensates for the political risk component of the domestic emission price.

On the other extreme, scenario II excludes any longsighted adaptation. The major problem in this regime is that long-term investments in abatement technologies will be hampered. High political uncertainty render expected emission price changes insignificantly different from zero. All up-front investments in climate technologies will, thus, be perceived unprofitable. Only abatement efforts with rather instantaneous emissions effects will be worthwhile. Firms will rather reduce variable costs and scale down output, while households will substitute consumer goods for energy, and leisure for consumption.

In scenario III both down-scaling and technological adaptations take place in spite of lack of confidence, but the latter are triggered not by emissions pricing, but through subsidies. The subsidy amount exactly compensate for the abatement costs of the agents.

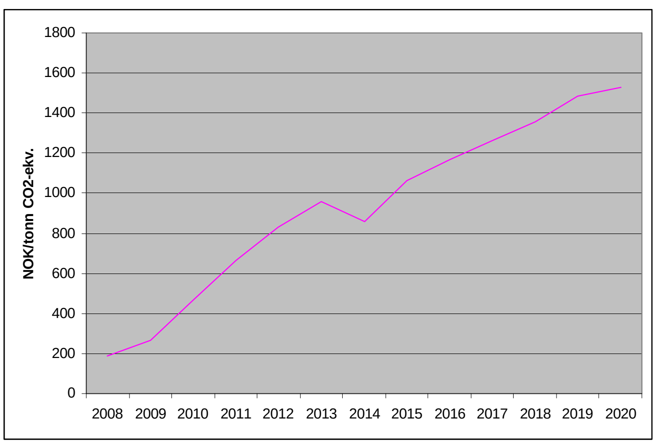
4 Analysis and comparison of the three policy scenarios

4.1 Scenario I: Guaranteed future emission prices

Impact on domestic emissions and allowance trading

To comply with the domestic target, the uniform emission price rises to 1500 NOK – equivalent to 188€ - per tonne of CO2 equivalents within 2020; see Figure 7.

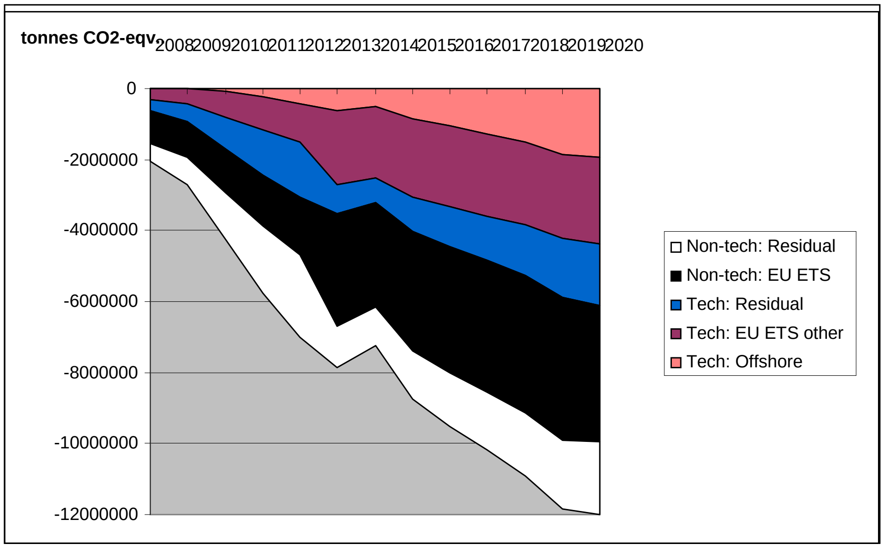
Figure 7: Scenario I: National emission price curve; NOK/tonnes of CO2 equivalents (2004 prices)



100 NOK = 12.5 €

Since the CO_2 taxes in the reference path were primarily levied on sources not covered by the EU ETS (the residual sector), the uniform emission price releases relatively small effects in this sector in the very first years. The main adjustments take place in the previously untaxed EU ETS sector; see figure 8. Thereafter, gradually more will take place in the residual sector. In the beginning, the largest reductions will be achieved within technologies existing in the reference path (called *Non-tech* in figure 8), particularly by scaling down operations. Gradually, technological adaptations (called *Tech* in the figure) acquire increasing significance. From 2013, when metal production is incorporated into the EU-ETS sector, most of the emission cuts in the period to 2020 will be explained by measures in the EU-ETS sector, and technological measures will account for about as much as the scale adjustments.

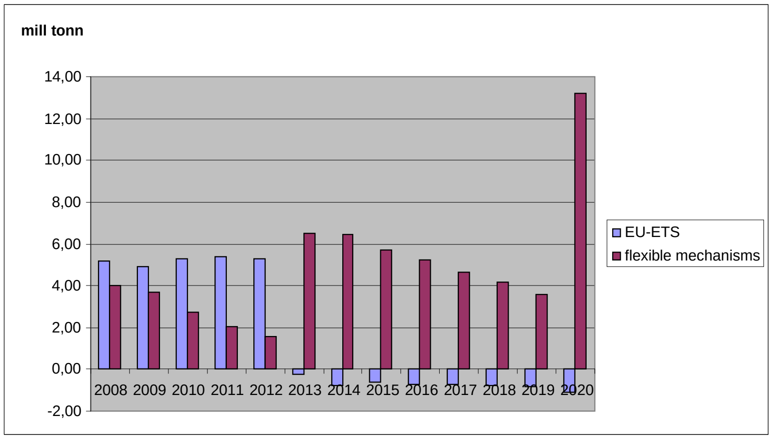
Figure 8: Scenario I: Emission reductions by category



Of the total emission cuts of 12 million metric tonnes CO_2 equivalents by 2020, 8.2 million tonnes are taken in the EU ETS sector, including the petroleum sector. Technological adaptations in the EU ETS sector account for about 4.4 million metric tonnes CO_2 equivalents; the remainder follows from scaling down activity levels. Within the EU ETS sector the petroleum sector helps cut emissions by 1.9 million metric tonnes CO_2 equivalents. The model calculates as per assumption very small activity changes in this industry, and virtually the entire reduction results from technological adaptation. The residual sector cuts 3.8 million metric tonnes CO_2 equivalents. Here, per assumption, only road traffic emissions can be cut by technological improvements, and accounts for cuts amounting to 1.7 million metric tonnes CO_2 equivalents. The remainder comes from downscaling energy consumption and activity levels.

While the uniform emission price enables domestic climate policy targets to be achieved, the international commitments over and above the domestic abatements will still be met by allowance purchases abroad. Figure 9 depicts the evolution of allowance purchasing in the EU–ETS markets and via the flexible mechanisms.

Figure 9: Scenario II: Allowance purchases abroad, in million metric tonnes CO_2 equivalents



The estimates show that in the pre-2013 phase the domestic cuts made by firms will be too small to fulfil EU ETS commitments. After that time, however, domestic reductions will more than meet commitments, and Norwegian firms will be in a position to sell emission rights on the EU ETS market. Norway's target for *global* contributions requires, however, more substantial cuts than the national ceiling provides for. The government must therefore purchase emission rights via flexible mechanisms. In 2020, the self-imposed ceiling will require purchasing more than 13 million metric tonnes CO_2 equivalents via these mechanisms and, by assumption, at a price in the same league as the EU ETS allowance price.

Social abatement costs

The social costs of fulfilling the targets equal a cut in welfare of ¼ per cent, equivalent to 100€ yearly per person. The largest component of welfare costs will in this scenario be associated with the efforts within firms and households to cut domestic emissions. The marginal cost of these changes is represented for each year by the estimated domestic emission price. Its path is shown in Figure 7. Allowance purchases constitute the other main cost component. In spite of negative purchases (i.e. sales) in the European allowance market for much of the period up to 2020, the real value of the total allowance acquisition for the country as a whole equals about 20 per cent of the total macroeconomic costs.

Since the emission prices paid by the firms for residual emissions will rise considerably in time, significant government revenue will be generated in this scenario. This additional revenue is fed back into the economy through reduced pay roll tax rates of around 30 per cent compared with the reference path. This helps bring about lower wage costs which are shifted on to higher real wages. As a consequence, labour supply rises of between a ½ and 1 per cent. As initial tax distortions are considerable in the labour/leisure choice, these adjustments improve social efficiency and welfare.

In addition, we find that the induced changes in the industrial pattern are beneficial for the economy as whole. A main explanation is large input price distortion in the process industries. The down-scaling that takes place, particularly in production of chemical raw materials and of metals, releases resources for activities with relatively higher macroeconomic marginal returns.

4.2 Scenario II: Unreliable future emission prices

Impact on domestic emissions and allowance trading

The emission price reaches far higher levels in absence of reliable signals, because potentially profitable up-front investments are discouraged. The estimated development is depicted in Figure 10. In 2020 the level exceeds 4000 NOK/metric tonnes of CO2 equivalents, which is about three times higher than in the more cost-effective case of scenario II.

Figure 10: Scenario II: National emission price curve; NOK/tonnes of CO2 equivalents (2004 prices)

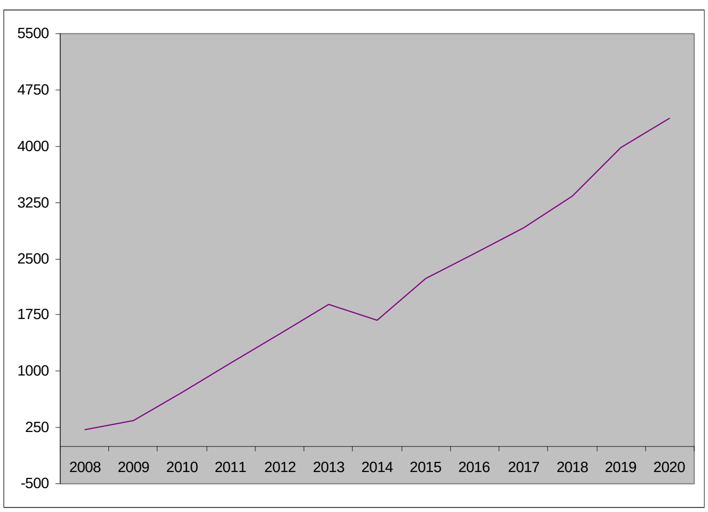


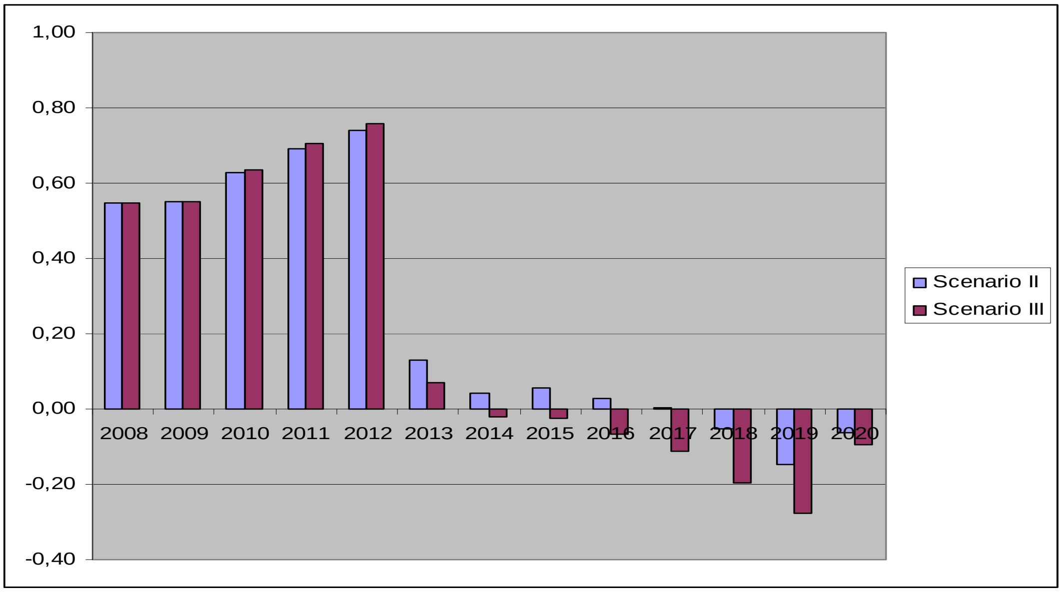
Figure 11 illustrates the change in the distribution of emission cuts from scenario I, where technological adaptations are encouraged, to scenario II, where incentives for technological measures are absent. We see that abatement in the EU ETS sector increases after 2012; the share of total abatements increase by 5 to 6 percentage points. The internal composition of the cuts within the sector shifts from emission sources in the petroleum industry, where opportunities consist, by assumption, only of technological investments, to the process industries. Reductions within production of Metals and of Chemical Raw Materials predominate. These industries take more of the burden, since their production is highly cost elastic due to high export shares and negligible opportunities for cost shifting within the world markets. Since the Metal industry is part of the residual sector before it enters EU ETS in 2013, the abatement within the residual sector also increases and actually acquires a 2 percentage points larger share in scenario III during the first years.

The activities within rest of the residual sector are less elastic. This translates into a lower abatement share for the residual sector after 2012. Service production is more oriented towards the home markets, where costs to a higher degree can be passed on to the consumers. Road transportation is typically little price elastic. When up-front technology investments render unprofitable because of high perceived uncertainty, less car driving hardly compensates, and GHG emissions from road transport inevitably rise. Domestic shipping does, however, adjust more elastically and takes a significantly larger share of the burden.

Figure 11: Scenario II vs I: Shares of domestic abatement undertaken by the EU ETS sector

The EU ETS allowance trading mirrors the increased abatement efforts within the EU ETS sector post 2012, which reduces the need for allowances. There is a stronger bias towards use of the flexible Kyoto mechanisms. The overall international trading of allowances will be the same and determined by the domestic and global targets (see Figure 4).

Figure 12: Scenario II vs I: Shares of European allowance purchases in total purchases



Social abatement costs

Failing to signal that the climate policy is reliable and enduring renders the welfare costs of the policy almost four times higher. Domestic abatement costs explain most of this. Replacing socially profitable technological measures by costly contractions of consumption and industrial activities will increase average costs than the tripling of *marginal* domestic abatement costs, defined by the emission price, indicate. This is because the domestic marginal abatement cost curve in absence of technology measures becomes markedly concave.

Several changes between scenario I and scenario II contribute to dampen macroeconomic costs. Firstly, the allowance purchases become slightly cheaper because of the compositional change. Secondly, production and employment in traditional manufacturing tend to suffer the most. This, in isolation, benefits the economy as a whole, since the sector enjoys favourable industrial policy arrangements at the outset. In addition, the revenue recycling gains are larger in scenario III than II because of the high emission tax rates necessary. Labour supply increases by 1½ per cents.

5 Final discussion and conclusions

Two main conclusions can be drawn from our computations. Firstly, our estimates suggest a tripling of costs if the government fails to give reliable policy signals that match its announced domestic target. The reason is that up-front investments in climate technologies will be hampered. We have interpreted the barriers as a policy failure and suggested some lines of policy response. Whatever the origin, the scenarios with technology barriers can also illustrate the shortcomings of a traditional CGE analysis as compared to our hybrid approach. It points to the large danger of overestimating abatement costs in top-down (as well as bottom-up) analyses and the necessity of combining the two approaches.

Secondly, even if technological adaptations fail to be triggered by emissions pricing, a second-best subsidy policy can ensure their implementation. Subsidising technological diffusion can be politically and practically easier than designing an insurance scheme. A subsidy scheme will increase costs, as significant budgetary transfers will be needed. We have assumed that conversion to new technologies involves investment costs, only. Albeit technology adaptations are typically capital intensive, the cost structure of climate friendly technology adaptations vary in practice, as does the durability of the capital. The estimated need for subsidies is, therefore, overestimated.

Likewise, the substantial cost addition caused by low faith in the future climate policy also hinges on the precondition that all costs must be borne up-front. In reality, different technologies will be hampered to different degrees by the lack of trust.

The large cost differences we find is sensitive to the marginal abatement cost estimates of technology projects. There are reasons to believe that abatement costs differ considerably between firms, industries, countries, contexts, and through time. Our data are based on sector-specific, current knowledge and primarily on Norwegian studies, which should give a good representation of costs. However, future technological potentials are difficult to predict.

Another source of uncertainty applying to the technology assumptions is that the basic data tend to depict *social* costs of climate investments. If there are significant market failures in technology diffusion, the data may poorly represent the decision bases of firms. Stakeholders frequently claim that market failures tend to hamper climate technology diffusion and call for public facilitation. However, empirical evidence on such failures is still scarce, and there is reason to expect that if they exist, they tend to be largely case and market specific.

These reservations have led us to conduct sensitivity analyses of the technological abatement cost assumptions. They indicate that the implications of technological barriers, although uncertain, most likely are severe and should be avoided. Even with conservative estimates they turn out to be higher than indicated by the global study of Bosetti and Victor (2011), who find an additional cost of 70 per cent. This is reasonable. Abatement in a prosperous and well-organised economy is likely to be relatively costly, because there is reason to expect that climate consciousness and policies have already inspired to climate-friendly economic behaviour, that the state of technology is more advanced, and that resources including energy are more efficiently used.

The estimated cost levels of all the scenarios, including the reference scenario, are uncertain. Apart from a large variety of unsystematic sources of uncertainty, two main shortcomings of our method should be emphasised. Firstly, the CGE approach leaves out transition costs, tending to underestimate the abatement cost levels, particularly when the perspective is as short as in this study. The second reservation we wish to make is that, as shown, costs are highly sensitive to the range of potential abatement measures covered by the model. Some adjustments are by assumption excluded from the simulations. We have mentioned that possible contractions within the petroleum industry are omitted. Similar assumptions apply to agriculture and fisheries. There are also reports covering technological opportunities beyond those modelled in our approach (e.g. within heating; see NWREA, 2010), which would add to the abatement potential. Generally, including more abatement potential would decrease the cost levels (though not necessarily the ranking of the policy strategies).

References

(Preliminary - to be updated)

Bosetti V., C. Carraro, M. Galeotti, E. Massetti and M. Tavoni (2006): WITCH: A World Induced Technical Change Hybrid Model; *The Energy Journal*, Special issue on Hybrid Modeling of Energy-Environment policies: Reconciling bottom-up and top-down, 13-38.

Böhringer, C., A. Müller, and M. Wickart (2003): Economic impacts of a premature nuclear phase-out in Switzerland – An applied General Equilibrium Analysis, *Swiss Journal of Economics and Statistics*, 139 (4): 461-505.

Bye, B. (2008): Macroeconomic modelling for energy and environmental analyses: Integrated economy-energy-environmental models as efficient tools, Documents 2008/14, Statistisk sentralbyrå.

ETSAP (2004): Documentation for the MARKAL Family of Models, Energy Technology Systems Analysis Program, http://www.etsap.org/documentation.asp.

Fæhn, T., L.-M. Hatlen, K. Jacobsen og B. Strøm (2010): MSG-TECH: Analyses and documentation of a general equilibrium model with endogenous climate technology investments, forthcoming in Reports, Statistics Norway.

Hamilton, L. D., G. Goldstein, J.C. Lee, A.S. Manne, W. Marcuse, S. C. Morris, and C.O. Wene (1992): MARKAL-MACRO: An Overview, Brookhaven National Laboratories #48377, November.

Hoel, M (2008): Økonomiske analyser av klimaproblemet (Economic analyses of the climate problem), *Samfunnsøkonomen* 6/7, 50-61.

Kanenergi/INSA (2009): Vurdering av biodrivstoff i transportsektoren, tiltak, virkemidler, effekter og kostnader i 2020 og 2030 (An assessment of biofuels in transportation), Report.

Klimakur 2020 (2009): *Vurdering av framtidige kvotepriser (An assessment of future emission allowance prices)*, TA 2545/2009, Statens forurensningstilsyn (now Klima- og forurensningsdirektoratet), Norges vassdrags- og energidirektorat, Oljedirektoratet, Statistisk sentralbyrå, Statens vegvesen.

Klimakur 2020 (2010): *Tiltak og virkemidler for å nå norske klimamål mot 2020 (Measures and public instruments for meeting Norwegian climate targets towards 2020)*, TA 2590/2010, Klima- og forurensningsdirektoratet, Norges vassdrags- og energidirektorat, Oljedirektoratet, Statistisk sentralbyrå, Statens vegvesen; English summary available at www.klimakur2020.no.

Laitner, J.A and D. A. Hanson (2006): Modeling Detailed Energy-Efficiency Technologies and Technology Policies within a CGE Framework, *The Energy Journal*, Special Issue on Hybrid Modeling of Energy-Environment Policies: Reconciling bottom-up and top-down, 151-170.

Loulou, R. and D. Lavigne (1996): MARKAL model with elastic demands: Application to GHG emission control, in C. Carraro and A. Hairie (eds): *Operation Research and Environmental Engineering*, 201-220, Boston: Kluwer Academic Publishers.

NWREA (2010): Energy supply and demand, an analysis for the KLIMAKUR 2020, Norwegian Water Resources and Energy Administration

NPI (2010): Prospects for abatements in the Norweigan oil and gas industry; a subreport of Klimakur 2020, Norwegian Petroleum Institute (NPI)

Rosendahl, K. E. and J. Strand (2010): The clean development mechanism and carbon leakages, forthcoming as discussion paper, Statistics Norway.

SFT (2007): Tiltak for reduksjon av klimagassutslipp i Norge, delnotat om virkning av mulige tiltak for reduserte utslipp fra kjøretøy, Statens forurensningstilsyn (nå Klima- og forurensningsdirektoratet)

SINTEF (2009): Tiltak og virkemidler for reduksjon av klimagasser i norsk prosessindustri (Measures and public instruments for abating climate emissions from Norwegian processsing industries, Report A11606 SINTEF.

Stern Report (2007): *The economics of climate change*, Cambridge UK, University Press, Cambridge

TELTEK (2009): CO2-fangst av utslipp fra industrianlegg,(Carbon capture of emissions from manufacturing) Report 2109020

Appendix 1

Table A1: Production activities in MSG-TECH (forthcoming)