THE ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAMME: HISTORY, THE ETSAP KYOTO STATEMENT AND POST-KYOTO ANALYSIS

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Abstract

The IEA Energy Technology Systems Analysis Programme (ETSAP) has a long-standing tradition as an internationally cooperative partnership that develops methodologies and tools to study energy and environmental issues, and applies these to inform national and international bodies. The core tool of ETSAP is the energy model MARKAL, over time expanded into a suite of centrally maintained models allowing for the integrated assessment of economic impacts and feedback, of material flows, and of the impact of uncertainties on policy and investment decisions. Today the ETSAP tools are available and used by over 50 institutions in more than 35 countries for a variety of purposes, including preparation of FCCC communications and related climate response policies.

Already in the early nineties, ETSAP embarked on exploring common strategies for groups of countries cooperating to meet jointly agreed environmental targets. The detailed representation of technical energy systems in MARKAL-type models allows to capture the specific national conditions and concerns such as access to resources, historically developed structures, preferences and policies, and future options in the analyses. Thereby the main drivers for current and future energy consumption patterns and associated emissions of Greenhouse Gases and other pollutants are identified, together with the options and costs to break from baseline trends to arrive at more sustainable energy futures. The role for new technologies in energy supply and conversion, but well balanced by end-use efficiency and conservation options in all sectors, remains the key element of ETSAP's concerns. However, in recent years the MARKAL-MACRO linked model and other comprehensive Energy/Economy/Environment (E3) applications, provide for a more general economic framework for the energy systems analyses.

In preparation for the COP-3 meeting in Kyoto, several participants and cooperating partners were actively contributing with ETSAP tools to national activities and discussions. ETSAP as a group submitted and presented analyses to the AGBM and SBSTA (groups established to assist and prepare COP meetings), illustrating its capabilities to perform multi-national analyses pertinent to the development of a Protocol on legally binding commitments under the FCCC. Together with a brief introduction of ETSAP, main messages from these analyses were summarized in the so-called 'ETSAP Kyoto Statement' that was distributed and presented at the COP-3 meetings. Core features of these analyses are comparative assessments of alternative criteria and formulas to arrive at differentiated emission reduction commitments, focusing on aspects of cost-effectivity and equity. Key conclusions are that cost-effectivity and equity are not easily reconciled in strategies, even among relatively homogeneous economies like OECD member states. It was also observed that implementation of flexible, international instruments could form an important factor to bridge the two requirements, least overall costs and equity. Tentative exploration of these directions was undertaken on an experimental basis, confirming the favorable prospects.

In the Kyoto Protocol ample room is given to such internationally collaborative instruments, besides allowing for flexibility with regard to what emissions in a basket of six gases and associated with many types of economic activity to reduce to comply with the commitments. Anticipating further development and application of ETSAP tools at the national and international level, ECN Policy Studies has initiated an analysis recognizing the requirements and opportunities of the Kyoto Protocol to examine alternative schemes to distribute the overall EU commitment among its member states. Further analyses can also start to draw on information from LDCs and other non-OECD countries available within the ETSAP/MARKAL community to broaden the scope of supplying material for an informed discussion on collaborative greenhouse gas mitigation policies.

HISTORY OF ETSAP

The Energy Technology Systems Analysis Programme (ETSAP) has a long-standing tradition. It was founded in 1980 as the successor to a joint project launched by the International Energy Agency (IEA) as early as 1976 with the aim to develop capabilities to analyze long-term energy futures and related R&D programmes. ETSAP is an internationally cooperative partnership in which participants work together under an IEA/OECD research agreement. Active membership has fluctuated somewhat over the years, but today 14 IEA/OECD member countries participate in the ongoing research programme. Through bilateral and multilateral collaborative projects, ETSAP tools are available in and used by over 50 institutions in more than 35 countries for a variety of purposes, including preparation of national communications and related climate response policies for the UN Framework Convention on Climate Change.

The objectives of ETSAP can be summarized as follows:

- to perform comprehensive, consistent and comparable system analysis of energy/economy/environment (E3) issues;
- to provide information to national and international bodies;
- to promote and support global coverage of consistent analyses;
- to develop methodologies and tools.

Through the existing ETSAP network, coordinated multi-country studies have been undertaken based on its common methodology and approach and guided by shared assumptions on key exogenous inputs such as internationally traded energy forms and technological options. Central to these joint studies are the models developed and maintained at the national (and sub-national) level by teams of experts, often guided by so-called reference groups to ensure proper communication with science and research bodies, decision makers and other stakeholders. The core tool of ETSAP is the energy model MARKAL, the core of which was established in the early eighties. Over time this core was enhanced and expanded into a suite of centrally maintained models allowing for the integrated assessment of economic impacts and feedback, of material flows, and of the impact of uncertainties on policy and investment decisions (see below for more details on methodologies and tools).

The common ETSAP "language" in the form of methodologies and tools is accompanied by technology rich national databases that are under constant revision and updating, further aided by exchanges between participants to enhance harmonization and share resources. The detailed representation of technical energy systems in MARKAL-type models allows to capture the specific national conditions and concerns such as access to resources, historically developed structures, preferences and policies, and future options in the analyses. Thereby the main drivers for current and future energy consumption patterns and associated emissions of Greenhouse Gases and other pollutants are identified, together with the options and costs to break from baseline trends to arrive at more sustainable energy futures. These ingredients not only allow for interesting and useful comparative assessments of national strategies and options, but also to explore group strategies. Already in the early nineties, ETSAP embarked on exploring common strategies for groups of countries cooperating to meet jointly agreed environmental targets [ETSAP, 1994]. The role for new technologies in energy supply and conversion, but well balanced by end-use efficiency and conservation options in all sectors, remains the key element of ETSAP's concern, e.g. in the form of assessments and ranking of technologies and resources under varying future conditions and constraints. These include simultaneous consideration of multiple, often linked, areas of concern such as energy security, acidification, climate change, land-use changes, etc.

In line with national and international developments, the ETSAP programme went through a process of strategic evolution, reflected by key elements of its subsequent three-year research programmes or Annexes to the IEA research agreement since 1980:

Annexes:

I	Increase capabilities to analyze energy systems
II	Exchange data; promote and support stimulate common analysis
III	Energy and environment: acid gases
IV	Energy and environment: CO_2
V	Outreach: twinning (bilateral cooperation)
VI	Energy and environment: greenhouse gases (GHG)
VII	Combined technological and economic assessment
VIII	Outreach: contribute to international projects
IX	Coordinated GHG policy strategies
X	Planning under uncertainty
XI	Re-engineering models and new shells

Since the early nineties, the migration from large mainframe computers to desktop PCs, the introduction of user-friendly model shells like MUSS (MARKAL Users Support System) and the adoption of the more widespread modeling language GAMS, has initiated multiple experiments leading to a series of methodological innovations and advancements [ETSAP, 1997].

First, starting under Annex V, economic interactions were explored by various attempts to link the MARKAL technical process model with alternative economic model concepts. This development towards more comprehensive energy/economy/environment (E3) applications, was aimed to provide for a more general economic framework for the energy systems analyses. Thereby the scope of the assessment is broadened and a contribution is made to narrow the gap between the traditional 'bottom-up' and 'top-down' type of analytical assessments.

The **MARKAL-MACRO** model [Manne and Wene] is obtained by a building a hard-link between MARKAL and a (simple) neoclassical growth model. The linkage is based on the concept of an economy-wide production function, in which MARKAL provides the energy inputs and the energy costs incurred by MARKAL are subtracted from the total economic output. The remaining output is allocated to replace and expand the capital stock, and to consumption such that overall utility is maximized. Through the linkage GDP and consumption adjustments induced by energy and/or environmental developments are included, but also energy service demand feedback and economic impacts of technological changes, including the so-called rebound effect [Nystrøm; Musters]. It is tested and used by many and has become the standard tool for quite a few users throughout the world.

The scope of the **MARKAL-MICRO** model [van Regemorter] is not as wide as MARKAL-MACRO. It provides for price-elastic demands for energy services, with specific elasticities per end-use category. A similar goal is pursued by the MARKAL-ED model, but now the non-linear demand functions are stepwise linearized, so as to exploit the high performance of modern linear programming (LP) solvers. Both models provide a proxy for welfare adjustments due to energy and/or environmental developments in the form of the total producer and consumer surpluses.

While these two approaches are fully consolidated and part of the standard suite of MARKAL models, others have embarked on other experiments towards E3 formulations such as MARKAL-MACROEM (Japan), Endogenous (Italy) and Linked (Netherlands) I/O models and others; for more information, see [ETSAP, 1997]

Another line of research, started under Annex V and further developed and explored under Annex VI, relates to stochastic modeling. This to incorporate the impact of uncertainties with respect to endogenous and exogenous parameters into decision making. For example, decision makers are confronted with the need to decide on investments in energy equipment, while future levels of

demand are uncertain and future environmental restrictions are unclear. In particular if such bifurcations are expected to occur within the lifetime of the technology under consideration, the question arises what choices to make to minimize the risk of being "wrong" in future. For example, while coal power plants show the best economics in the absence of serious climate concerns, they may lose their viability in case of greenhouse gas reductions. As long as no firm, long-term commitments to the latter are made, the question is whether or not to build new coal power stations. By assuming alternative future trajectories each with a certain probability, and a point in time by which the uncertainty is resolved, so-called hedging strategies are identified that yield the least regret.

Production of energy-intensive materials, driven (indirectly) by the demand for products and services in an economy, typically make up a large share of total industrial energy consumption and related emissions. Therefore it can be argued that options to increase material efficiency (less materials to perform the same service), more efficient production processes, materials substitution and waste management options including re-use and recycling will become increasingly important for more sustainable economic development. An extended version of the MARKAL model is implemented and used to explore the potential for integrated energy and material flow assessment. Preliminary results for the Netherlands and for OECD-Europe confirm the relevance of this extension of the scope of MARKAL beyond the traditional energy sector boundaries.

Together with less profound, though equally valuable, enhancements and improvements (multiple electricity and heat grids; more flexible refinery structures; improved hydro reservoir operation; etc.) the above mentioned methodological extensions are all incorporated into the suite of centrally managed ETSAP tools.

THE ETSAP KYOTO STATEMENT

The adoption of the UN Framework Convention on Climate Change (FCCC) in 1992, now signed by some 160 countries, and the work of the Intergovernmental Panel on Climate Change (IPCC), induced a marked increase in interest for longer term energy assessments at the national and international levels. As mentioned in the previous section, ETSAP and its members started relatively early to perform such analyses and inform the relevant national and international bodies of the findings and insights gained.

As part of the FCCC process, it was decided that industrialized countries would agree to a Protocol on legally binding greenhouse gas emission targets for the period after the year 2000. This protocol was to be adopted at the third meeting of the Conference of the Parties (COP-3) in Kyoto, Japan late in 1997. During the preparation and discussions preceding the COP-3 meeting, country delegations submitted their views and proposals for so-called Quantified Emission Limitation and Reduction Objectives (QELROs). Within countries supporting analytical work was done to explore alternative QELRO schemes and alternative sets of rules and indicators on which these could be based. Several participants and cooperating partners were actively contributing with ETSAP tools to national activities and discussions in this stage [ETSAP News]. In addition, the ETSAP community as a group performed multinational analyses drawing upon the national model activities. The results of these efforts were submitted and presented to the AGBM and SBSTA (groups established to assist and prepare COP meetings), illustrating its capabilities to perform multi-national analyses pertinent to the development of a Protocol on legally binding commitments under the FCCC.

In light of guiding principles adopted in the FCCC, reflecting more general views on international environmental (and other) policy principles, it will be clear that QELRO schemes should be (a) **cost-effective**, so as to reach environmental goals at the lowest economic impacts; (b) **equitable** (or 'fair'); and (c) feasible in the technical and political sense. A related discussion was whether QELROs should be differentiated, or that relatively simple common reduction rates were to be preferred. In

case of differentiation, the guiding principles and rules for allocating targets were also an important subject of discussion and analysis.

If one wishes to explore alternative QELRO schemes and their implications, quantitative assessments would require that:

- a well-defined, transparent and common methodology is applied;
- model data and exogenous assumptions are sufficiently harmonized;
- national issues and concerns are reflected in the assessment;
- national case studies are adequately coordinated;
- a mechanism for comparative assessment is available.

As stated before, the ETSAP community has a proven track record of meting these requirements, summarized in its Kyoto Statement as follows:

'Providing an Internationally Collaborative and Comparable Capacity for Identifying Cost-Effective and Equitable Policies for Achieving Climate Change Objectives'.

A brief introduction of ETSAP, and the main messages from the analyses performed were summarized to give evidence of the Kyoto Statement, that was distributed and presented at the COP-3 meetings in Kyoto. Core features of these analyses are comparative assessments of alternative criteria and formulas to arrive at differentiated emission reduction commitments, focusing on aspects of cost-effectivity and equity. Starting point for the analysis is a series of trade-off curves describing marginal and total emission reduction costs associated with increasing reduction levels, see figure 1 for an example.

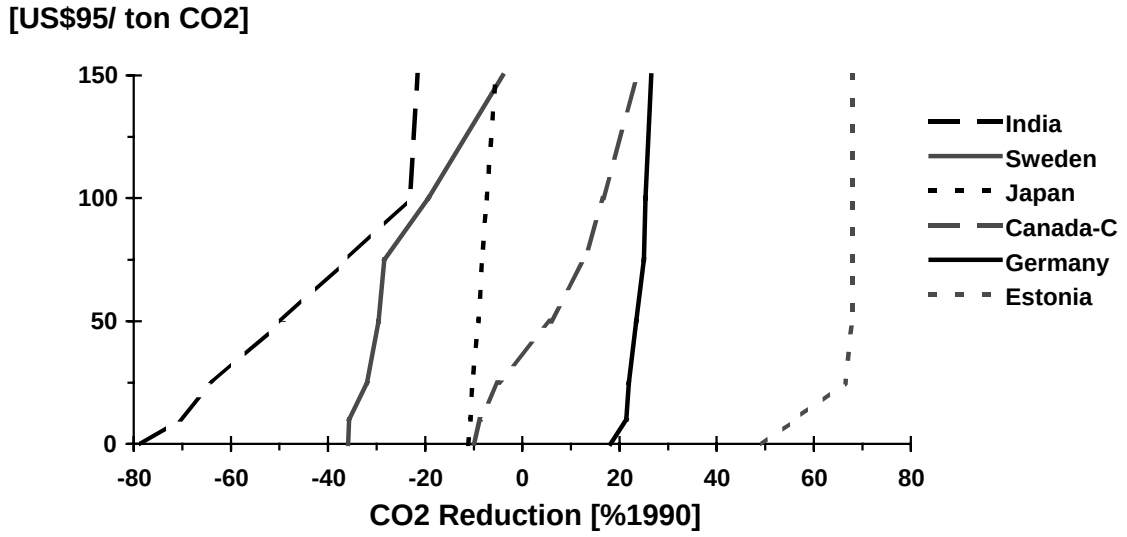

Figure 1: Marginal reduction cost curves for selected countries vary enormously

The example provided by figure 1 illustrates that some form of differentiation will be required to reach at least feasible QELROs, and even more to arrive at cost-effective and equitable schemes. The ETSAP analysis for the FCCC bodies looked at strategies for OECD countries only and compared the following three strategies:

- **Uniform Carbon Charge:** the same marginal reduction cost level is applied to all countries to reach stabilization as a group by the year 2020 (by default the most cost-effective solution to reach the common reduction goal in that year);
- **Individual Stabilization**: each country stabilizes its 2020 emissions at the 1990 level;

- **Norwegian Proposal**: country targets are differentiated by means of a formula combining 3 indicators (CO_2/capita; GDP/capita and CO_2/unit of GDP) to reach stabilization as a group by the year 2020.

For each of these strategies the outcome with respect to **cost-effectivity** (maximized if the marginal reduction cost level is the same for all countries, and poorer with larger differences between countries) and to **equity** (here expressed as the percentage of GDP spent by a country to comply with its emission reduction target; maximized if all pay the same percentage and poorer again with larger differences between countries). This implies that the spread between countries for these two indicators, represented by the standard deviation of the samples, represents the performance of the strategy with respect to each indicator. The result is displayed in figure 2, illustrating that while a uniform carbon charge yields the maximum cost-effectivity (on the horizontal axis, note that the origin represents the maximum scores possible), the associated burdens show considerable spread between the countries and the strategy is thus not very equitable when it comes to sharing the burden. Note that in the framework of this assessment no international instruments like emission permits trading or joint implementation were allowed, nor compensation payments between countries to make up for unbalanced sharing of the emission reduction efforts. The figure also shows that for this group of OECD countries both individual stabilization or a differentiated set of targets according to the Norwegian proposal would lead to more equity, but far less cost-effectivity. In other words: the total cost of the strategy is higher, but the burdens are more equally distributed. As the weight attached to either of the two indicators (and possibly to other implications not covered by the analysis) can differ, no conclusive indications can be derived from the comparison of strategies. The remaining key conclusion is that cost-effectivity and equity are not easily reconciled in QELRO strategies, even among relatively homogeneous economies like OECD member states.

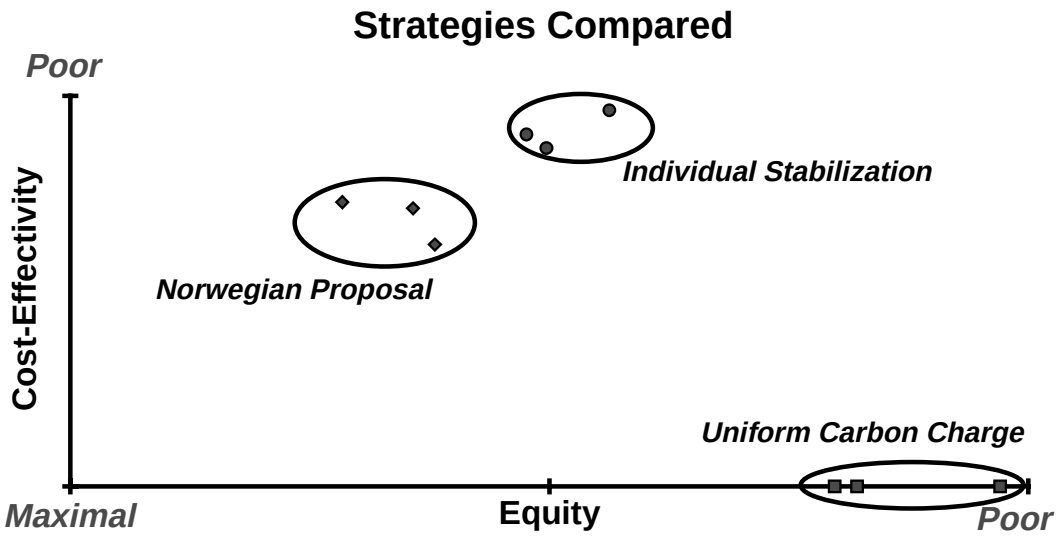

Figure 2: Cost-effectivity and Equity of three strategies compared

The results also suggests that implementation of flexible, international instruments could form an important factor to bridge the two requirements, least overall costs and equity. Tentative exploration of these directions was undertaken on an experimental basis, confirming the favorable prospects.

The information and insights gathered in the common ETSAP study were also utilized in two other studies conducted at ECN Policy Studies.

Cost implications of the EU March'97 proposal

The first study [Kram et.al] aimed to investigate if quantitative scenario studies performed in recent years for EU member states could provide indications of the cost implications of the March'97 proposal of the EU. This proposal resulted from negotiations that started from a differentiation scheme based on the so-called Triptych approach. It represented the EU position before the Kyoto meeting and effectively implied a 10% reduction for the EU by the year 2010 (compared to the 1990 level). Individual countries, however, had adopted widely varying targets between -25% and +40% compared to 1990. Besides information from ETSAP, earlier studies with the EFOM and MIDAS models were used in this analysis. Indicator for the cost implications of the EU proposal was the level of expenditures on CO_2 reduction measures per capita for each country to reach its 2010 target. Although absolute levels reported varied considerably between the studies, see also figure 3, for most EU member states the relative positions within each of the studies were more consistent. In other words, some countries were consequently at the higher end of the range of costs per capita, and others invariably at the lower end. Some countries were covered in only one or two studies, making conclusive findings questionable. Some others showed high end costs in one study, and relatively low costs in other studies. Typically such differences could be explained by decisive differences in policy related constraints that changed over time (or are even not fully determined today). A good example is Germany, where the unification with the former GDR (in some studies not yet implemented) and the future of -subsidized- domestic hard coal mining play a crucial role.

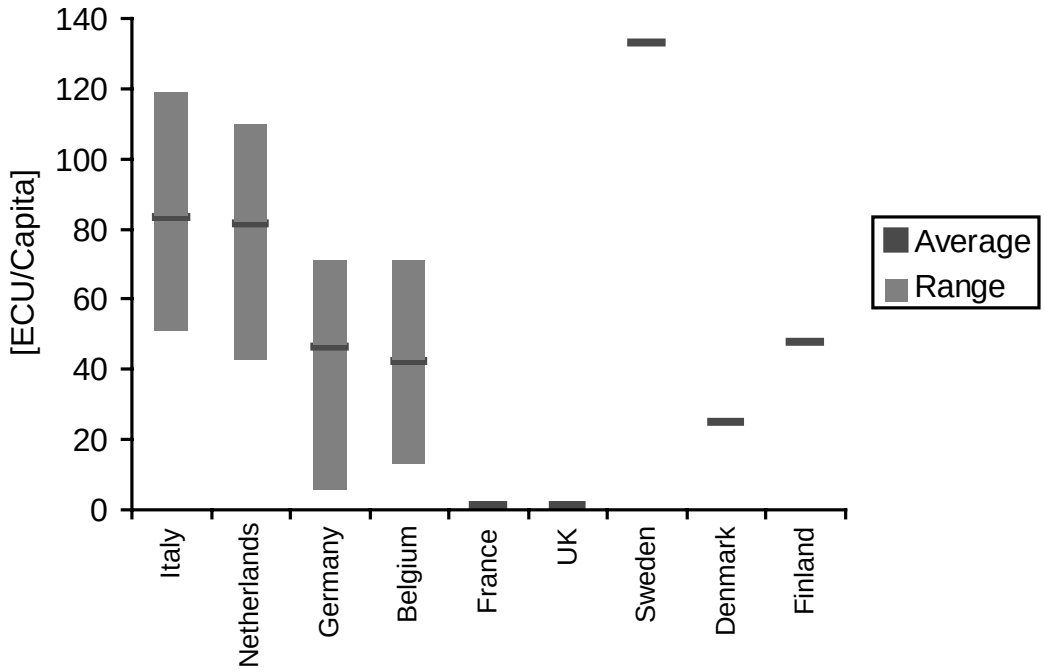

Figure 3: Estimated reduction costs per capita in the EU March'97 proposal

Despite the obvious limitations within and between the various studies, EU member states could be grouped with reasonable confidence as follows:

Group 1 -	Burden level probably (well) above average: *Italy, Netherlands, Sweden*
Group 2 -	Burden level likely high, but limited information: *Austria, Denmark*
Group 3 -	Burden level average: *Finland, Luxemburg, Portugal;* or undetermined: *Belgium, Germany*
Group 4 -	Burden level probably (well) below average: *France, Greece, Ireland, Spain, UK*

Implications of emission permits trading

In a second study [Koutstaal et.al], information from the ETSAP project was complemented with EFOM model results (for EU countries not represented in ETSAP) and own estimates based on literature and own assessments (OECD countries not represented in ETSAP, non-OECD Annex-1 countries). In this study, systems for trading emission permits between OECD countries or between all Annex-1 countries were introduced. The initial allocation of permits for OECD countries in each system was done following three alternative schemes: (a) flat rate of 0%, -5% and -10% compared to 1990; (b) the EU March'97 differentiation plus -10% for non-EU countries; and (c) the "Triptych" differentiation[1] rules applied to all OECD countries. In addition two special cases were analyzed: equal emissions per capita *before* permits trade, and: equal mitigation cost per capita *after* permits trade.

Besides the obvious gains in overall cost-efficiency to be expected from any smoothly operating systems of emission permits trading, other points of interest for the study were the traded volumes (in tonnes and in dollars), the allocation of "benefits" arising over the players and the impact on equity. The latter issue took two forms: equity of burdens (net reduction costs as % of GDP *after* permits trade, and equity of emission entitlements (CO2 per capita *before* permits trade). Similar to the common ETSAP assessment reported in the Kyoto Statement, the trade-off between cost-effectivity and equity was assessed by plotting the standard deviation of both indicators, see figure 4. The results displayed indicate that for each of the three initial allocations of emission permits, the trading system among OECD countries leads to a somewhat more equitable distribution of burdens (arrows pointing to the left). The improvement in equity of burdens within each case is relatively small, also when compared with the differences between the cases. The differentiated allocations perform better than the simple flat rate distribution of permits.

[1] The so-called "Triptych" approach was developed at the University of Utrecht, the Netherlands in support of the negotiations on a pre-Kyoto EU position during the Dutch chairmanship in 1997. The basic concept is that total CO_2 emissions are split into three categories (hence the name): electricity supply, heavy industry and domestic (=all others). For each category a 2010 allowance is calculated according to specific rules taking into account historic levels and firm plans for e.g. nuclear power. Compared to 1990, emissions from electricity generation would have to be reduced by varying percentages depending on the 1990 breakdown of fossil fuels and other inputs. Emissions from heavy industry are essentially retained, reflecting the vulnarability of these sectors on international markets. Domestic emissions are subject to a converging trajectory, aiming at a 20% reduction from the 1990 average by 2020.

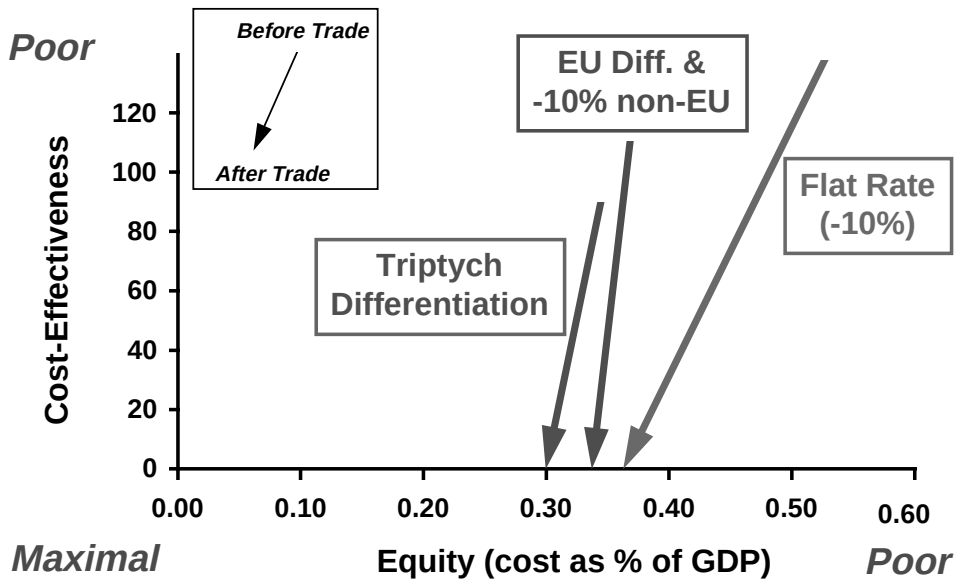

Figure 4: Equity of burdens improves slightly with various initial allocations of permits

To investigate how the two measures of equity compare, these are plotted against one other in a similar fashion, see figure 5. In addition, the two earlier mentioned special cases (equal emissions per capita *before* permits trade, and: equal mitigation cost per capita *after* permits trade) are included in the figure. It indicates that a focus on equal emission entitlements would lead to an even much more uneven distribution of burdens than any of the three allocations examined before. On the other hand it is shown that none of these cases does very much to obtain more evenly distributed emission rights.

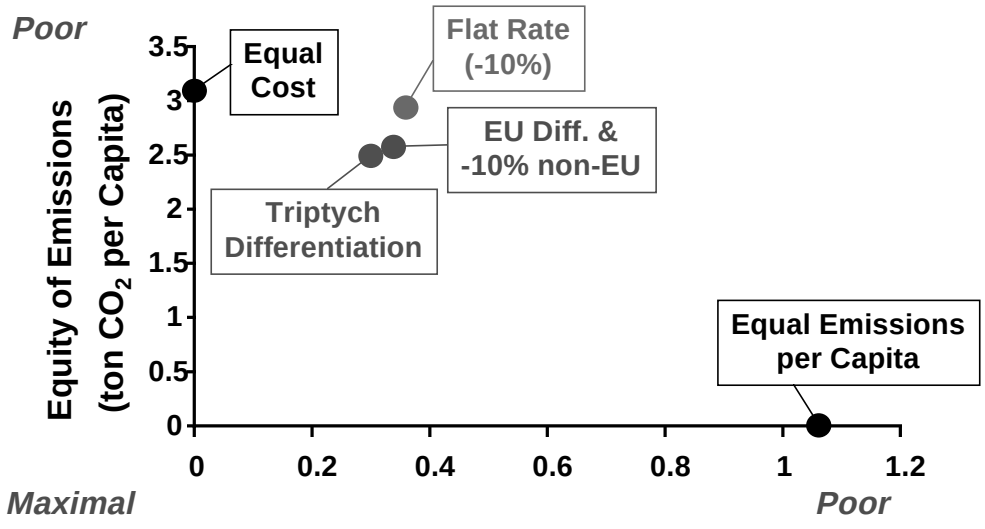

Figure 5: Two measures of equity compared: emission entitlements vs. burdens

As mentioned before, the overall reduction costs for the OECD countries can be reduced significantly (40 to 60% compared to the same allocations without trade) by means of a system of emission permits trading. The distribution of these 'benefits' clearly depends critically upon the initial allocation of emission permits. The examples indicate that even with emission permits trading cost effectivity and equity are not easily reconciled, especially if the equity argument is expanded to include emission entitlement criteria. As could be expected, significant benefits for all OECD countries are only conceivable if all Annex-1 countries would participate in the emission trading system.

POST-KYOTO ANALYSIS

In the previous sections several examples are presented of analyses done by ETSAP, or capitalizing on the information and insights gathered in the programme, in the run-up to the CoP-3 meeting in Kyoto, Japan in December 1998. In the Kyoto Protocol, following extensive and complex discussions during many preparatory meetings and CoP-3 itself right until the last minute, flexibility in meeting the binding commitments is allowed in principle. No doubt this reflects a widespread recognition that ample room should be given to internationally collaborative instruments, besides allowing for flexibility with regard to what emissions in a basket of six gases and associated with many types of economic activity to reduce to comply with the commitments. Anticipating further development and application of ETSAP tools at the national and international level, ECN Policy Studies has initiated an analysis recognizing the requirements and opportunities of the Kyoto Protocol to examine alternative schemes to distribute the overall EU commitment among its member states [Gielen et.al].

To this end the framework developed for the earlier analyses of CO_2 was extended to allow for comprehensive treatment of the six (groups) of greenhouse gases, including sources and sinks outside the energy sector. The approach implies the bottom-up treatment of emission reduction options for all 6 gases in all sectors and for all EU member states[2]. Options for all gases and sectors are aggregated into compounded country representations, but the aggregate numbers for each gas over all countries is also considered. Finally, all data are aggregated into a single EU curve encompassing all 6 gases, all sectors and all countries. The data are compiled from various sources, as follows:

- CO_2 emission projections, reduction options and costs are derived from existing modeling studies using the technological process models MARKAL and EFOM;
- non-CO_2 gas projections and 'allowable sinks' from land-use changes are taken from national communications for the UN-FCCC, updated and revised for the EU considerations after Kyoto;
- reduction potentials and their costs for non-CO_2 gases are estimated from a variety of literature sources, compiled for the purpose of the study.

Following the rules of the Kyoto Protocol the reference emissions of all gases in 1990 (CO_2, CH_4 and N_2O) and 1995 (HFCs, PFCs and SF_6) are established, see figure 6. Similarly, the projection for the year 2010, center year of the first budget period, is made allowing for sinks associated with the net uptake by new forests.

[2] For Austria, Ireland and Luxemburg no detailed information was available on CO_2 emissions and reduction options, hence these were not included in the analysis (contribution in 1990/95: around 3.5% of the EU total)

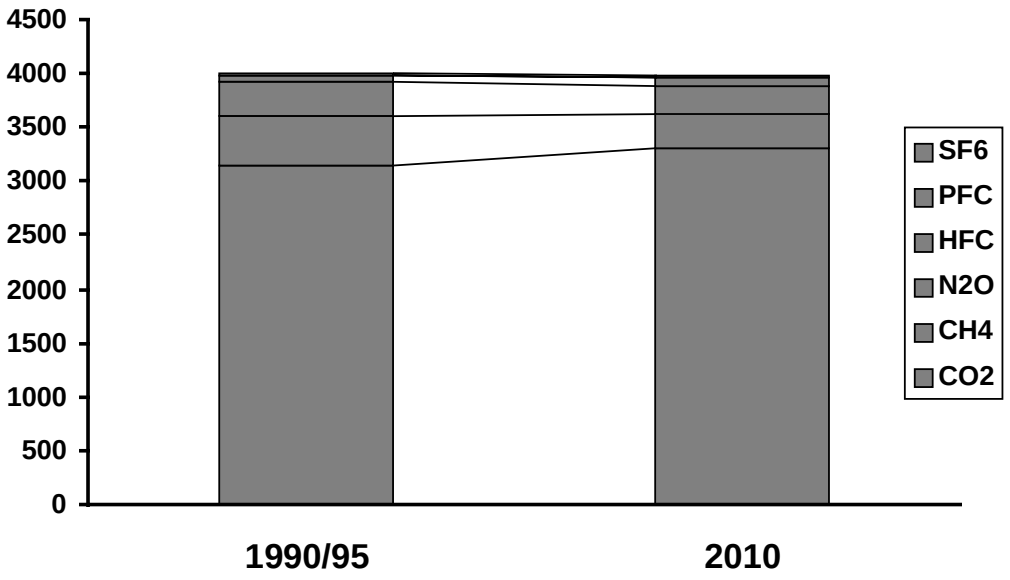

Figure 6: Greenhouse gas emission projection for the EU

Figure 6 illustrates that the projected emissions for the EU by the year 2010 are very close to the reference level of 1990/95. There is only a modest growth in CO_2, as the UK emissions hardly grow, and those in Germany drop significantly. Together these two countries account for about 50% of the EU total in the year 1990. The unification of Germany with the former GDR, and the shift away from coal use in both EU member states explain these country trends. Even though the CO_2 emissions in the other EU countries are projected to grow on aggregate by no less than 20%, the final result for the EU is the relatively small increase by some 5%. Figure 6 also shows that, besides CO_2, methane and nitrous oxide are the main contributors to the total in the reference year. Both are projected to decrease as a result of expected structural changes and implemented or firmly planned policies. The drops in CH_4 emissions by 100 Mton CO_2 equivalent and in N_2O emissions by around 50 Mton offset the rise in CO_2. Even though some of the other gases are expected to grow, their weight in the total remains very small and hence the 6-gas basket stabilizes in the EU.

Consequently, the EU the commitment under the Kyoto Protocol for the first budget period of 8% reduction below the 1990/95 reference level implies a comparatively limited effort. In addition, a tentative inventory of reduction measures for non-CO_2 gases made for this study indicates some low-cost potentials. In particular the N_2O emissions from industrial processes (nitric and adipic acid production) could be reduced significantly at very low costs, provided that ongoing research on suitable catalysts to treat exhaust gas flows is successful. This source of N_2O emissions makes up as much as 10 to 40% of the estimated total. Also for HFCs several relatively low-cost alternatives are identified. This explains why the compounded 6-gas reduction cost curve for the EU is not only shifted to the right, but also takes off on a less steep slope than the aggregate CO_2 curve, see figure 7. Figure 7 confirms that earlier studies focusing on CO_2, or at best just shifting the associated cost curves by a couple of percentages to account for the non-CO_2 gases, grossly overestimated the costs incurred with reduction targets. The solid 'Basket' curve in figure 7 represents the overall minimal cost curve, obtained after ordering by increasing marginal reduction cost all reduction options for all gases and from all sources in all EU countries. Once more this curve illustrates that the EU target of -8% could be reached at modest costs, provided that mechanisms are implemented to ensure that the most cost-effective reduction options are exploited first.

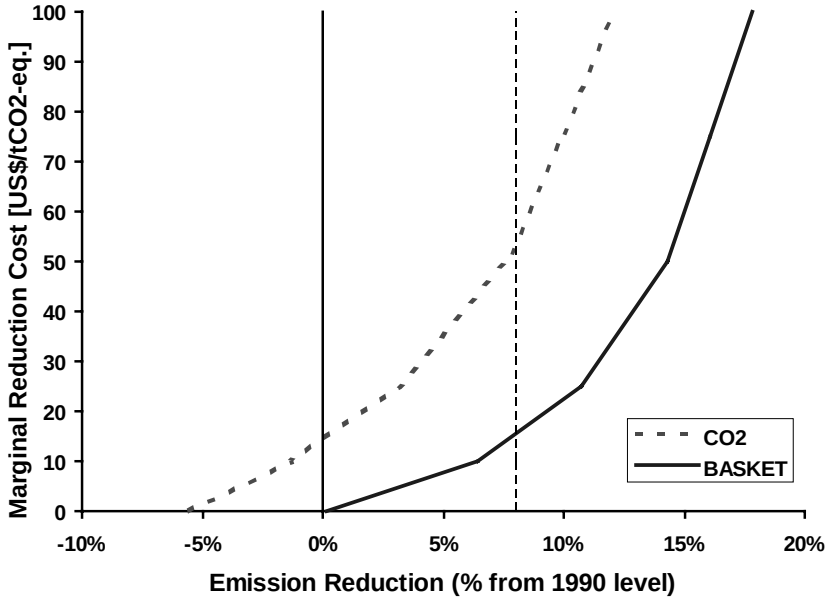

Figure 7: Emission reduction cost curves for the EU in 2010: CO_2 only vs. 6-gas basket

Several distributions of the overall EU commitment among its member states were evaluated, including the tentative flat rate of -8% for all member states currently listed in Annex B to the Kyoto Protocol. The assessment does not (yet) include the role of instruments like joint reduction projects and emission trading between Annex-1 parties, or projects under the Clean Development Mechanism (CAM) with non-Annex-1 parties. This as the primary purpose was to explore internal EU allocations of targets, serving as a further differentiated starting point by setting quantified emission limits for each member state. Besides the simple flat rate, the following three alternatives are investigated:

- *equal burdens* (the same per capita expenditures on reduction measures, expressed as percentage of GDP);
- *equal marginal costs* (the most cost-effective distribution, as indicated in figure 7);
- an adjusted March97 differentiation scheme (labeled *March97+* and obtained by adjusting the agreed pre-Kyoto percentages per member state --valid for CO_2, CH_4 and N_2O-- for the projections of the three new gases (PFCs, HFCs and SF_6) and for the 'allowable sinks' associated with land use changes.

As Table 1 shows, the projection for 2010 shows marked differences between EU member states. Emissions are expected to grow strongly in the so-called Coherence Fund (low income) countries like Greece and Portugal, and in Finland. Emissions in the UK and in Germany show a considerable decline due to their CO_2 developments mentioned earlier, amplified by cuts in CH_4 and N_2O emissions.

The differentiated targets associated with the equal burden, and equal marginal cost cases, appear to be very different from either the flat rate (-8%) or the March'97+ cases. This in turn suggests that the latter two are not very cost-effective and give rise to an unequal sharing of the burden in terms of reduction costs as share of the per capita GDP. In the equal burden and cost based cases the overall reduction target for the EU is reached while most countries are still allowed to increase their emissions over the reference level (though clearly less than their projection). With just a few exceptions (Belgium and Denmark), only France, Germany and the UK would have to reduce emissions below the 1990/95 level.

Table 1: Projection and target for three cases (6-gas basket) for EU member states in 2010

	Projection	Equal burden	Eq. marginal cost	March97+
the Netherlands	15.8%	5.5%	3.4%	-8.0%
Belgium	9.9%	1.1%	-0.6%	-9.5%
Germany	-19.7%	-26.6%	-25.8%	-23.7%
Italy	16.9%	8.4%	9.6%	-6.7%
Sweden	13.0%	5.8%	9.1%	5.9%
Finland	30.2%	18.2%	12.1%	0.3%
Denmark	6.1%	-1.2%	0.1%	-15.2%
France	1.5%	-9.7%	-8.0%	0.6%
Greece	44.4%	36.7%	26.5%	30.5%
Portugal	23.9%	15.6%	9.6%	39.1%
Spain	17.8%	7.3%	3.0%	15.1%
United Kingdom	-7.5%	-12.0%	-10.8%	-11.1%

The cost implications of the various cases are displayed in Table 2. This confirms that the flat rate and the March97+ cases are substantially (5 to 8 times) more costly than the two cases based on equal burden or on equal marginal reduction cost. In addition, table 2 confirms that differences between the member states, see the ranges of costs per capita and of marginal reduction costs, are very significant.

Table 2: Summary of reduction costs for the EU cases

Case:	Flat rate[3]	Equal burden	Eq. marginal cost	March97+
Reduction EU [% from 1990/95]	-11.5%	-8%	-8%	-8.4%
Total cost [bln US$]	16.9	2.4	2.0	12.4
Average cost [US$/capita]	46	6.3	5.5	33
Cost range [US$/capita]	0-190	2.4-8.9	NA[4]	0-162
Marginal cost range [US$/t$CO_2$-eq.]	0-252	7-39	0	0-251

The poor balance between the efforts requested from member states and the wide variance of reduction costs both arising in the March97+ case imply that:

- the same environmental goal could be met at far lower costs;
- these lower costs could be distributed more evenly over EU citizens;
- a more 'level playing field' can be created for EU member states to participate in international flexible mechanisms if and when these are implemented; and:
- more general support can be expected for EU wide policies and measures, in all likelihood an important factor to ensure compliance by all member states and thus the EU.

The implications for individual EU countries can also be investigated in more detail, an example is given for the Netherlands. As shown in table 1, the projection for 2010 implies considerable growth (+16%), the net result of even higher growth in CO_2 (30% up[5]), a marked decline in methane (45% down) and almost constant N_2O emissions. If the Netherlands would have to reduce emissions in 2010 to 92% of the reference level, as in the flat rate and March97+ cases, the volume to mitigate

[3] The projection for Germany ends up below 8% reduction; hence if all others cut their emissions to -8%, the total EU emssion rare reduced more.

[4] Not available: in the study this case is the result of a simulated EU emission permits trading system, rather than a uniform GHG charge, so costs per country include the cost of traded permits and depend on the initial allocation

[5] It must be noted that, like several other countries, the Netherlands also calculates a temperature-corrected CO_2 emission for the reference year. With this correction the growth would be less (25%), but this adjustment is not universally adopted and therefore not recognized in international discussions and negotiations.

amounts to 52.2 Mton CO_2-eq. The lions share would have to come from CO_2 reduction measures, see figure 8, as the affordable potential assumed for the other gases is already fully utilized.

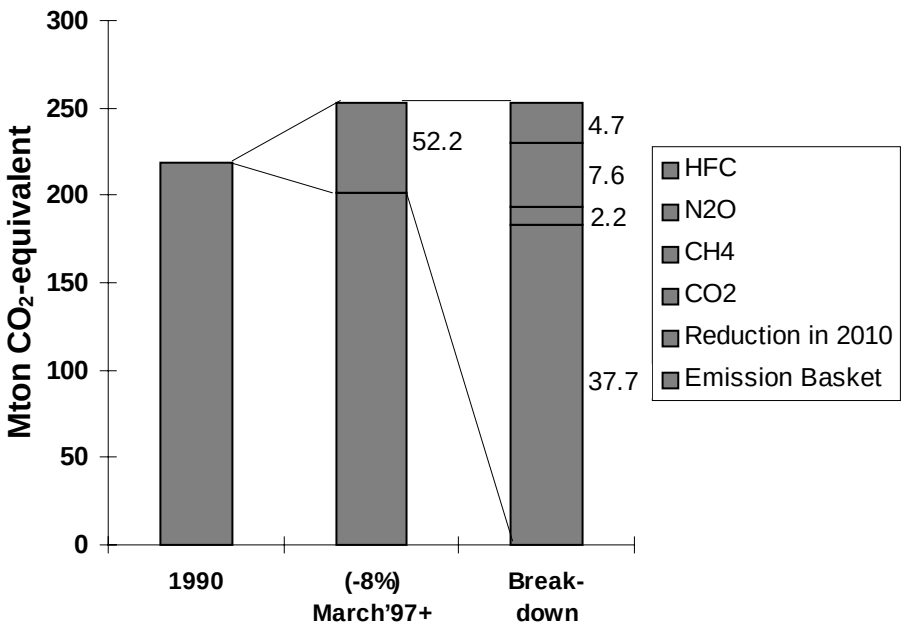

Figure 8: Netherlands 2010: emission reduction by gas in the March97+ case (-8%)

If on the other hand the 2010 target for the Netherlands would be set strictly according to the equal burden criterion, emissions would be allowed to grow by 5.5% over the reference level. Of the then required reduction of 22.5 Mton in 2010, CO_2 makes up just over 50%. A big part of the non-CO_2 reductions comes from nitrous oxide mitigation from industrial sources, a comparatively strong source in the country. In particular the big difference in CO_2 reductions between the two cases (38 vs. 12 Mton) is responsible for the big differences in cost. The total annual cost for the country in the year 2010 would drop from 1 bln US$ to 135 mln US$.

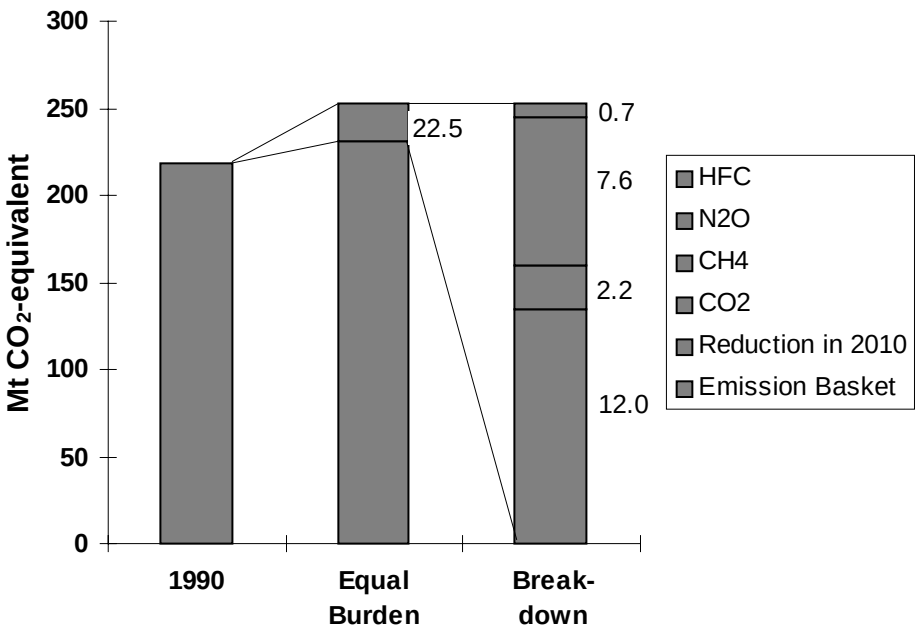

Figure 9: Netherlands 2010: emission reduction by gas in the equal burden case (+5.5%)

The post-Kyoto analysis described here underlines the importance of comprehensive treatment of greenhouse gases, their sources and sinks and mitigation options in line with some of the basic principles adopted in the Kyoto Protocol.

Further analyses will aim to include information for other OECD countries, other Annex-1 economies and from LDCs available within the ETSAP/MARKAL community and from other sources. Hence, similar to the earlier assessment of tradable emission permits, the scope of the analyses can be broadened to encompass (tentatively) the flexible instruments adopted in principle in the Kyoto Protocol.

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