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Report on Work Package B-2 of the ETSAP Project "Integrating policy instruments into the TIMES Model"

The representation of emission trading schemes in national energy system models

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1. Introduction

In the *Report on Work Package A* of this project, emissions trading systems have already been outlined as one of the most important market-based instruments in climate policy. In contrast to emission taxes, specifying a price for emission, the basic idea of emission trading is to control the amount of emissions by setting a cap and assigning property rights for the remaining emissions which can be traded between emitters. Such an approach therefore combines high levels of static and dynamic cost efficiency with ecological precision. Even though the theoretical concept of emission trading has already been established at the end of the 1960s, significant practical applications only followed at the beginning of the 1990s in the United States with measures addressing air quality like the U.S. Acid Rain Program or the Regional Clean Air Incentives Market (RECLAIM) in California. In climate policy, the development of tradable allowance systems gained momentum after the signing of the Kyoto Protocol in 1997 which names International Emissions Trading (IET) as one of the three flexible mechanisms to achieve emission mitigation targets in a cost efficient manner. Since then, several regional or national schemes have been implemented, for example in Tokyo, New Zealand or Canada (province of Alberta). In Europe, emission trading has become a reality on a large scale with the introduction of the supranational EU Emissions Trading System (EU ETS) in 2005, which currently constitutes the most extensive and advanced scheme.

To incorporate emission reduction targets or CO_2 prices into a scenario analysis has long been common practice in energy system modelling. Challenges may occur, however, when trying to depict the actual features of a specific trading scheme as realistically as possible. Here it becomes obvious that the design of real-world tradable permit systems can deviate substantially from the idealised and abstract representation in theoretical literature, especially in terms of regional and sectoral coverage or the mechanism for the allocation of emission certificates. The aim of this report is therefore to develop and describe a modelling approach with which the EU ETS can be incorporated into national TIMES models in a detailed and realistic manner.

After the development and the most important characteristics of the EU ETS are summarized in the next chapter, the basic approach for modelling emissions trading schemes in energy system models like TIMES is illustrated in Chapter 3. In many system analyses the problem arises that the model region does not cover the entire trading region such that not all abatement and trading options are represented in the model. That is why, in Chapter 4 a modelling procedure is presented with which supranational trading schemes like the EU ETS can be integrated into national energy system models such that both the overall certificate price and the national contribution to emission abatement are determined endogenously. Finally, Chapter 5 addresses some additional critical issues that can be observed in the real-world design of emissions trading systems, namely the limited sectoral scope and particularities in the allocation mechanisms for emission certificates in the EU ETS.

2. Basis for the case study: EU Emissions Trading System (EU ETS)

In Europe, emission trading gained greater attention as a viable market-based tool to reach mitigation targets with its mentioning in the Kyoto Protocol (cf. Ellerman and Buchner 2007). After attempts to introduce an EU-wide carbon tax had failed in the 1990s, a Green Paper on greenhouse gas (GHG) emissions trading within the European Union was published in 2000 with the intention to initiate the process of developing an adequate trading scheme on the EU level (cf. EC 2000). In October 2003, the EU ETS directive (cf. EC 2003) was adopted establishing the years 2005 to 2007 as the pilot trading period. Thus, the EU ETS was the first transnational and is currently the largest GHG emissions trading system in the world. At the moment, it covers about 11,000 energy conversion and energy-intensive industrial installations in 30 countries which are responsible for almost 50 % of the CO_2 emissions in these participating states. In the following, the most important features of the EU ETS, which are essential for developing a realistic modelling approach, are outlined.

Basic design and targets

The EU ETS has been set up as a typical cap and trade system, where a limit on the absolute amount of emissions in a given period of time is fixed and a market for emission allowances is created. In the case of the EU ETS, the tradable unit has been defined as *European Union allowance* (EUA) representing 1 ton of CO_2 emitted. Each emitter included in the scheme has to surrender the amount of allowances necessary to cover the total emissions of his installation in each year within the first four month of the following year.

For the first two trading periods relatively short timeframes were chosen, the first one (2005-2007) functioning as a trial period and the second one (2008-2012) coinciding with the commitment period for the emission reduction targets specified under the Kyoto Protocol. In these periods, the actual cap on emissions and the allocation of allowances were determined in a highly decentralized manner: each country had to develop a National Allocation Plan (NAP) resulting in individual caps for each member state such that the total ETS cap was unknown beforehand. Apart from being relatively complex, this approach gave rise to substantial differences in allocation rules and to concerns about fairness since each member state had incentives to favour its own industry (cf. Heindl and Löschel 2012).

As a consequence, in the third trading period (2013-2020) the National Allocation Plans have been replaced by a single EU-wide cap along with harmonized allocation rules. In line with the overall GHG reduction target of 20 % until 2020 compared to 1990 (cf. the EU climate and energy package, EC 2008a), a mitigation goal of 21 % compared to 2005 has been fixed for the ETS sectors in the third phase. In order to reach this target by 2020, the cap is reduced each year in a linear fashion by a factor of 1.74 %. It is planned that this annual reduction factor will also be applied in subsequent trading periods (cf. EC 2008b). For the sectors not covered by the EU ETS, a EU-wide mitigation target of 10 % until 2020 compared to 2005 has been laid down in combination with specific national targets assuming that with this division between ETS and Non-ETS sectors overall reduction costs will be minimized. In the EU climate and energy package from 2008 a proposal has been made to raise the general GHG mitigation target for 2020 from 20 % to 30 % if an international agreement is concluded in which other developed countries commit themselves to comparable emission reductions. This would result in an adjustment of the ETS target for 2020 to 34 % and of the Non-ETS target to 16 % (cf. EC 2010a). Figure 2-1 illustrates the development of the EU ETS cap for both potential targets in phase 3. It is assumed that after 2020 in both cases the linear reduction factor of 1.74 % is used leading to a decrease in ETS emissions until 2050 of 71 % compared to 2005 for the 21 %-target and of 84 % for the 34 %-target.

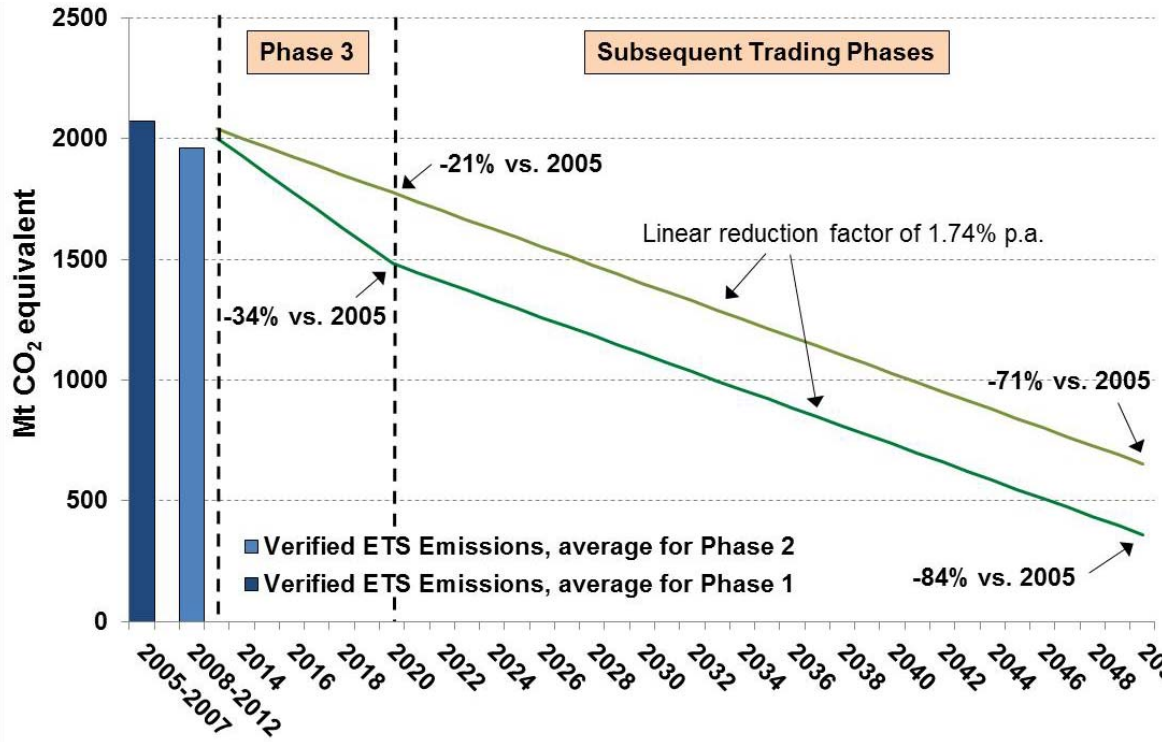

Figure 2-1: Development of the EU ETS cap until 2050 (own illustration based on EEA 2012a and EEA 2012b)

Scope

From economic theory it follows that the benefits of an emissions trading system in terms of cost efficiency will be the larger, the greater the scope of the system in terms of included regions, sectors and greenhouse gases. In reality, however, significant restrictions may arise when defining the extent of the trading system.

As far as the regional coverage is concerned, the then 25 EU member countries took part in the scheme when it was launched in 2005 with Romania and Bulgaria joining simultaneously with their accession to the EU in 2007. After the inclusion of the non-EU members Norway, Iceland and Liechtenstein in 2008, the EU ETS currently covers 30 countries accounting for about 11 % of global CO_2 emissions (cf. UNFCCC 2012 and BMWi 2012).

With respect to the target group, a downstream system was chosen meaning that emissions are directly controlled at their source and that emitters are responsible for submitting the required ETS certificates. From this it follows that only large installations could be included in order to limit the administrative cost burden (cf. Klepper 2011). From 2013 onwards, the following sectors take part in the EU ETS (cf. EC 2009a) accounting for almost half of the overall CO_2 emissions in the ETS member countries:

- Combustion installations with a total rated thermal input exceeding 20 MW
- Mineral oil refineries and coke ovens
- Production or processing of ferrous metals including metal ore, pig iron and steel
- Mineral industry including the production of cement clinker, lime, glass, ceramic products, mineral wool insulation material using glass, rock or slag and gypsum products
- Production of pulp, paper and cardboard (with a production capacity exceeding 20 tonnes per day)
- Since 1 January 2012: aviation, all flights arriving or departing from an airport in one of the ETS member states
- From 1 January 2013: Production of aluminium and other non-ferrous metals (with a total rated thermal input exceeding 20 MW)
- From 1 January 2013: Chemical industry, including the production of nitric acid, adipic acid, glyoxal and glyoxylic acid, ammonia, bulk organic chemicals by cracking, reforming, partial or full oxidation, hydrogen and synthesis gas as well as soda ash and sodium bicarbonate
- From 1 January 2013: Carbon capture and storage from ETS installations

While in the first and second trading period only CO_2 emissions were covered (with the option to opt-in other greenhouse gases in phase 2), perfluorocarbons (PFCs) from the production of primary aluminium and nitrous oxide (N_2O) from the production of nitric acid, adipic acid, glyoxal and glyoxylic acid (cf. EC 2009a) are added to the scheme from 2013 onwards.

Allocation mechanisms

Mainly for reasons of political acceptability, free allocation of permits was chosen as the basic principle in the first two trading periods. Member countries had the possibility to auction up to 5 % of all allowances in the first and up to 10 % in the second phase, but, especially in the first period, this option was hardly made use of (cf. Klepper 2011). In the EU ETS directive from 2003, no strict regulations were prescribed with respect to the method of defining the amount of allowances allocated to each installation, but for existing emitters allocation was generally based on historical emission levels (concept of grandfathering) or the projection of growth rates of business-as-usual emissions (cf. Sijm 2012, p. 44). In order to ensure equity between existing and new installations, each member state was required to set aside a reserve of free permits for new entrants, which on average amounted to 3 % of total permits in the first trading period with substantial differences in the size of the reserve and the allocation rules across countries (cf. Parker 2010).

Strong criticism has been voiced with respect to the large windfall profits that electricity generators were able to make by passing on the opportunity costs of the freely allocated permits to consumers (cf. Ellerman and Buchner 2007). Against this background, allocation rules will change considerably with the beginning of the third trading period. With the elimination of the National Allocation Plans, allocation rules are harmonized for the whole system and a stronger emphasis is put on auctioning. It is expected that in 2013 about half of the allowances will be auctioned and this share will rise gradually until 2020 (cf. EC 2010b). For those sectors where all or part of the allowances are allocated for free a product benchmark approach is applied which is generally based on the average greenhouse gas performance of the 10 % best installations in the EU in that product group (cf. Heindl and Löschel 2012). Table 2-1 gives an overview over the allocation procedures for the different sectors under the EU ETS from the third trading period onwards. For new installations or the extension of existing installations, a new entrants' reserve of 5 % of the total amount of allowances has been set aside for the third trading period (cf. EC 2009a).

Table 2-1: Harmonized allocation mechanisms in the EU ETS from 2013 onwards

Sector	Allocation rule
Electricity generation	Full auctioning[1]
Industry & heat generation	Free allocation of 80 % of allowances in 2013 reduced linearly to 30 % in 2020 Allocation is based on benchmarking: - **Product benchmark:** allocation dependent on the production of products (in: t CO_2/t product); if not applicable - **Heat benchmark:** allocation dependent on the amount of measurable heat consumed (in: t CO_2/TJ of heat consumed); if not applicable - **Fuel benchmark:** allocation dependent on the amount of fuel consumed (in: t CO_2/TJ of fuel used); if not applicable - **Process emissions approach:** allocation is 97 % of historical emissions **Exemption:** Sectors and subsectors which are deemed to be exposed to a significant risk of carbon leakage receive 100 % of their allowances for free (allocation based on benchmarking)[2].
Aviation	Free allocation of 82 % of allowances Based on benchmarks calculated as the airline's share in the total amount of passengers and cargo transported in 2010 (measured in terms of tonne kilometres)

Sources: EC 2008c; EC 2009a; EC 2011a; EC 2011b

[1] Option for transitional free allocation of up to 70 % in 2013 decreasing to zero until 2020 under certain conditions for economically weaker member countries (cf. EC 2009a)

[2] For eligibility criteria cf. EC (2009a); the selected sectors are listed in EC (2009b)

Increased flexibility: banking/borrowing and CDM/JI

In order to increase intertemporal flexibility and smooth compliance costs over time, banking, i.e. the option to store unused allowances for future periods, is allowed in the EU ETS within trading periods. While transferring allowances from phase 1 to phase 2 was practically not conceded (cf. EC 2006), unlimited inter-period banking is permitted from phase 2 onwards. With respect to borrowing, i.e. the option to borrow allowances from future periods to use them in the current one, the regulations in the EU ETS are more restrictive. Within one period, borrowing is possible from one year to another, as installations receive their allowances for each year (end of February) before they have to hand in the required allowances for the previous year (end of April). Inter-period borrowing is officially not allowed – the only option would come at a very high interest rate by paying the penalty (see below) and surrendering the missing permits at a later date (cf. Chevallier 2012; Ellerman and Buchner 2007).

With the aim of expanding the available compliance options and potentially reducing compliance costs, access to the project-based mechanisms CDM (Clean Development Mechanism) (since 2005) and JI (Joint Implementation) (since 2008) defined under the Kyoto Protocol has been granted through the Linking Directive (cf. EC 2004). It allows emitters to use credits gained from CDM or JI projects[1], i.e. for emission reductions outside of the European Union, to fulfil their obligations under the EU ETS. In the first trading period, the decision on the maximum amount of "external" credits allowed per installation was left to the member states. The only requirement was to comply with the principle of supplementarity, stipulated in the Marrakesh Accords (cf. UNFCCC 2001), according to which the use of CDM and JI has to be supplemental (usually defined as up to 50 %) to domestic action in Annex I countries. After stricter regulations were applied in the second period (cf. De Sépibus 2008), for the phase from 2013 to 2020 the EU ETS legislation is specified such that the use of CDM/JI credits cannot exceed 50 % of the ETS emission reductions below the 2005 levels (cf. EC 2009a).

Monitoring and enforcement

With the implementation of the EU ETS, a new administrative infrastructure had to be developed, including the creation of a national regulatory authority in each member state. These institutions are responsible for establishing and managing allowance registries that track all allowance transfers and emissions by installation and report to the Community registry (the Community Independent Transaction Log, CITL). With the beginning of the third trading period the national registries are replaced by the Union registry. Apart from that, the monitoring and verification of the operators' emission reports is performed by the national authorities subject to harmonized Community guidelines (cf. EC 2012a and EC 2012b).

To ensure compliance, a penalty of 100 € (40 € in the first trading period) for each tonne of CO_2 equivalent not covered by an allowance has been put in place. Even after paying the fine, the missing allowances have to be surrendered in the following year (cf. EEA 2005).

Experiences so far

The introduction of the EU ETS entailed the creation of a completely new commodity market in the European Union, whose performance can be evaluated by the development of the price for emission allowances (EUAs) and the trading volumes.

[1] Credits from land use, land-use change and forestry projects as well as from nuclear facilities are excluded (cf. EC 2004).

At the beginning of the first trading period, EUA prices rose steadily with peaks at over 30 €/EUA and exhibited high levels of volatility (cf. Figure 2-2). A significant price drop occurred after the verified emissions data for 2005 was published in April of 2006 and it became obvious that a considerable overallocation of allowances had taken place. Until the end of phase 1, the EUA price fell to zero as allowances could not be "banked", i.e. carried over to the next trading period. Against the background of substantial cutbacks in the allocation of emission permits from 2008 onwards, prices recovered and only started to drop with the onset of the international financial and economic crisis at the end of 2008. Since the middle of 2009, a relatively stable price level (in nominal terms) of around 15 €/EUA can be observed (cf. Wråke et al. 2012). The maturing of the market for emission allowances is also reflected in the significant increase in the transaction volumes from 362 million allowances in 2005 to about 5.2 billion in 2010 (cf. EC 2008d; Point Carbon 2011). The use of CDM and JI credits is still comparatively limited with surrendered CERs ("Certified Emission Reductions" from CDM projects) amounting to less than 6 % and surrendered ERUs ("Emission Reduction Units" from JI projects) to about 1 % of total surrendered allowances in the EU ETS from 2008-2011 (cf. EEA 2012b).

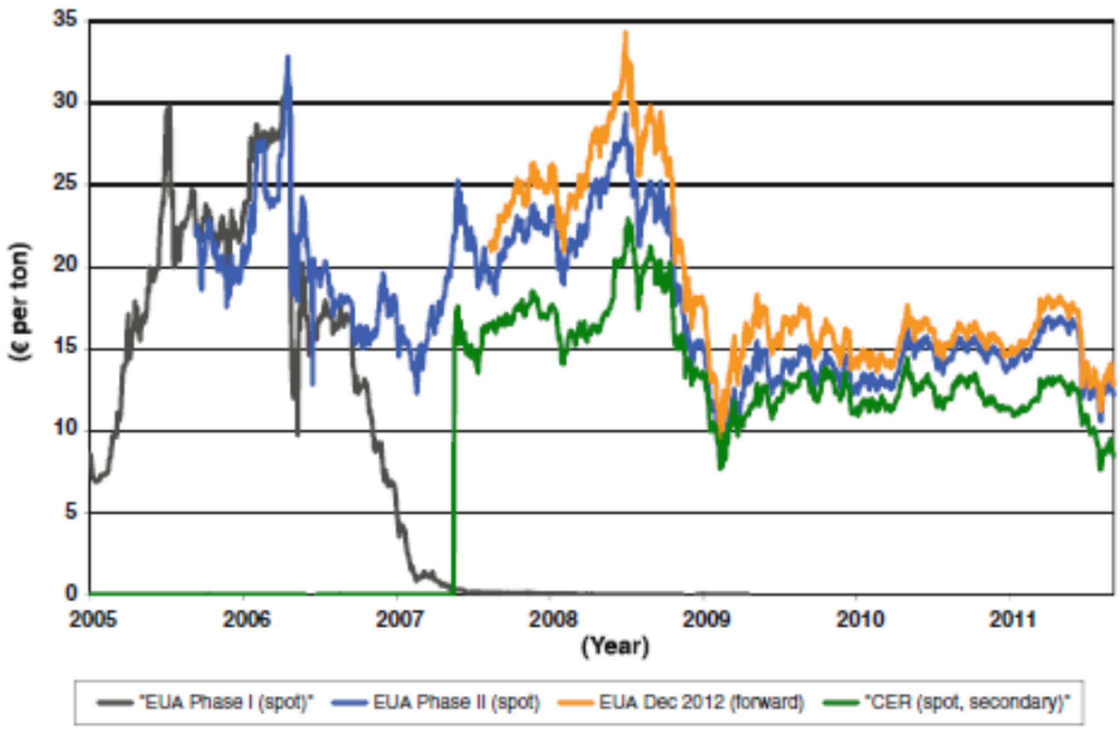

Figure 2-2: Prices of emission allowances (EUAs) in the EU ETS (Source: Wråke et al. 2012)

3. Modelling emissions trading systems in TIMES: basic approach

Emissions trading systems represent quantity-based mechanisms such that the basic approach for their integration into an energy system model is comparatively straightforward.

The cap on greenhouse gas emissions can be modelled by putting an upper bound on the flow of emissions of those sectors participating in the trading scheme with the help of a user-defined constraint (based on the parameter *UC_FLO*). The dual variable of this bound equals the marginal costs of the last (most expensive) unit of emission abated to fulfil the constraint. It can be therefore interpreted as the certificate price that would arise in the emissions trading system under the modelled conditions[2]. At the same time, the dual variable of the emission constraint reflects the impact of the emissions trading system on the objective function (cf. Remme et al. 2009).

The second fundamental feature of a cap and trade system, the trading mechanism, is already implicitly included in an optimization model like TIMES. The linear optimization approach ensures that the most cost efficient way of fulfilling the cap is realized – as it would be the case when emission allowances can be traded between emitters. Hence, sectors (or regions) that exhibit lower abatement costs and therefore deliver a disproportionately large contribution to the necessary emission reductions in the model can be understood as the emitters who, under an emissions trading system, sell certificates to those installations with higher abatement costs that contribute less to emission mitigation (cf. Remme 2006).

In order to exemplify the impact of introducing a tradable allowance scheme into an energy system model, a look is taken at the electricity generation costs of a fossil power plant which are represented by the dual equation of the activity variable of the respective generation process (assuming that the activity is defined as the electricity output) (cf. Remme 2006, pp. 136f):

$$ACT_{r,v,t,p,s}: \quad act\_cost\_d_{r,t,p,s} + \frac{1}{\eta_{r,t,p,s}} \cdot combal_{r,t,FUEL,s} + capact_{r,v,t,p,s} - \frac{\boldsymbol{\varepsilon_{r,t,p,EMIS,FUEL}}}{\boldsymbol{\eta_{r,t,p,s}}} \cdot \boldsymbol{ghg\_bnd_{r,t,EMIS,s}} \geq combal_{r,t,ELC,s} \qquad (1)$$

With:

c	commodity index,
p	process index,
r	region index,
t	index for the current time period from 1,..,*T*,
s	time-slice index,

[2] Alternatively, the shadow price of a GHG constraint can also be considered as the tax rate on emissions that would be required to achieve the given reduction target. With respect to the allocation mechanism, an ideal-typical mechanism where the same incentive effect for each ton of CO_2 abated is created irrespective of the mitigation measure is established with this modelling approach, which in reality could be achieved with the help of auctioning (cf. Chapter 5.2).

$\boldsymbol{v}$	index for the vintage year,
$\boldsymbol{act\_cost\_d}_{r,t,p,s}$	discounted variable operation cost (without fuel cost),
$\boldsymbol{capact}_{r,v,t,p,s}$	dual variable of the capacity-activity constraint,
$\boldsymbol{combal}_{r,t,ELC,s}$	dual variable of the commodity balance of the output electricity (*ELC*),
$\boldsymbol{combal}_{r,t,FUEL,s}$	dual variable of the commodity balance of the fuel input (*FUEL*),
$\boldsymbol{ghg\_bnd}_{r,t,EMIS,s}$	dual variable of an upper bound on greenhouse gas emissions (*EMIS*),
$\varepsilon_{r,t,p,EMIS,FUEL}$	emission factor specifying how much emissions (*EMIS*) are produced per unit of the input commodity (*FUEL*) and
$\eta_{r,t,p,s}$	activity-based efficiency of converting the input flow (*FUEL*) into the output flow (*ELC*).

With the emissions trading system in place, electricity generation costs for fossil power plants are extended by an additional cost component representing the cost of purchasing allowances for the emission output of the respective installation. This cost term is calculated as the shadow price of the GHG emission constraint multiplied by the ratio of the emission factor for the respective fuel and greenhouse gas and the efficiency of the power plant. Thus, the emissions trading system will have an impact on the electricity price determined in the model (assuming that a generation process based on fossil fuels is the price-setting technology) and the competitiveness of fossil power plants. For other sectors that might be covered by the tradable allowance system the effect can be determined in the same way, as, for example, in the industry sector the production costs in manufacturing processes using fossil fuels will also rise with the additional costs for emission certificates.

4. Supranational emissions trading schemes in national energy system models

4.1. Problem definition

One of the main benefits of emission trading as a climate policy instrument, namely its ability to ensure that emission targets are fulfilled in a cost efficient manner, can be the better exploited the more emitters are covered by the trading scheme. Thus, in political reality one of the objectives is to create tradable allowances systems with a large regional scope, as it is the case with the EU ETS which currently comprises 30 countries.

In energy system modelling, this often gives rise to the problem that the model does not represent the entire trading region. Even though European energy system models, like the TIMES PanEU model (cf. Blesl et al. 2009), have been developed, national models are still in use as they exhibit a number of advantages. Due to their smaller size in terms of regional coverage, they often feature a higher level of sectoral as well as technological detail and/or a higher time resolution. Especially for the explicit representation of policy instruments, where the methodological approach can become comparatively complex, a flexible modelling tool with manageable computation times is of great relevance. For the case study at hand, the aim consists in modelling the EU ETS in a flexible way in the national energy system model for Germany TIMES-D (cf. Remme 2006; Götz et al. 2012).

In the past, energy systems analyses have dealt with the problem of the model region not coinciding with the trading region in mainly two different manners. One possibility is to set a fixed emission reduction path for the respective country (cf. for example EWI et al. 2010). This allows to calculate a CO_2 price within the model, which would, however, only apply to the considered country. At the same time, the trading system with the foreign ETS participants is completely neglected presuming the national emission mitigation as invariant to changes in the scenario assumptions. Alternatively, fixed certificate prices can be integrated into the model (cf. for example BMU 2010; UBA 2009). This would ensure that the emission reduction in the ETS sectors of the respective country is determined endogenously. However, the influence of changing national framework conditions on the allowance price is not taken into account. This effect might be negligible for small member states, but it can be assumed that countries like Germany, being currently responsible for almost a quarter of the ETS CO_2 emissions, can impact the certificate price significantly when, for example, changes in the national policy on nuclear energy or renewable electricity are implemented.

To overcome these shortcomings, a modelling approach has been developed that makes it possible to determine both the emission reduction in the national (here German) ETS sector and the ETS certificate price endogenously within the model.

4.2. The modelling approach

The basic idea of this model approach, as illustrated in Figure 4-1, is to depict both the emission reduction options for Germany and the rest of the EU ETS system in the national model. In order to do so, an additional process is introduced into the model which contains the emissions of all ETS sectors outside of Germany which would arise if no tradable allowance system was in place and therefore no reduction measures would be undertaken. This procedure makes it possible to put a cap on total EU ETS emissions instead of on Germany alone. While the emission mitigation in the German ETS sector is still based on the explicit modelling of technologies within the reference energy system, the reduction options in the rest of the countries participating in the EU ETS need to be added to the model.

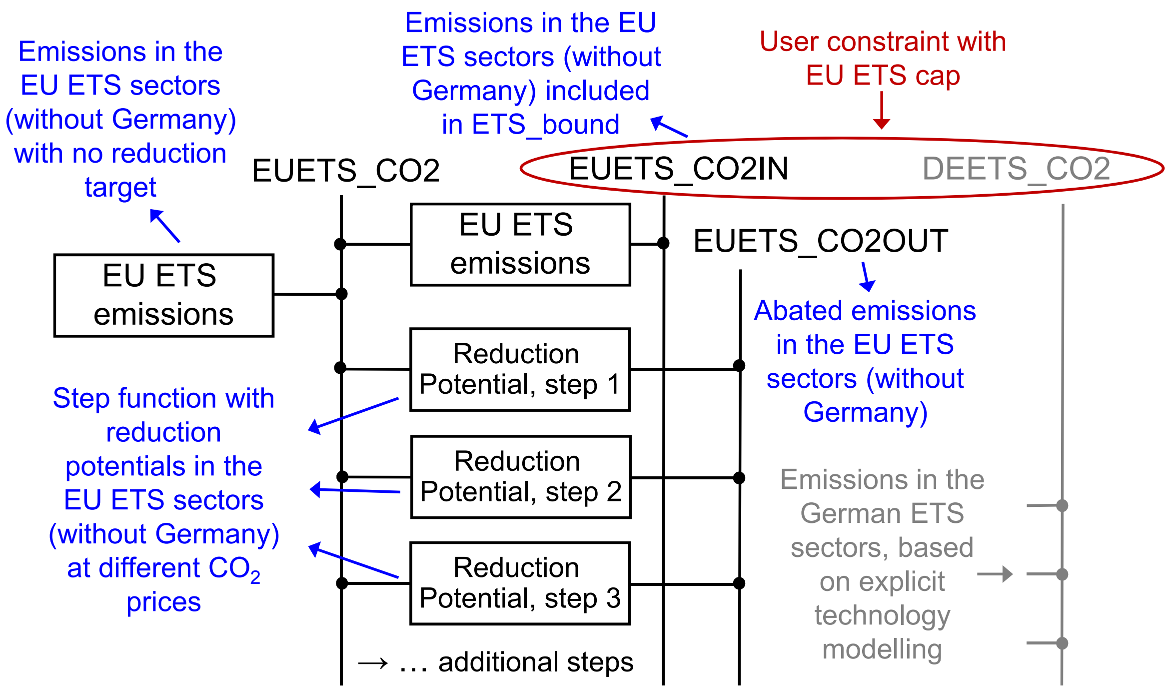

Figure 4-1: Modelling approach to represent the EU ETS in a national TIMES model

This is done with the help of a CO_2 abatement cost curve, modelled as a step function containing the CO_2 reduction potentials in the ETS sectors outside of Germany at different certificate price levels. In the model, each step is represented by a separate process comprising the maximum abatement potential (modelled with the parameter *ACT_BND*) and the marginal abatement costs for the corresponding step (modelled with the parameter *FLO_COST*). An additional process needs to be implemented which contains those ETS emissions from outside of Germany which are not avoided through one of the mitigation processes. The user constraint representing the EU ETS cap will then be put on the German ETS emissions and those from the rest of the ETS which are not abated. Hence, in the model the decision is to either reduce the ETS emissions outside of Germany and pay the associated abatement costs laid down in the cost curve or to increase mitigation efforts in Germany where all technologies are modelled with their cost parameters. Through the optimization approach, marginal abatement costs for Germany and the rest of the ETS sectors are approximated and a uniform certificate price for the whole system will be determined as the shadow price of the upper bound on total ETS emissions.

It becomes obvious that to realize this modelling approach comprehensive data on the emission reduction potentials at different certificate price levels in the ETS sectors outside of Germany are required. This information can be either obtained by an extensive literature research, by conducting a model analysis at European scale or by aggregating the results from several national model analyses. For the case at hand, a version of the Pan-European TIMES model, TIMES PanEU, which has been created in the scope of the NEEDS project (cf. Blesl et al. 2009) and is constantly further developed at the IER Stuttgart (cf. for example Blesl et al. 2010; Blesl et al. 2011), is applied. TIMES PanEU comprises 30 regions (EU-27 plus Switzerland, Norway and Iceland) with a less detailed time resolution (12 time slices) and less sectoral detail than TIMES-D. For the current study, instead of fixing an upper bound on CO_2 emissions in the ETS sectors, several model runs with different ETS certificate price levels (discounted to the base year) are executed in the Pan-European model.

In the first model run, an allowance price of zero is assumed in order to determine the amount of ETS emissions which would arise if no emissions trading system was in place. In the following model runs, the certificate price is raised gradually. Here, a time-integrated approach is chosen, i.e. the abatement potentials for each modelling year are calculated in one model run. The difference in emission abatement between one model run and the next represents the reduction efforts that would occur at the corresponding allowance price level. For example, deducting the emission quantity resulting from the model run with a certificate price of 10 €/t CO_2 from the one with a price of 20 €/t CO_2 would yield the reduction potential for the step in the abatement cost curve between 10 and 20 €/t CO_2. Hence, with the help of these model runs in the European TIMES model, the mitigation potential for each of the reduction processes that are implemented in the national TIMES model can be ascertained. The emission abatement in Germany can be simply subtracted from the European potential, as with fixed certificate prices the mitigation efforts in one country are independent of the other countries.

In the present case, an abatement cost curve with 12 steps corresponding to CO_2 prices between 10 and 150 $€_{2000}$/t CO_2 in 2030 has been constructed based on the model runs. As an example, the resulting curve for 2020 is shown in Figure 4-2. In the national model TIMES-D, each of the steps is then translated into one of the reduction processes. It has to be pointed out, however, that the thus calculated reduction potentials on the European scale only apply for the given framework conditions. If it is assumed that major policy changes, for example regarding the promotion of renewable energies, occur in the EU as a whole or in a number of member countries, the abatement cost curve would have to be determined anew.

Furthermore, the interaction between the reduction targets in the EU ETS and the cross-border exchange of electricity has to be kept in mind. If the participating electricity generators in one country do not possess comparatively cost efficient abatement options, their strategy might be to increase electricity imports from neighbouring countries at the expense of their own production given that this is less expensive than purchasing the required emission allowances and generating the electricity themselves (cf. Enzensberger et al. 2002). In order to take this effect into account in the model approach, data on electricity imports to and exports from Germany at different certificate price levels and the corresponding electricity prices on the European level are also taken from the scenario runs with the TIMES PanEU model and are bound to the different steps in the abatement cost curve (with the help of the parameter *FLO_SUM*). That means that the amount of electricity imported to or exported from Germany is associated to the burden sharing in emission mitigation between Germany and the rest of the EU ETS.

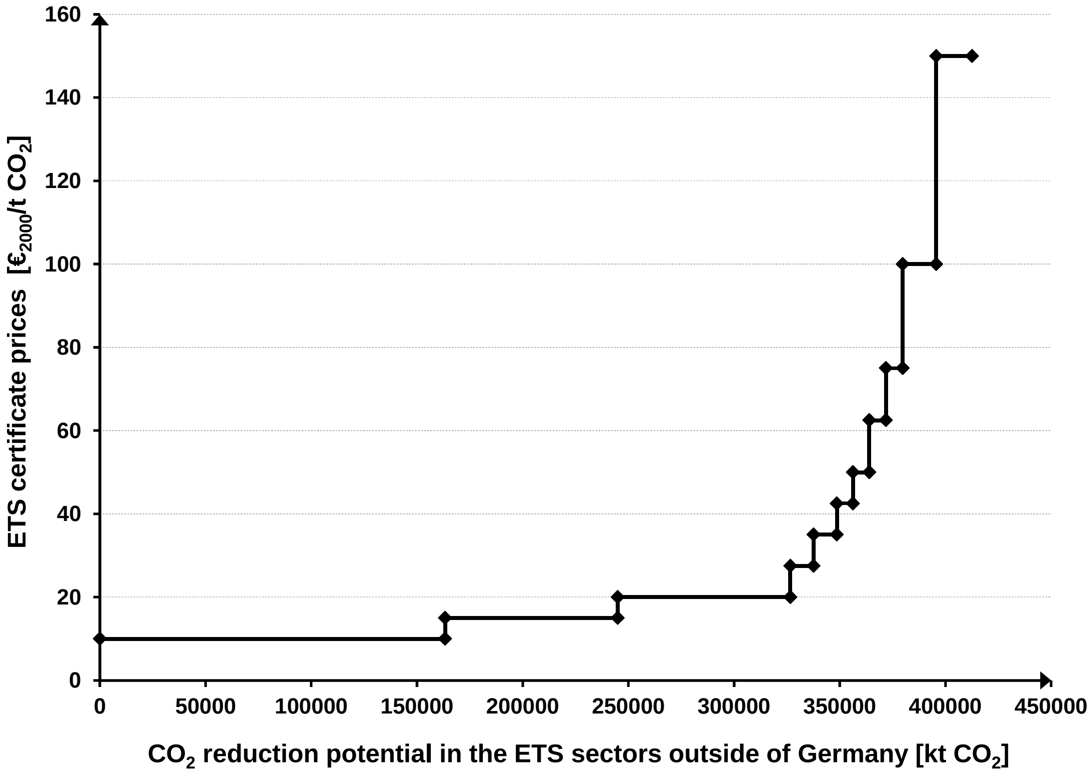

Figure 4-2: Exemplary abatement cost curve for the ETS sectors outside of Germany for 2020 generated with the TIMES PanEU model

5. Modelling of further features of emissions trading systems

5.1. Sectoral scope

Mainly due to administrative reasons, the EU ETS was set up with a limited sectoral coverage concentrated on large combustion installations and energy-intensive industries limiting its ability to induce the most cost efficient manner in reaching the overall reduction target. This feature complicates the realistic representation of the EU ETS in an energy system model and at the same time gives rise to a number of interesting research questions.

With the aim to reproduce the actual sectoral scope of the EU ETS as close as possible in the model, a high level of technological and sectoral detail is needed. In the industry sector, the TIMES-D model, which will be used for the scenario analysis in this project, differentiates between energy intensive (subdivided into iron and steel, aluminium, copper, ammonia, chlorine, cement, lime, glass as well as pulp and paper) and non-intensive branches (other nonferrous metals, other non-metallic minerals, other chemicals and other industries). Consequently, from 2013 onwards the bound on ETS emissions in the model is put on all industries except the category “other industries”. In energy conversion, all installations with a total rated thermal input exceeding 20 MW are covered which leads to the exclusion of a number of smaller, decentralized CHP and electricity only plants. When comparing the statistical values with the model results on ETS emissions it turns out that the sectoral delimitation made in the model meets the current overall ETS emission levels fairly well.

Under the present design of the EU ETS as a downstream trading system, where the actual emitters of greenhouse gases are targeted, an extension to additional sectors would raise considerable challenges. In sectors like transport or private households a large number of small emitters would have to be included entailing prohibitively high transaction costs for those participants and an extreme increase in monitoring costs. At the same time, enhancing the sectoral coverage offers the advantage of increasing the cost-efficiency and liquidity of the system and also of reducing the risk of price volatility (cf. Sorrell 2010). The objective of integrating all sectors into an emissions trading system could be achieved with the help of an upstream scheme, where the suppliers (or importers) of fossil fuels are responsible for holding the emission certificates and meeting the predefined cap. The resulting certificate costs are directly passed on to fossil fuel prices such that in the whole economy a uniform price signal for emission mitigation emerges (cf. Philibert and Reinaud 2004). Such an upstream system is easily implemented in an energy system model by putting an upper bound on total CO_2 or GHG emissions. This approach can then be applied to conduct a comparative analysis contrasting the effects of the EU ETS and a comprehensive upstream trading system in terms of the sectoral contributions to emission reduction, certificate prices, energy system costs etc.

Apart from that, when looking at an emissions trading system with limited sectoral coverage one must not forget that the EU ETS is part of an overall strategy on emission mitigation assigning reduction targets to both the ETS and the Non-ETS sector with the aim to equalize marginal abatement costs between the two sectors. Under the "Effort Sharing Decision" (cf. EC 2009c), national binding targets for the emitters not included in the emissions trading system have been established. Energy system models provide an appropriate framework to analyse the question whether the target division between ETS and Non-ETS sectors actually turns out to be efficient in the long run. An equalization of marginal abatement costs might especially be inhibited when additional (national) climate policy instruments are introduced whose impact on emission abatement has not been accounted for when setting the targets.

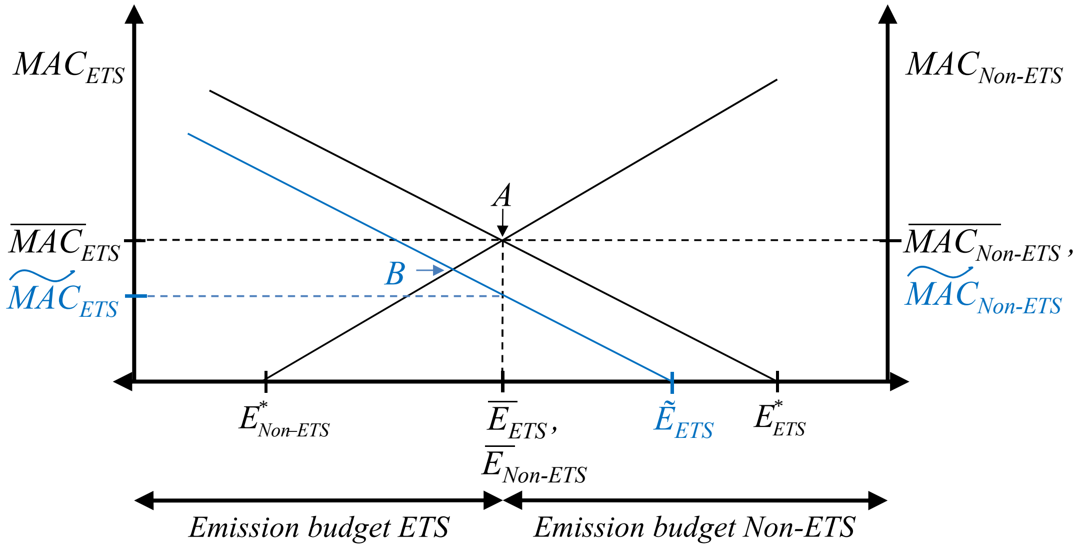

Figure 5-1: Graphical depiction of the effect of an additional policy instrument reducing emissions in the ETS sector on the cost efficient division of targets between the ETS and the Non-ETS sector (own illustration based on Walz 2005)

This problem is graphically highlighted in Figure 5-1. Here, both the marginal abatement costs for the ETS sector (MAC_{ETS}, left y-axis) and the Non-ETS sector ($MAC_{Non\text{-}ETS}$, right y-axis) are depicted. Without a reduction target in place, the emission levels amount to E^*_{ETS} (to be read from left to right) in the ETS sector and $E^*_{Non-ETS}$ (to be read from right to left) in the Non-ETS sector. It is assumed that in the beginning, before any additional policy instruments are introduced, a cost efficient distribution of the overall mitigation target is achieved such that when fulfilling the emission caps ($\overline{E}_{ETS}$ and $\overline{E}_{Non-ETS}$) each sector reaches the same marginal abatement costs ($\overline{MAC}_{ETS}$ and $\overline{MAC}_{Non-ETS}$ in intersection A). When, however, an additional policy instrument is implemented that reduces emissions in the ETS sector, the marginal abatement cost curve and the initial emission level in the ETS sector ($\tilde{E}_{ETS}$) shift to the left. An example for such a policy measure would be a national support system for renewable electricity that displaces electricity generation from fossil fuels and therefore causes an emission reduction in the ETS sector. In the illustration at hand, this reduction is given by the difference between the emission levels E^*_{ETS} and $\tilde{E}_{ETS}$. Consequently, if the emission budget for the ETS sector is not changed, the marginal abatement costs that are necessary to comply with the original ETS emission budget drop to $\widetilde{MAC}_{ETS}$, while in the Non-ETS sector marginal abatement costs remain the same. In order to realize a cost efficient division of reduction targets with the national policy instrument in place, the emission budgets would have to be adjusted to point *B* where the original marginal abatement cost curve of the Non-ETS sector and the new one of the ETS sector intersect leading to lower (and equal) abatement costs in both sectors (assuming that the overall emission cap is not altered). It has to be noted that the cutback in the ETS emission budget is smaller than the emission reduction associated with the additional policy instrument (cf. Walz 2005). Moreover, it has to be kept in mind that additional policy measures are generally associated with additional transaction costs such that the cost efficiency of reaching the overall reduction target is further affected when more than one instrument is implemented.

In an energy system analysis, the target division between the ETS and Non-ETS sector can be examined by setting a separate emission cap in both sectors. When analysing the cost efficiency of the initial distribution, attention needs to be paid to the fact that a number of national instruments have been introduced to ensure compliance with the Non-ETS targets, like efficiency standards in the building sector, biofuel quotas in transport etc. The impact of these measures should not be taken into account when determining the marginal abatement costs in the Non-ETS sector in the model, as this would already lead to a reduction in the shadow price of the constraint on Non-ETS emissions.

5.2. Allocation mechanisms

In the *Report on Work Package A* of this project, it has already been outlined that from a static perspective the mechanism with which emission certificates are initially distributed in a tradable allowance scheme, i.e. auctioning or free allocation, have no influence on the market outcome, as in both cases the most cost-efficient abatement options will be realized. When integrating an emissions trading system into an energy system model with the approach described above, an ideal-typical allocation mechanism is assumed under which the same incentive effect for each ton of CO_2 abated arises irrespective of the actual mitigation measure.

In reality such an incentive structure can be induced by auctioning[3] all certificates, while the free allocation regulations that have been applied in the EU ETS clearly deviate from this ideal-typical distribution. One of the provisions that might lead to a distortion in abatement efforts that has been highlighted specifically in literature is the use of fuel-specific benchmarks for the free allocation of certificates to new installations that most countries have applied in the first and second period. This free distribution can be understood as a reduction in investment costs that favours the installation of new power or industrial plants (cf. Fichtner et al. 2007). Some attempts have been made to consider this effect in energy system models by adding a power plant specific investment subsidy (amounting to the value of the freely allo-

[3] It is assumed that for the auctioning of emission certificates, a clearing-price auction is applied such that all units are sold for the same price.

cated certificates) to new processes (cf. Blesl 2007; Golling and Lindenberger 2008; Fichtner et al. 2007; Schwarz 2005). It becomes apparent that under auctioning fewer power plants based on fossil fuels are installed such that the expansion of low-emission technologies is facilitated and certificate prices are slightly lower. While in general such deviations from the idealistic design of policy instruments in the implementation practice should be kept in mind, the distortions stemming from the allocation mechanisms will get less significant in the EU ETS in the future as auctioning gains in importance and are therefore not further regarded in this analysis.

5.3. Banking and borrowing

The option to bank emission certificates for future use or to borrow certificates from later periods allows for greater intertemporal flexibility in the EU ETS. Typically, in energy system models one time period, represented by one model year, comprises several years. As emission reduction targets are only fixed for each time period and not each actual year, flexibility in the compliance time within one period is taken into account in the model. The intertemporal flexibility can be additionally increased in the model by using a cumulative constraint on GHG emissions leading to the same reduction over the entire time horizon but without setting mitigation targets for each model period (cf. Läge et al. 1999).

5.4. Inclusion of CDM/JI credits

The possibility to use credits from CDM or JI projects for compliance under the EU ETS widens the range of potentially cost-efficient abatement options. With respect to the modelling process, the inclusion of CDM/JI credits can be understood as an extension of the regional coverage to areas which are (usually) not covered by the model. Hence, the model approach that has been developed for the representation of supranational emissions trading schemes in national energy system models (cf. Chapter 4) can be transferred in order to integrate the potentials for CDM/JI projects in a regional or national energy systems analysis. This requires the creation of an abatement cost curve containing the reduction potentials of CDM/JI projects at different prices levels for all model years (cf. Enzensberger et al. 2002). Apart from that, a restriction needs to be implemented in the model to account for the limitation on the use of CDM/JI credits for the overall emission reduction under the EU ETS.

6. Conclusion

In general, emissions trading systems can be easily integrated into energy system models by putting an upper bound on total GHG emissions. An examination of the EU ETS has, however, clearly shown that mainly due to political constraints the structure and organisation of real-world emissions trading systems differ considerably from the ideal "textbook" description. Therefore, when the aim is to depict a specific tradable allowance system with as much detail as possible, a more complex modelling approach might be necessary.

In the analysis at hand, a focus has been laid on the correct representation of the regional coverage of the EU ETS. Due to their high level of detail and comparatively manageable size, national energy system models provide an appropriate framework to quantify the long-term impacts of different types of energy and climate policy instruments. When it comes to the modelling of supranational measures like the EU ETS, though, limitations become apparent. The benefits of an emissions trading system with large regional scale in terms of cost efficiency can only be appreciated in a model analysis if the entire region is covered and all abatement and trade options are considered. That is why, in the scope of this project an approach has been developed that makes it possible to integrate the mitigation options for the entire trading region into a national model with the help of a stylized abatement cost curve. Moreover, the implications of several additional features associated with the real-word design of the EU ETS, its limited sectoral scope, special provisions in the allowance allocation mechanism, banking/borrowing as well as the integration of CDM/JI projects, have been examined.

The advantages of the modelling approach presented in this report can be found in its high practical relevance and flexibility. The realistic representation of the EU ETS allows for evaluating its impacts on the energy system in an endogenous manner. The flexibility, as both the national share in emission mitigation and the allowance price can be determined endogenously, makes it possible to assess how changing scenario assumptions influence the abatement choices and the burden sharing in the trading system. Furthermore, the interactions with other policy instruments, like national instruments for the promotion of renewable energies, can be analysed in a flexible manner.

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