Abstract

Starting from CO_2 emissions data collected during both the production phase and during the lifetime of cars and trucks, we argue that impressive opportunities to reduce emissions can be found in the consumption phase. It is however obvious that energy taxes alone will not lead to a strong reduction of transport emissions. New instruments that stimulate technological innovations should therefore focus on emissions during product use.

In our opinion, current designs and proposals for CO_2 emission trading systems do not provide incentives to stimulate cross-sectoral energy efficiency investments like the development of cleaner cars and trucks. We think manufacturers should be >rewarded= when their products allow consumers to save energy during consumption.

To adapt these flexible designs, we introduced the concept of a >tradable certificate=, an allowance for each tonne CO_2 avoided as a result of selling a vehicle that is much more energy efficient than other new vehicles. We then developed two dynamic models in which we linked the value of these certificates to the diffusion of the cleanest vehicles. We found that the introduction of the certificate in tradable permit systems can lead to very significant reductions of CO_2 emissions. Our models indicate that emissions resulting from the car fleet can be reduced by 25 to 38% over a period of 15 years (starting in 1999). The potential of this new instrument is less spectacular for the truck market as a result of some fundamental differences compared to technological evolutions for car engines. But if the value of the certificate were high enough, emissions resulting from the truck fleet could be reduced by 12% over the same period.

Non-technical Abstract

In climate policy, new instruments are considered to reduce the emissions of greenhouse gases. One of the most interesting new instruments is emission or allowance trading that is already used in the U.S. Acid Rain Program. We think however that most designs for CO_2 emission trading are too strongly based on SO_2 trading designs while the abatement strategies for both environmental problems are clearly different. In our paper, we focus on CO_2 emissions in transport.

Starting from CO_2 emissions data collected during both the production phase and lifetime of cars and trucks, we argue that impressive opportunities to reduce emissions can be found in the consumption phase. We calculated the relative importance of the production and consumption phase in terms of total CO_2 emissions. We found that for the production of cars, emissions during the lifetime are 25 times more important than emissions during manufacturing. For trucks, emissions during lifetime are 375 times more important than emissions during manufacturing. Most policies do focus however on emissions during production and just assume that higher energy prices for consumers will lead to lower emissions.

It is however obvious that energy taxes alone will not lead to a strong reduction of transport emissions. Even in the countries with the highest energy taxes, total emissions in transport continue to increase. New instruments that stimulate technological innovations should therefore focus on emissions during product use.

In our opinion, current designs and proposals for CO_2 emission trading systems do not provide incentives to stimulate cross-sectoral energy efficiency investments like the development of cleaner cars and trucks. We think manufacturers should be >rewarded= when their products allow consumers to save energy during consumption.

To adapt these flexible designs, we introduced the concept of a >tradable certificate=, an allowance for each tonne CO_2 avoided as a result of selling a vehicle that is much more energy efficient than other new vehicles. We then developed two dynamic models in which we linked the value of these certificates to the diffusion of the cleanest vehicles. We found that the introduction of the certificate in tradable permit systems can lead to very significant reductions of CO_2 emissions. Our models indicate that emissions resulting from the car fleet can be reduced by 25 to 38% over a period of 15 years (starting in 1999). The potential of this new instrument is less spectacular for the truck market as a result of some fundamental differences compared to technological evolutions for car engines. When other truck emissions like NO_X need to be reduced, this will lead to a higher fuel consumption. But if the value of the certificate were high enough, emissions resulting from the truck fleet could be reduced by 12% over the same period.

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Making CO_2 Emission Trading More Effective : Integrating Cross-sectoral Energy Efficiency Opportunities

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Abstract

Starting from CO_2 emissions data collected during both the production phase and during the lifetime of cars and trucks, we argue that impressive opportunities to reduce emissions can be found in the consumption phase. It is however obvious that energy taxes alone will not lead to a strong reduction of transport emissions. New instruments that stimulate technological innovations should therefore focus on emissions during product use.

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Keywords : emission trading, greenhouse gases, energy efficiency, clean technologies, car and truck industry

JEL Classification : Q25, Q28, O3, L62

1. Introduction

Reducing greenhouse gas emissions will require a strategy that combines various policy measures and economic instruments. Next to traditional instruments like taxes on energy or the reduction of subsidies to energy-related sectors, some relatively new instruments entered the international fora. Systems of tradable permits for greenhouse gases (GHG), Joint Implementation (JI) and the Clean Development Mechanism (CDM) are currently considered or already in an experimental phase. Many of these instruments are of special importance for international emission reduction efforts but they do not provide a stand-alone solution. If they will be introduced in the near future, they will function next to many other instruments, depending on national priorities and political sensitivities.

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New instruments with a national scope followed. In late 1998, the Credit for Early Voluntary Action Act of 1998 has been submitted to US Congress (EDF, 1998). The Early Credit was part of President Clinton=s Climate Change Proposal of October 1997 and will provide emission reduction credits for early voluntary action (pre-2008) to US industries that reduce greenhouse gas emissions.

In this paper, we discuss current designs of tradable permit or allowance systems for carbon dioxide emissions and propose some modifications that could improve the environmental effectiveness of the instrument. We start from the general perception that the >flexible= instrument of permit trading has some clear advantages. It is accepted that permit trading will enable to reduce average abatement costs for developed countries as the trading will involve participation of developing countries and regions with lower abatement costs. The estimated savings through emissions trading with developing countries, compared to the GDP cost of unilateral emission stabilisation policies vary from 50% for the group of Annex I countries to 75% for specific countries like Japan (Mullins and Baron, 1997). Even among developed countries, there could be cost savings up to 50% by implementing carbon dioxide (CO_2) emission trading (Bohm, 1998). There are however still many uncertainties and discussions on implementation issues. An important issue will be the share allocated to (international) emission trading in total greenhouse gas reduction policies.

We will focus our attention on the environmental effectiveness resulting from permit or allowance trading. Can current designs of tradable systems result in accelerated reductions of carbon dioxide and other greenhouse gases, or will the trading mainly result in achieving the >emissions cap=, with or without an active market for tradable rights?

There are two other questions that we try to answer in this paper ; are current designs of CO_2 emission trading the most optimal designs and if not, can we redesign the mechanisms of allocation and trading to achieve better results? In case we can, how significant would be the improvement and at what cost?

In the next sections, we will elaborate on the need and opportunity to stimulate cross-sectoral energy efficiency investments, using data from the production of cars and trucks. Then we introduce a specific type of tradable allowance that enables to integrate these cross-sectoral efficiency investments in existing designs of emission trading. In the last sections, we present the output of dynamic models for the car and truck fleet that we have developed to estimate the impact of our instrument on CO_2 emissions for a period of 15 years. We also briefly illustrate that one of the used concepts is already introduced in another field of air quality policy in the United States.

2. The missing link

Most proposals for designs of systems of tradable emission rights start from an initial distribution of permits based on the production of carbon : >*The first step is to measure emissions of carbon* *dioxide into the atmosphere in terms of the fuels that consumers and industry actually buy (EC, 1998)*=. In this paper, we focus on carbon dioxide since it is the most important greenhouse gas. This initial entitlement of rights to emit is of course a crucial element for the political acceptability and the effectiveness of the system. Every year there will be an allocation of emission rights and by reducing the annual entitlement, total emissions can be reduced.

After the allocation of emission rights to a few sectors like energy producers and importers, price implications for the other sectors need to be considered. On this issue, opinions differ. If we assume that administrative costs need to be limited and that permits are allocated or >grandfathered= based on the carbon *produced* by the heavy industries or the importation of energy, the most important consequence of emission trading will be that energy prices increase for the consuming sectors in the economy ; households, light industries and the tertiary sector. These sectors will pay more for their electricity needs and for fuels used in transport and for internal power generation. The increase of the energy price will depend on the permit or allowance price that reflects the imbalances between demand and supply on the emission market. The results of this mechanism will be similar to those of energy taxes. The chance that emissions by households and transport decrease strongly is limited, due to low energy price elasticities that are currently experienced in most developed countries (Albrecht, 1998). It is a striking reality that in every developed country, even in those with high energy taxes, transport CO_2 emissions *continue* to increase. Next to energy taxes, other instruments are clearly needed.

In other CO_2 trading designs that are less depending on the role of a limited number of energy producers and importers, every economic agent (including households) has a personal private electronic account with carbon units. Individuals can escape from a general rise of energy prices if they consume less than their initial carbon unit credit or allowance : >*Purchases and sales of quota [carbon units] are made through automatic teller machines (ATMs), over the counter of banks and post offices and energy retailers, by direct debit arrangements with energy suppliers, and in numerous other ways... (EC, 1998).*=

We believe that these personalised emission trading designs have some advantages - consumers have clear incentives to save on energy used - but it will probably take a long time before these systems will function properly. Why not just include carbon units in existing electricity bills? This would be much cheaper compared to installing ATMs everywhere. The administrative costs of these multi-source-systems are also assumed to be very high. Therefore, we work in the next section with the more traditional designs of CO_2 trading that are in many cases based on the positive experiences with SO_2 trading in the United States. The Clean Air Act of 1990 created the sulphur dioxide trading program that started in 1994. According to the US Environmental Protection Agency (EPA,1997), the program is a success because utilities could reduce their emissions to a level below allocated emissions (e.g. 35 percent below allocated levels in 1995). Many participating utilities probably overcontrolled their SO_2 emissions in order to bank their allowances for use in future years (Phase II of the Acid Rain Program that starts in 2000) but some environmental groups stated that the initial allocations by EPA were simply too generous.

We would also like to stress that real reductions of SO_2 emissions are the result of cleaner inputs used like lower sulphur coal and on-site technological process improvements like placing scrubbers. Technological improvements will remain an essential condition for the realization of environmental targets. The trading between polluters provided an incentive to overcontrol emissions and diffuse reductions over the group of participating utilities. In the SO_2 program, the typical end-of-pipe technological option is strongly emphasized while CO_2 trading offers in our opinion much more potential for clean technologies of which saving energy is the cleanest of all.

The main difference with an energy tax is that permit trading - if effectively monitored and enforced - will always lead to the desired level of total emissions. The uncertainty of achieving specific emission targets is strongly reduced.

If trading with developing countries is allowed, the price of this emission cap would be limited compared to making use of energy taxes. But can permit trading offer something more than reducing average abatement costs? In the Kyoto Protocol it is stated that further reductions are needed after the initial commitment period that ends in 2012 (UNFCCC, 1997). Suppose that a reduction of 25% is needed in 2020 (relative to 1990). Will it be enough just to reduce the cap or the allocation of permits and will all parties accept this further reduction? Will majority voting procedures be applied during these negotiations? It is always possible that some countries do not want to reduce emissions further after 2012. Other complications could emerge when China, Indonesia or other developing countries do not open their gigantic markets for Western energy efficiency projects. Can we then easily enforce additional reduction of GHG emission to our already efficient electricity and industry sectors? The answer to one of these questions might be >no=...

Therefore, a strategy to reduce emissions by using trading mechanisms that only involve developed countries is very valuable to start with. In this perspective, the Early Credit could turn out to be an interesting experiment.

Currently, the allocation of permits is mostly modelled as an >upstream= or >downstream= system (Zhang, 1998 ; UNCTAD, 1998). Upstream systems allocate emission rights only over fossil fuel producers and importers. The participation in emission trading would be limited and many other policy measures will be needed. If transparancy and effectiveness of climate policies are a priority, we suggest that it would be better to develop a broad and integrated mechanism of emission trading. The use of many different instruments could result in conflicting means and targets.

More participation in emission trading is offered by downstream systems that include also other sectors, especially large industrial sources. Small sources will probably not be included for reasons of too high administrative costs. For instance, monitoring and enforcement costs in applying trading mechanisms to individual motor vehicle owners may be prohibitive (Hinchy e.a., 1998).

We can assume that the traditional energy-intensive sectors will be targeted. Some of these sectors have already formulated policy statements on permit trading. CEFIC, the European chemical industry council, will not oppose CO_2 emissions trading but explicitly demands for a *relative* grandfathering based on the changes in industrial production (CEFIC, 1998).

Industry can sell emission rights if the sector reduces its own CO_2 emissions. But if industry and the electricity sector are already efficient, how can we then reduce further GHG emissions at an acceptable cost? The answer on this question is not integrated in current tradable emission designs but is rather evident : we need to create incentives that make it interesting (not to say profitable) for industry and the electricity sector to reduce the GHG emissions of other sectors (transport, households and the tertiary sector). This is possible for each product that needs energy during the use or consumption. And many technical surveys indicate that the energy efficiency in transport and household energy use is still relatively low (Albrecht, 1998).

Therefore, we should stimulate cross-sectoral efficiency investments. Emission trading systems need to integrate cross-sectoral transactions like permits allocated to car manufacturers because they did sell very energy efficient cars to households. Therefore a new type of permits should be created for efforts that lead to reductions of emissions in other sectors. If the electricity sector, or another industry, provides a technology to a firm or industry that can reduce, just by the implementation of this technology, its own GHG emission by x tonnes, the provider of the technology should receive a number of tradable allowances[2] - in terms of GHG reduction units - for its sold product or technology. Later we will use the term >certificate= for this type of allowance. If other manufacturers, like the car industry or producers of heating systems or refrigerators, present a new energy efficient type, they could also receive a similar allowance or permit for the realized reductions. These allowances can be sold on the GHG Permit Market. The benefits from selling will reward industries for investing in GHG reductions realised by other sectors.

In the next section, we will work out an example for the car and truck industry to illustrate that what we propose is not just a further complication of existing proposals for permit systems but will offer significant environmental potentials.

3. Car and truck manufacturers and the tradable certificate

Next to many other sources, GHG emissions result from the production and the use of cars and trucks in transport. In most OECD-countries, transport accounts for more than 25% of all GHG emissions. The relative share of transport is estimated to increase further (COM(97)481). The

[2] Credits are denominated in terms of a pollutant flow such as tonnes per year. Allowances are defined in discrete terms like tonne CO_2, without a time specification. Working with allowances facilitates the development of future markets (Tietenberg, 1997).

CO_2 emitted in the production phase is however identical to the CO_2 emitted while using the car or truck. As a result of an upstream or downstream system of tradable permits, energy prices will increase and the already efficient car and truck manufacturing industry will further invest in abatement at the production phase or will buy emission rights.

In this >traditional= CO_2 emission trading system, the households that buy the cars will pay higher energy prices. The shift to very efficient cars will be insignificant. Considering the very low energy price elasticities for transport purposes, the diffusion of energy efficient cars will not be stimulated because industry is not *directly* rewarded for investing in reducing transport GHG emissions. Industry is only rewarded for reducing its *own* GHG emissions. We do not think that this should be the major environmental priority for car and truck manufacturers.

In Table I, we calculated total CO_2 emissions for producing one car in 1997. The data are collected for European Volvo plants. For other manufacturers, there could be significant differences. In our example, we limit the in-house production phase of cars to the four operations in Table I. The total CO_2 emissions in this table are relatively high compared to data for some other Volvo plants. We also included one tonne of steel per car in the example. This is probably too much ; the 1995 U.S. family car weighted 1470 kg (RMI, 1998). Another consideration is that CO_2 emissions depend on the used fuel mix used during production . A good illustration is the Volvo plant in Floby (Sweden) that has *no* CO_2 emissions because it uses district heating based on biofuel.

Table I - CO_2 emissions for the production of one car in 1997

Operations	Volvo Plant	unit	tonne CO_2/unit
Pressing of car body components	Olofström, Sweden	1 tonne of sheet steel	0.125
Production of gearboxes, rear axles and drives	Köping, Sweden	1 set of components	0.013
Foundry ; engine manufacturing	Skövde, Sweden	1 car engine	0.219
Assembly and painting	Ghent, Belgium	1 car	0.281
Total			0.638

Source : own calculations based on Volvo (1998a), Environmental data for Volvo production plants 1997

For the other supplies (seats, glass, electrical components,...) that are used during the assembly, we assume that the resulting CO_2 emissions amount to half of the in-house generated emissions. This results in total CO_2 emissions around 1 tonne per Volvo passenger car produced. Adding emissions during transportation and the end-of-life phases, we used in our further calculations (Box I) a figure between 1 and 2 tonnes carbon dioxide emissions per car. As a result of future emission caps and allocations in permit systems, this figure could decrease over time if the producer (here Volvo) does not prefer to buy permits on the emission market but will opt for internal emission reduction. The reduction will probably not be spectacular, at most a reduction of 0.5 tonne CO_2 per car. The cost of this emission reduction could be considerable.

The produced car is then sold and used in traffic. The average fuel efficiency of this car is around 10 litres for 100 kilometres (Volvo, 1998b). We estimate that one kilometre in traffic results in an average emission of 25 g CO_2 per litre fuel consumed (calculation based on EC, 1998b). For the car in our analysis, CO_2 emissions will be around 250 g/km. Assuming that the car will be used for 150000 kilometres and that the average fuel efficiency will be constant as a result of good maintenance, total emissions of CO_2 during the lifetime will be 37.5 tonnes. Emissions during car use clearly outweigh emissions during production.

On the issue of total CO_2 emissions of popular cars, some organizations even publish lists with the worst and the best cars in terms of environmental damage. In 1990, it was calculated that the BMW 750iL with an average fuel efficiency around 17 l/100 km produced 66 tonnes of CO_2 during its lifetime (Public Citizen, 1990).

If industry should make a choice between investing in reducing emissions during manufacturing or investing in cars that need less fuel during their lifetime, the best environmental results will be achieved by the latter option, probably at the lowest cost.

This is even more clear in the similar case of trucks and buses. We define trucks as heavy duty vehicles, starting from 16 tonnes. Trucks that are used for long-distance transport have an average lifetime ranging between one and one and a half million kilometres, depending on the quality of the truck and the maintenance. For trucks that are used for short distances (e.g. each day ten journeys of 30 km), the lifetime ranges from 750000 and one million kilometres. If we take average emissions of CO_2 around 30 g/km per litre fuel needed - truck engines mostly burn diesel - and an average fuel efficiency[3] of 40 l/100 km, a lifetime of 1.25 million kilometres leads to total emissions of 1500 tonnes CO_2. If the truck were very efficient and consumed only 30 l/100 km with a shorter lifetime of only 750000 kilometres, total emissions of CO_2 would still be 675 tonnes. Compared to emissions during the production of trucks, estimated around 3 to 5 tonnes, the difference is extreme. Box I summarizes our two examples.

[3] In this paper, all assumptions on fuel efficiency and lifetime or mileage of trucks are based on interviews with experienced maintenance engineers at SCANIA Belgium. We would especially like to thank Mr. Roger Lauwers. Data from Volvo (1998) and interviews at four transportation firms that use trucks of Renault, Iveco and Mercedes confirm our data.

Box I - CO_2 emissions during production and use of the product

	Car	**Truck**
emissions during production	1 - 2 tonnes CO_2	3 - 5 tonnes CO_2
emissions during lifetime	37.5 tonnes (150000 km)	1500 tonnes (1.25 million km)
relative importance of consumption phase	37.5/1.5 = 25	1500/4 = 375

–> conclusion : instruments should target emissions during product use

As shown in the examples, we think that policy instruments should focus on the emissions during the use of the product. The problem is that the car or truck manufacturer does not yet receive a tradable permit or allowance for his investment in clean vehicles. But if the new product of this manufacturer emits 10 tonnes CO_2 less over its lifetime, why not allocate allowances for this reduction to the manufacturer? In this perspective, it is interesting to note that some surveys mention the emission reduction potential of electric cars but then link this reduction of emissions to increased emissions for electricity generators. When the increases of emissions in one sector are more than offset by emission reductions in another sector, the term >negative leakage= is used (Nordhaus e.a., 1998). We think that this case illustrates that too often emissions reduction efforts are connected to electricity producers or to the group of energy-intensive industries. The fact that emissions in transport can be reduced is of equal importance.
The manufacturer of cars and trucks would then be able to sell these allowances on the permit market and use the benefits for lowering the price of the new and highly efficient product or for financing further R&D in ecodesigns. To emphasize the difference with other credits of permits, we will call this received allowance for realizing reductions in other sectors a >tradable certificate=.

4. Advantages of the tradable certificate

Next to the stimulation of intensive research in energy efficiency, the main advantage of the tradable certificate is the broadening or acceleration of industry involvement. Every firm with products that need energy can be rewarded for energy savings during the lifetime of its product. If the permit or certificate price is high, the price of these highly efficient products can be significantly lowered and this will stimulate their market penetration. A competitive advantage can be created when cross-sectoral reductions of CO_2 can be sold on allowance markets.
We can also be sure that at least a few firms will realise fundamental breakthroughs that can change our patterns of energy consumption significantly during the coming decades. Another advantage is that we create a permit market with much more activity and less dependency on some economic sectors. Not only the electricity providers or energy importers will be on the market - probably buying permits from Russia and increasing the energy price for consumers-, but every firm that realized cross-sectoral energy savings can participate. The supply of energy

efficiency will come from many parties. The stricter the caps imposed on the main emitting sectors, the more attractive their efficiency gains.

Some other issues need to be considered. In the case that manufacturers of cars or refrigerators can improve the energy efficiency of their products by making use of light materials or insulation solutions provided by the chemical or other industries, the allocation of the certificate is partly made possible by the inputs from other industries. These supply industries could claim a part of the certificates for themselves. It would however be very complicated to calculate the specific contribution of each input in total energy savings. Another option is that car or refrigerator manufacturers just pay a higher price for these specific inputs. On the other hand, the increased interest in energy saving technologies and inputs creates new and important markets for these supplying industries. They can increase their sales and this is partly made possible by the allocation of the certificates to the car and refrigerator industries.

If we introduce certificates for car manufacturers or other sectors to increase their CO_2 emissions during production, it is clear that the allocation of other - probably grandfathered - emission rights needs to be reduced. Otherwise, total emissions would increase. In our later model, we will explain that each year only a part of total received certificates will be available on the market for emission rights. We suggest that this annual inflow of certificates on the emission market will be deducted from the annual allocation that is planned for the country or industries in the analysis.

Compared to the Early Credit, the main difference is the cross-sectoral incentive to improve energy efficiency. Many aspects associated with the Early Credit are also valid for the tradable certificate : reward real reductions and not gaming, no predetermination of the eventual domestic regulatory program to control domestic GHG emissions, focus is on domestic early action, a mechanism that is not made contingent upon ratification of the Kyoto or later protocols,...

If the tradable certificate were developed as a voluntary mechanism, it would provide at the moment of the introduction of international emission trading some form of recognition for past voluntary GHG emissions. This should be preferred compared to a grandfathering mechanism that does not include past efforts. This is an important aspect since most observers estimate that international trading of emissions will not be a reality before 2004.

5. Performance standards

If we want to allocate certificates based on improved energy efficiency, a baseline to measure the efficiency gains is needed. The measurement of the energy efficiency improvement is rather easy to establish. For cars and trucks, detailed information on CO_2 emissions per kilometre are available in most countries. In our example, we calculated the efficiency gain as the reduction of emissions per kilometre.

Electronic devices need electricity and their electricity consumption is expressed in kilowatt-hours (kWh). In Europe, the most efficient refrigerators are already differentiated form the least efficient by energy labels. The price difference was in some countries reduced by a subsidy for the most efficient or A-types. If we want to allocate a certificate to the manufacturer, we can use an average CO_2 emission rate per kWh. Most figures fall inside the interval 400 - 800 g CO_2 per kWh used, depending on the input mix of the national electricity providers (EC, 1998). In the calculations in Box II, we assume 500 g CO_2/kWh. For countries that depend strongly on renewable or nuclear energy, lower values should be used. If we assume all refrigerators are equal in volume and quality, the difference in energy consumption per sold refrigerator should be multiplied by the number of sold products on the relevant market.

In Box II we present three examples with a sales volume typical for an important manufacturer selling in an average European country. We assume a lifetime of 15 years for the three products in the example and find that selling energy efficient products can reduce annual emissions of CO_2 with thousands of tonnes. Equal reductions will probably not be possible during the production phases.

Box II - Calculations of emission reductions based on performance standards

	Refrigerator	**Car**	**Truck**
Baseline	2 kWh/day	250 g CO_2/km	1200 g CO_2/km
Expected lifetime	15 years	150000 km	1500000 km
Efficiency new type	0.6 kWh	150 g	900 g
Savings (lifetime)	3.8 tonnes CO_2	15 tonnes CO_2	450 tonnes CO_2
Sales	10000	40000	5000
Total savings			
- lifetime (15 year)	38 000 tonnes	600 000 tonnes	2 250 000 tonnes

On the permit markets, the certificates allocated to the manufacturers of only three products, would lead to an annual inflow of 212 533 tonnes CO_2 equivalents during a period of 15 years. This inflow of certificates needs to be deducted from the total annual allocation of CO_2 emissions. If the baselines are set stricter, the inflow will be limited.

6. Modelling the impact of the certificate on the car and truck market

In this section we present two dynamic models to estimate the potential reductions of CO_2 emissions that could be realized if the tradable certificate were integrated in permit systems. We present two separated markets : the car market and the truck market.

We believe that the truck market receives much too little attention compared to the many policy initiatives for cars that have been taken in many countries. Heavy duty vehicles are of course less in number but with a mileage tenfold the car mileage and an average fuel efficiency five times the car fuel efficiency, a small truck fleet is responsible for the same level of CO_2 emissions as a car fleet that is 50 times bigger.

6.1 The car market

We start with a car fleet of 5 million vehicles and annual sales of 500000 cars. These assumptions are close to the actual situation of the Belgian car market.

We introduce three stock variables : existing car fleet, ecocars and other new cars. There are two types of new sold cars : an ecocar or a >normal= new car. The difference between the two categories is based on average fuel efficiency. Over a period of 15 years, we assume that the fuel efficiency of ecocars will fall from 5.5 l/100 km to 3.5 l/100 km. This is a realistic assumption (Von Weizsäcker, 1997 ; Lovins, 1996). A good example is the recent commercialization of Toyota=s Prius, a hybrid electric-gasoline car. The Prius consumes only 3 to 4 l/100 km with CO_2 emissions that are half of those of a conventional car. Emissions of toxic gases are reduced by 90%. Since the launch in December 1997, 3500 hybrid cars are sold each month in Japan and Toyota employees need to work overtime (Hinrichs, 1998). The reason for this >success= is the competitive price of the Prius in Japan ($ 16500) that is only 10 to 15% higher than the price of comparable but less fuel efficient cars. Some market analysts suggest that Toyota is not making profits on the Prius but wants to build up experience with the coming generation of ecocars.

Most surveys on the costs of ecocars estimate that hybrid and fuel cell vehicles would cost $ 4000 to $ 7000 more than comparable cars with traditional internal-combustion engines. Some manufacturers, like Ford and Mercedes - both corporations did invest heavily in the applications of fuel cell technology -, predict that the difference could be smaller (Leslie, 1998).

The fuel efficiency of the other new cars in our model will start at 8 l/100 km and will remain more or less constant in the first 5 years. Then the fuel efficiency will also improve and converge to the level of the ecocars. This assumption is made because we believe that when major corporations develop new engines and car bodies for their ecocars (35-75 kW), these new technologies will also be used - in a later phase - in their other types (more than 75 kW). Manufacturers will not develop car types based on two completely different technological trajectories. This would be too expensive.

For each of the stock variables, we defined a scrapping rate. Evidently, we used in the first phase a scrapping rate for the existing car fleet that is higher than the scrapping rates for the new cars. During the subsequent periods, the scrapping rates converge. We also assumed the scrapping rate of the existing car fleet to be dependent on the declining price of the energy efficient cars. Once these ecocars overcome their initial price disadvantage as a result of scale economies in the production, their inflow in the car market will increase and the scrapping of older cars will accelerate.

In our model, we introduced tradable certificates based on a fuel efficiency baseline of 9 l/100 km. The setting of this baseline is arbitrary. In the car example in Box II we took a baseline of 10 l/100 km. We calculated that the use of the more efficient new car will make it possible to

avoid the emission of 15 tonnes CO_2. This improvement will result in an allocation of 15 certificates to the manufacturer, each with an intrinsic value of abating one tonne of CO_2 emissions. These 15 certificates cannot be sold in the first year because they are based on the use during the complete lifetime of the vehicle. We assumed that manufacturers can only sell 20% in the first year. Of the total certificates, 80% will be banked[4] and sold in the next years.
We assumed that reducing the average fuel efficiency by one litre (for 100 kilometres) results in receiving four allowances, each representing one tonne CO_2. The efficient car in Box II consumes 4 litres fuel less than the baseline type. As a result, emissions will be reduced by 100 g/km. As already mentioned, over the lifetime of the car, 15 tonnes CO_2 are not emitted compared to the less efficient type.
The value of these earned certificates is linked to price developments on the permit market. Prices will depend on abatement costs for carbon producing industries, major market developments (like China or Indonesia participate in GHG emission trading) and the functioning of the market. In order to attract developing countries, it is obvious that permit prices need to be relatively stable, preferably at a high level. Making abstraction of other different opinions on climate policy and burden sharing between developed and developing countries, it will be hard to convince developing countries to join emission trading schemes if the price of the permits is very unstable and crashes frequently. We therefore assumed a mechanism of market intervention to keep permit prices inside a range. Using annual emission allocation quota that depend on average price developments and on the number of introduced certificates, could be an approach for this market intervention. If the allowance or permit price is falling, the allocation to energy intensive industries could be lowered to increase demand for permits and support the price level. If average abatement costs turn out to be around \$ 30 - \$ 40 /tonne CO_2 , we assume that the premit price will be around \$ 40 - \$ 50. In our model we will test for some widely accepted price levels, but not exceeding \$100 - \$150 (Bohm, 1998). Higher prices could however be possible since the marginal CO_2 abatement cost for some countries is estimated to be much higher (Mullins and Barron, 1998).
To reduce emissions, the market share of the efficient ecocars needs to increase. The commercial success of the ecocars will depend on the price difference compared to the other new cars. The price of the Prius is comparable - i.e. some 15% higher - to the price of its direct competitors and this is a crucial part of its success.
It would be too optimistic to assume that consumer preferences will shift to light microcars that are of course very efficient. We prefered therefore only to work in our model with rather large

[4] Banking means saving allowances for future use or for selling them to other participants in the future. A general advantage of banking is the provided flexibility for participants to go further than their required emission limit (Mullins and Baron, 1997).

cars with high comfort levels. Of this car with a high price of $ 30000, only two types are sold on the market. We clearly do not limit the category of ecocars to small cars because we think it is necessary to compare levels of comfort offered by cars. If an ecocar with only two places costs the same as a small family car with four places, the relative price of the ecocar is de facto twice the price of the other car. Many very efficient cars are small to reduce weight. This might be a positive development but households with three children that are also interested in efficient cars, are more concerned about the comfort level of their car. So we need to upgrade our average ecocar to the quality level of the average family car. We assume in our model that the ecotype of the average family car is 15% more expensive compared to the other type. We remind that the difference is probably smaller, especially for average cars with turbo diesel engines. In most countries, cars with the very efficient turbo diesel engines of Volkswagen and Seat cost some 5 to 10% more than the models of their competitors. The assumptions in our model are therefore rather conservative. If price differences are smaller, many stories like the Prius would follow. The same conclusion holds when the market share of small cars would increase.

Production prices of ecocars will fall as a result of economies of scale. For the new engines and materials, the economies of scale will be more important than for existing models.

We further assumed that prices to consumers will be reduced by the total actual value of the certificates that will be allocated to the manufacturer when selling an ecocar. We assumed that the banked certificates will not lose or gain value.

It is clear that buyers will only opt for the ecocar if the price is good and the comfort level comparable. In our model, 500000 new cars will be sold each year. If the price of the very efficient car equals the price of the other car, we assume that the market share of the ecocars will be 75% because comfort levels are identical. There will always be consumers that do not care about fuel efficiency and consider other characteristics more important. If the price of the ecocars is only 5% higher than the price of the other cars, we assume a market share of 30% for the ecocars. These buyers include the discounted energy savings in their decision to buy. If the price of the ecocar is 10% less than the other cars, we assume a market share of 95%.

The diffusion of the ecocars and the reduction of CO_2 emissions depend mainly on the difference in production cost and the value of the certificates that the producers of ecocars receive *more* than the producers of the other cars. If the baseline is set at 9 l/100 km, for *every* new sold car certificates will be received. Box III summarizes the main interactions that determine the market share of ecocars in our model.

Box III- Determining the market share of ecocars

fuel efficiency baseline (9 l/100 km) : b
fuel efficiency ecocars : f_{eco} (< b) fuel efficiency other cars : f_{other} (< b)
production cost eco : P_{eco} production cost other cars : P_{other}
value tradable certificate (4 certificates/saved litre) : VTC

IF (P_{eco} - 4 * (b -f_{eco})*VTC) < (P_{other} - 4*(b - f_{other})*VTC)
THEN market share ecocars increases, or :

IF (P_{eco} - P_{other}) < ((f_{other} - f_{eco})* 4 * VTC) THEN market share ecocars increases

When the baseline is higher than the two levels of fuel efficiency, the total difference (f_{other} - f_{eco}) will lead to receiving certificates. If the baseline is between the two levels of fuel efficiency, the instrument of certificates is less powerful because the manufacturer of the ecocars does not receive certificates for the total reduction in fuel needs he offers to his customers. He will only receive certificates for the difference (b - f_{eco}). We conclude therefore that relatively high baselines could indeed lead to high inflows of certificates but they guarantee that the total difference in fuel efficiency is valuated on the market.

6.2 Results of the car model

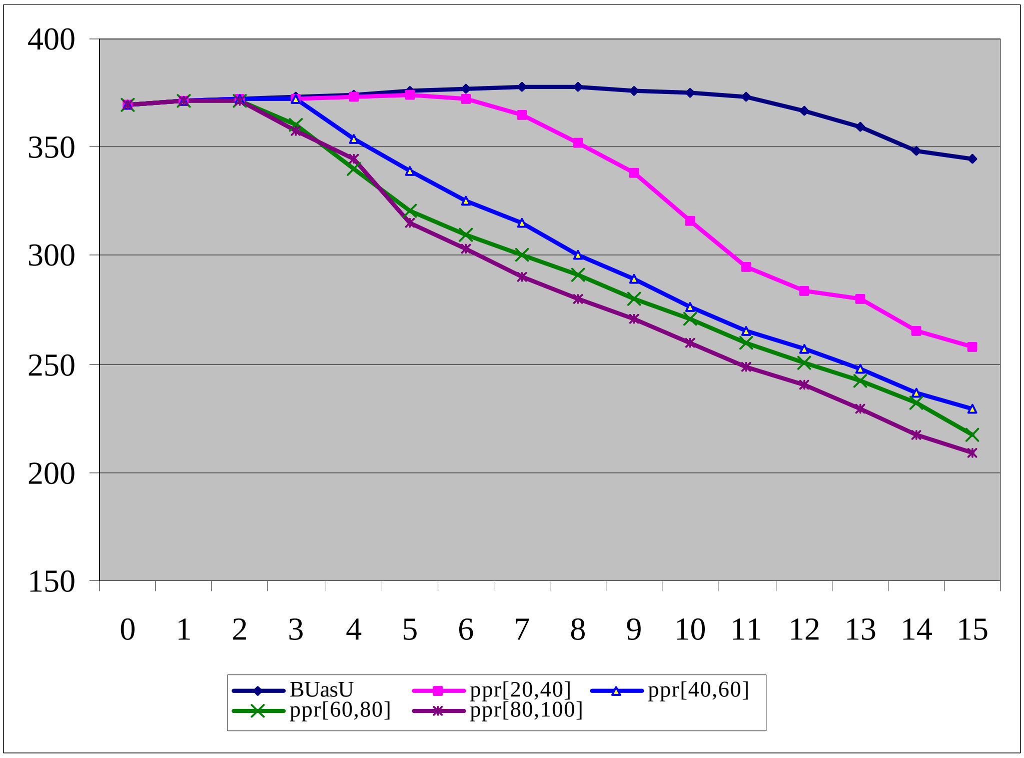
To estimate the potential of the permit system with tradable certificates, we first calculated the future development of CO_2 emissions without the tradable certificates. This is the business-as-usual scenario (BUasU in Figure I). The start of our model is the year 1999. This should be kept in mind when comparing our model output to other models that start in 1990. We find that without certificates, the market share of the ecocars will remain too insignificant to have a clear impact on emissions.

In our model, the car fleet increases with 15% but due to the scrapping of the oldest cars first, CO_2 emissions do not rise similarly. Cars sold before 1985 can have an average fuel efficiency that is 50 to 75% higher compared to the cars sold in 2000. This improvement of efficiency can outweigh increases in the fleet and car use (km/year). As a result, only during the first 8 years, emissions rise slightly and when the most inefficient and polluting cars - cars sold during the 1980s and early 1990s - are scrapped, the average fuel efficiency of the car fleet will lead to a stabilization and modest reduction of CO_2 emissions starting from 2010. This (positive) development is of course depending on the ability and goodwill of manufactures to produce efficient cars without strong incentives like in the case with the certificates.

We then introduced tradable certicates into our model for an average car of the upper segment of the market (price :$ 30000). We took four price levels (in $) for the certificates or permits on the emission market : 20-40, 40-60, 60-80 and 80-100.

From Figure I - permit price ranges are indicated as ppr[,] - it is clear that the reduction of CO_2 emissions strongly depends on the introduction of the certificate. However, the differences for each price interval are small once prices on the permit market exceed $ 40. The patterns presented in Figure I are trend lines derived from numerous runs for each permit price interval. For each run, random permit prices were selected out of the relevant price interval.

Figure I - CO_2 emissions of the car fleet (million tonnes, 15 years)



Since our baseline remains at 9 l/100 km, there is a strong incentive for the most efficient manufacturers but certificates will also be received by other manufacturers. As a result, the level of the total reduction depends also on the improved fuel efficiency for the other cars. The improved average efficiency of all new cars is as important as the market share of ecocars.
Compared to the scenario without certificates (business-as-usual), the reductions of CO_2 emissions range between 25 and 38%, depending on the value of the certificate. Compared to the level of emissions in the first year of the model, the reductions are even higher : from 32 to 43%. If we had included in our model an increasing market share for small cars, the reductions would have been even more impressive. Since emissions from transport are assumed to increase more than emissions from other sources - for the European Union, transport emissions are projected to increase by 39% for the period 1990-2010 if no measures are taken (COM(97)481) - the potential of our instrument proves to be very attractive, even when working with this market segment of expensive cars. For smaller ecocars, compared to other cars of average size, the value

of the certificates will lead to a more explicit price advantage.

6.3 The truck market

We developed a similar model for heavy duty trucks, starting from 16 tonnes. The success of CO_2 policies will also depend on evolutions in fuel efficiency for these vehicles. Many authors who write on the car market assume that developments for the truck market will be similar. There are however a few fundamental differences.

First of all, the truck market is more competitive than the car market. Buyers are very interested in the energy consumption of the truck they will use for many kilometres. The strong competition on the transportation market guarantees that transportation firms want to lower their energy costs. If the price of the most efficient trucks will fall, the reaction of transporters would be significant and the market share of ecotrucks would increase strongly.

Another difference with evolutions on the car market is related to the link between fuel efficiency and payload. The fuel efficiency of cars can be improved by reducing the weight of the cars. Trucks are developed to transport a heavy load. The use of weightsaving materials in the production of trucks will not yield similar results as in the car industry because the load remains heavy. The heavy load also has other implications. The average fuel efficiency of heavy trucks ranges between 30 and 40 litres for 100 km. In very congested traffic, the fuel consumption can even double. The two most important determinants of the fuel efficiency are not engine performance aspects but very basic elements : aerodynamics of the truck and load and tire pressure (the latter as a result of the weight of the load). Surprisingly, driving an empty or full container results in a difference in fuel consumption of only 5 litres. More surprisingly, driving an open (no roof) or closed container results in the same difference, with or without load. And the same additional 5 litres will also be consumed when the tire pressure is 25% below the optimal level (8 to 8.5 bar).

A rather conterintuitive difference is that for heavy vehicles, cleaner engines are less fuel efficient engines. There is generally a trade-off between exhaust emissions and fuel consumption (Samuelsson, 1998). Reducing emissions of pollutants did result in increased fuel consumption of turbo diesel engines. This depends to a large extent on the link beteen NO_X (nitrogen oxides) emissions and fuel efficiency. And from Table II, it follows that the focus of emission reduction requirements by the EC has been on reducing NO_X.

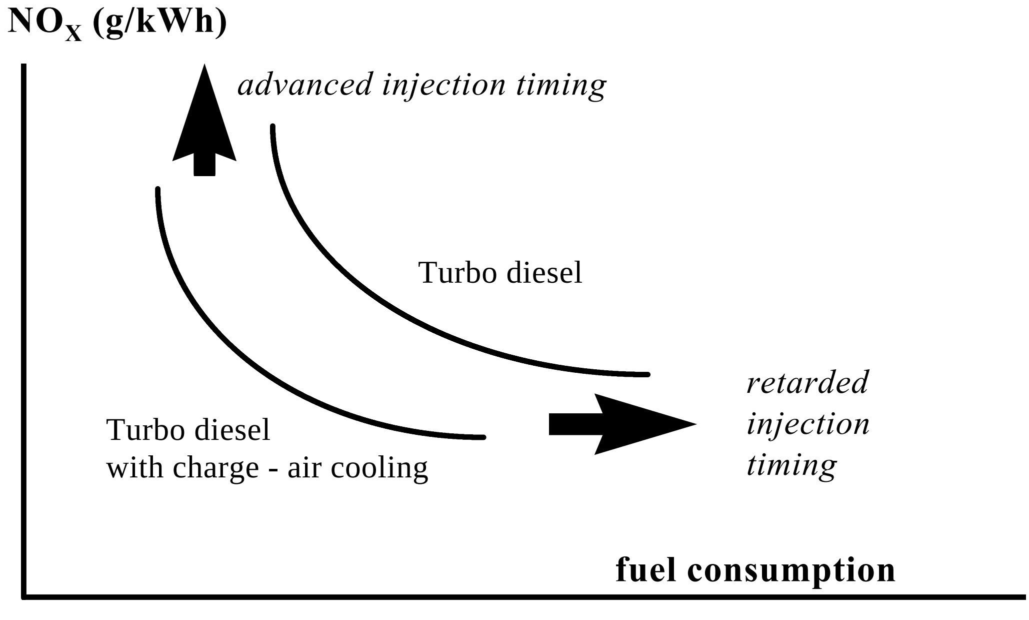
The relationship between NO_X and fuel consumption is shown in Figure II.. The emissions of turbo diesel engines depends on the timing of the injection. When the injection is retarded, the emissions of NO_X (g/kWh) will be reduced but the fuel consumption will increase. The challenge in most engineering departments of truck manufacturers is to anticipate the stricter Euro III standard while keeping fuel consumption stable. For SCANIA, it is expected that fuel consumption will increase by 0.5 to one litre per 100 kilometres as a result of the Euro III standard. For other manufacturers that are less advanced in the reduction in NO_X, the increase in fuel consumption is expected to be up to 5 litres! This is a good illustration of the benefits from investing first in clean technologies.

Table II - Development of emission requirements for trucks, g/kWh, 1989-1999

Standard	Year	NO_X	HC	CO	Particulates
ECE R 49	1982	18	3.5	14	-
Germany	1986	14.4	2.8	11.2	-
EEC	1990	14.4	2.4	11.2	-
Euro I	1992-development 1992-commercial	8.0 9.0	1.1 1.25	4.5 5.0	0.36 0.40
Euro II	1995/1996	7.0	1.1	4.0	0.15
Euro III	1999	under disc.	u.d.	u.d	u.d.
SCANIA	1989	14	0.5	1	-
SCANIA	1991	7.8	0.5	1	0.25

Source : SCANIA, 1998

Figure II - Relationship between NO_X and fuel consumption (diesel engines)



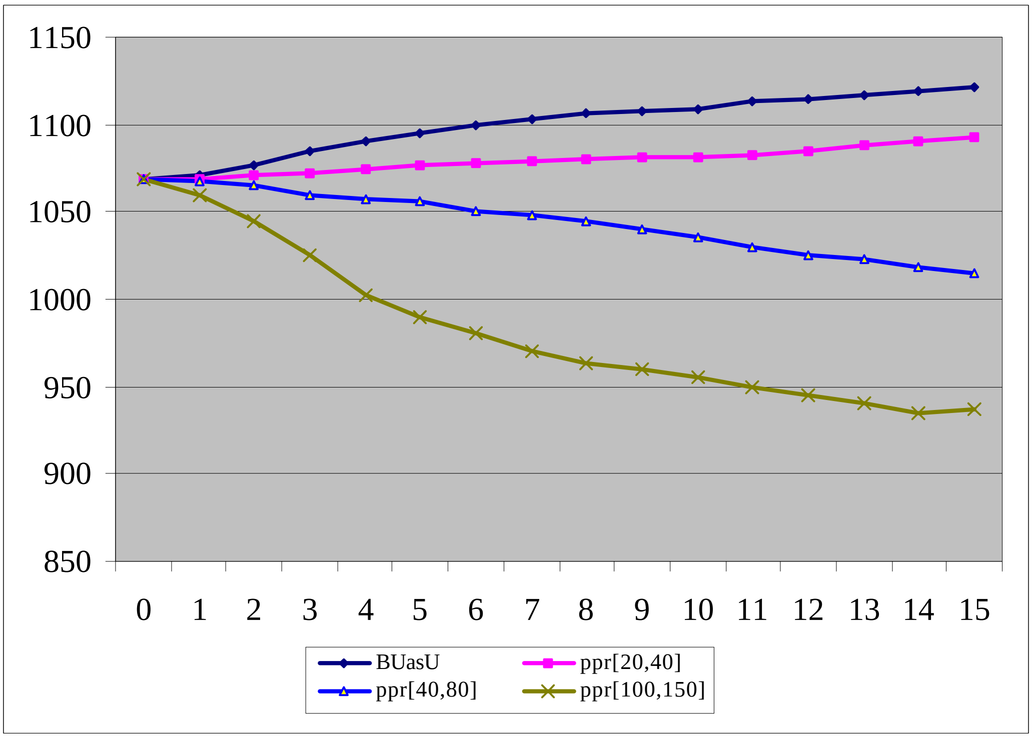
Source : Nylin, 1991

As a result of this trade-off, we cannot expect that the average fuel efficiency of the truck fleet will be strongly reduced in a few years. It will take more time. Furthermore, it is not speculative to state that the firms with the cleanest engines will have a significant advantage over their competitors who invested later in the development of clean engines. This difference could lead to lobbying activities to influence the implementation of new standards.

6.4 Results of the truck model

In our model we start with a truck fleet of 570000 units. Over a period of 15 years, the fleet increases with 12% to 638883 trucks. We first work with a production price of $ 65000 for a new truck (average fuel efficiency of 37.5 l/100 km) and $ 70000 for an ecotruck (average fuel efficiency of 32.5 l/100 km). The baseline for fuel efficiency was 45 litres/100 km. In later runs, we increased the production prices and changed the efficiency baseline.
In the scenario without the tradable certificate, we found that CO_2 emissions will increase by 6%. We then introduced the certificate at three permit price levels (ppr in $) : 20-40, 40-80 and 100-150. The results are presented in Figure III.

Figure III - CO_2 emissions of the truck fleet (million tonnes, 15 years)



It is shown that with the low value of the permits ([$ 20,$ 40]), the certificate will not have a strong impact on emissions : emissions will increase by only 3% compared to 6% in the business-as-usual scenario (BUasU). If the permit price ranges between $40 and $80, we found that CO_2 emissions will be reduced by 3 to 6%. With the high permit prices, the reductions are significant : - 12%. As indicated in Box III, the level of the baseline is important in determining the number of certificates a manufacturer will receive. We therefore did run the truck model with baselines

from 35 to 50 l/100 km. The results - best and worst model output for the specific baseline - are presented in Table III. As already suggested, too low and too high levels for the baseline reduce the attractiveness and environmental impact of the tradable certificates. The best baseline in the emission trading design is a fuel efficiency that slightly exceeds the fuel efficiency of the other new vehicles sold on the market. For the truck market, the differences resulting from the changes in the baseline are not that spectacular. From Table III, it is shown that we reach the best results with a baseline of 40 l/100 km.
For all the runs used for Table III, the price of the permits was selected at random from the interval [$20, $100]. The percentage reductions are always calculated compared to the start of the model.

Table III - Fuel efficiency baselines for trucks and CO_2 emissions

Fuel efficiency baseline for the certificate	Change of CO_2 emissions *worst case(% change)*	Change of CO_2 emissions *best case(% change)*
35 l/100 km	+2	-7
37.5 l/100 km	+1	-5
40 l/100 km	+0.5	-8
45 l/100 km	+1	-6
50 l/100 km	+1.5	-5

Finally, we present some results when the average production costs in the truck model were increased from $ 65000 - $ 70000 to $ 80000 - $ 85000 and to $ 90000 - $ 95000. The price difference of $ 5000 is relatively smaller for expensive trucks. The output of the model is similar for the two cases with higher prices. The reduction in fuel costs and the value of the certificates will in both cases lead to an earlier shift to ecotrucks if the certificate is introduced. We found that with prices for trucks between $ 80000 and $ 85000 and permit prices taken from [$20, $100], CO_2 reductions will decrease by 4 to 10% over 15 years. With production prices of $90000 and $ 95000, the projected reductions range between 3 and 9%.

6.5 Conclusions of the models

It is clear that emissions of CO_2 can only be reduced when the diffusion of cleaner engines and new vehicle designs is strongly stimulated. This could be achieved with subsidies but then some sectors would be more able than others to influence the subsidy mechanisms. If we should opt for certificates fitting in permit system designs, we increase transparency and limit administrative costs. The potential reductions depend on many specifications of which the used baseline to allocate the certificates might be an important one. With realistic permit prices, we found that the system with tradable certificates offers very significant reduction potentials, especially for the car market. For the truck market, the reduction potential is more limited but still very interesting.

7. The case of permits for scrapping

The tradable certificate, like we have presented it, receives its value from avoiding CO_2 emissions. We found another case related to cars - especially to very old cars - where permits were also allocated as a result of avoided emissions. There are however many differences in the case that we will briefly present. The term >permit= is here an air quality permit, like city and county permits and should not be compared with permits in emission trading.

The Clain Air Act amendements of 1990 required US states to consider possible remedies for pollution from old cars. These cars pose serious problems. Tests in the early 1990s on thousands of vehicles in Los Angeles, Chicago and elsewhere showed that 50% of all carbonmonoxide (CO) emissions came from only 10% of the cars on the road. Similarly, half of the hydrocarbons (HC) were emitted by 14% of the vehicles (Totten and Settina, 1993).

A few programs were established to accelerate the scrapping of these older cars. The first was SCRAP (South Coast Recycled Auto Project). SCRAP could offer $ 700 to each owner that sold his old car. Compared to our case, SCRAP gave the owner the certificate for avoided emissions and he sold it immediately on the CO- or HC-market for $ 700. In the first phase of SCRAP, 8400 cars were bought. This resulted in the elimination of 13 million pounds of pollutants from the air. To make the program more attractive, participation of other corporations could be stimulated by linking their construction permits to proven reductions from other sources. These firms would then estimate their future emissions and buy the necessary number of old cars to >offset= their own pollution debt (Totten and Settina, 1993).

Another program is the Bay Area Vehicle Buy Back program (San Francisco). Since 1996, this program has already bought 2000 old cars and paid each owner $500 (BAAQMD, 1998). By recently adding 1980 and 1981 model years to the program, the potential pool of eligible vehicles in the Bay Area approximates 100000 vehicles, each 5 to 50 times more polluting than new cars. Almost every environmental program receives criticism from action groups but these scrapping programs were opposed by some unexpected groups next to environmental organizations. Associations of collectors of old cars tried to stop the scrapping because the prices of spare parts for collectors would increase as a result of the scarcity. Some of these groups used however interesting arguments to oppose the scrapping[5]. They stated that when the pollution credits resulting from the scrapping are applied for permitting new plants - and this was the basic

[5] An overview of the position of these groups with economic and environmental arguments can be found at <http://home.fuse.net/sdun/Scrappage.htm> (visited 16/10/98).

principle when introducing SCRAP -, there is no net change in emissions and air quality. When the owners who scrapped their old car, replace this vehicle by another relatively old and dirty car, total emissions could even increase.

Environmental groups complained that some cars for which their owner received the scrapping premium were barely running. They argue that the realized reductions by the program are much lower.

8. Conclusions

Starting from reliable data on CO_2 emissions during the production and the use of cars and trucks, we found that opportunities for reducing emissions are impressive in the consumption phase. Emissions during the production phase are almost negligible compared to emissions during the use of the vehicles. The only available instruments that directly influence energy use by households and industry are energy taxes. The price elasticity of energy used in tranport is however much too low to have a significant impact on transport emissions. It is striking that in every developed country, even in those with the highest energy taxes, transport emissions continue to increase. New instruments should therefore focus on emissions during the phase of product use or lifetime but current designs and proposals for tradable CO_2 emission systems do not provide incentives to stimulate cross-sectoral energy efficiency investments. We argue that manufacturers should be rewarded for their products when they make it possible for consumers to save energy during consumption.

To modify these designs, we introduced the concept of a >tradable certificate=, an allowance for each tonne CO_2 avoided as a result of selling a vehicle that is much more energy efficient than other new vehicles. We then developed two dynamic models in which we linked the value of these certificates to the diffusion of the cleanest vehicles. We found that the introduction of the certificate in tradable permit systems did lead to very significant reductions of CO_2 emissions. Emissions resulting from the car fleet will be reduced by 25 to 38% over a period of 15 years (starting in 1999). The accelerated scrapping of old and energy inefficient cars is also very important in this process.

The potential of the new instrument is less spectacular for the truck market as a result of some fundamental technological differences. But when the value of the certificate would be high enough, emissions resulting from the truck fleet could be reduced by 12% over the same period.

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