Multi Agent Simulation in Transport

Assessing Impacts of Policy Instruments

to Reduce CO_2 Emissions in Germany

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Abstract

Knowing the possible impacts of Global Warming the European Union decided to join in the Protocol of Kyoto and to abate 8 % of its carbon dioxide (CO_2) emissions until 2010 compared to 1990. For that a European Trading Scheme (ETS) for CO_2 certificates was implemented. So far, the transport sector, who contributes around 28 % of the European CO_2 emissions, has been exempted from the ETS, although a further increase is expected for the following years. Furthermore it is the only sector which increased its emissions (by about 32 % since 1990). This article shows that behavioral multi agent models are suitable to handle an impact assessment of policy instruments to reduce CO_2 emissions in road transport in introducing a prototype model and its preliminary output for the German transport sector. In doing so a hypothetic CO_2 emission trading scheme is implemented to a java-based simulated transport sector. Effects on certificate prices and fuel demand are calculated with respect to individual reaction functions of households and shippers. It becomes apparently that the willingness to pay for 'fuel-inefficient' (but prestigious) transport is very high. This leads to a net payer position of the transport sector in an expanded ETS.

Key words: *CO_2 emission trading, Germany, multi-agent, multi-agent-modeling, road transport.*

JEL-Code: *H30; Q38; Q54; C69; O21*

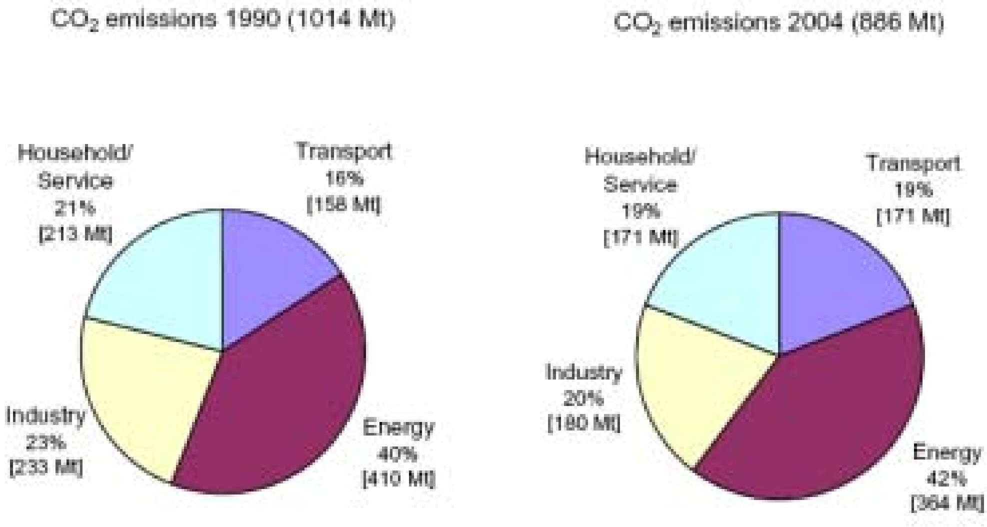
1 Introduction

The most recent IPCC (Intergovernmental Panel on Climate Change) report shows that the increase of globally averaged temperature is very likely due to the observed increase in anthropogenic greenhouse gas concentration (IPCC, 2007). Additionally the former Chief Economist of the World Bank, Sir Nicolas Stern, advised against the huge costs arising in the end of this century resulting from global warming. He alerted, investing 1 % of the GDP today in reducing carbon dioxide (CO_2) emissions would prevent us from losses from more than 20 % in some decades.

In the Protocol of Kyoto Germany has pledged to cut 21 % of its CO_2 emissions until 2010 with respect to the base year 1990. Up to now, Germany has already reduced its emissions by about 17 %. The sectors which have already contributed include industry processes (-4.5 %), energy generation and transformation (-12.1 %), manufacturing and construction (-35 %) (which is particularly due to the breakdown of the industry in the New Laender), as well as other sectors (a. o. households) (-21.0 %). One exception is the transport sector, which has actually increased its emissions by 8.2 % – from 158.1 in 1990 up to 171 Mio. t/a in 2004.[1] But emissions start to decline as only aviation and freight road traffic still maintain its fast increasing growing rate (Ziesing, 2006). Hence the portion of national transport on the overall CO_2 emissions in Germany increased from below 16 % up to 19 % in 2004 (see figure 1). This increase is beside huge raises in national aviation however mainly caused by an almost constant amount of CO_2 emissions by passenger cars (especially due to the expansion of passenger car density in the eastern part of Germany) and road freight transportation (+20 %) due to eastward enlargement of the European Union, where Germany move more and more in the centre of important flows of trades.

1 These CO_2 emissions of the transport sector in classification of energy balances are calculated – according to the accounting directive of the Kyoto Protocol – on the basis of the sales of Diesel fuel and fuel for spark-ignition engines for transport in Germany (Ziesing, 2006).

Figure 1: CO_2 emissions in sectors in 1990 and 2004 in Germany



Source: Ziesing (2006)

For this reason it is desirable (both for fairness and for ecological efficiency) that traffic participants should also contribute to the national (and international) emission target. Since it is unlikely that traffic participants would reduce their CO_2 emissions voluntarily, the legislature should assist. One possibility among others could be an incorporation of the transport sector into the European Trading Scheme (ETS); but its design is so far vague. Furthermore an interesting question would be which policy instrument (taxes, prohibitions, charges etc.) or design of certificate market is the most efficient and most suitable with respect to impacts on traffic participants? For this question the most crucial participants are those of road traffic, as they contribute 92.3 % to the overall CO_2 emissions from transportation, which could be diminished only by a higher efficiency, substitution of fuel through not fossil ones, or through change in the modal split (UBA, 2003).

Most studies forecast a further increase in emissions of transport at last till 2010 (BMU, 2000, p. 60). Compared with the in the long run (necessary) CO_2 emission targets for industrialised nations as Germany with -30 to -40 % until 2030 with respect to 1990 (Enquête Kommission, 2002) or -80 % until 2050, the actual CO_2 emissions in the transport sector are considerably to high. Particularly when considering the high potentials of emission reductions (especially in road traffic) (BMU, 2006, p. 25); even if mitigation costs (or better: willingness to pay) are high by given preferences for heavy, save and high performed cars (CE Delft, 2006). But a demand shift to more efficient cars has a double dividend:

cars (still suitable for driving from A to B) are much cheaper and use less fuel. But as long preferences stay constant Goodwin et al. (Goodwin et al, 2004) remarks that the price-elasticity of total transport demand is about -0.6 in the long run where as the income-elasticity of demand is a factor 1.5 to 3 higher. Thus prices of transport should increase much faster than income to avoid selling of more upsized cars. Therefore an imperatively need for action is imposed. Besides technical innovations also a rethinking in the demand should be considered. The latter can be supported by political instruments as regulatory (obligations, commandments, and prohibitions), informatory, voluntary (among others self obligations), and economic policies (taxes, charges, and certificates). How far these instruments could be economically legitimised might be evaluated by criteria compiled by Rennings et al. (1997): aim- and system conformance, cost efficiency, as well as institutional controllability. Certificates may convince particularly with respect to three of those criteria: the actors are highly free in decision (*system conformance*), actors with low marginal abatement costs have the highest incentive to reduce their emissions and innovative behaviour is rewarded (*cost efficiency*), and the aim is precisely reached (*aim conformance*). However empirically these theoretical advantages may emerge as drawbacks when transaction costs arise, information veiled and tactical considerations are exerted. Additionally with institutional controllability there is up to now no experience in Europe with trading certificates in this topic (Stronzig et al., 2003).

The remainder of the paper is organized as follows. After illustrating the German transport sector the following section motivates the implementation of emission trading. Afterwards essential composition options for trading with certificates in the transport sector are defined. In addition, possible starting points for a trade with certificates in the transport sector will be worked out. Finally, after a short introduction to multi agent models, a prototype model with its preliminary outputs is presented and in the following conclusion the essential results are summarised.

2 The German transport sector and policy instruments for reducing CO_2 emissions

Accounting the above depicted raising high share of road traffic in CO_2 emissions other traffics are (firstly) neglected in the following. This is especially true when including only direct emissions, as road traffic contributes 94 % of the CO_2 emissions in the transport sector. Rail (1.4 %), aviation (fast rising 4 %) and transport on inland waterways (0.5 %) contribute far less than 10 % of CO_2 emissions in the German transport sector (Deutsches Verkehrsforum, 2006).

Besides the freight road transport, aviation also contributes to the rising emissions in the transport sector. Despite a fundamental improved efficiency of aircrafts its CO_2 emissions increased by 73 % between 1990 and 2003 in the EU-25 (EEA, 2005). The forecast, that this emissions will double in the following decade deteriorate the problem significantly (Eyres et al., 2004 und Wit et al., 2005), especially as impacts from emissions in the tropopause are twice to four times effective as emissions in the lower troposphere (IPCC, 1999). Notwithstanding the implementation of a policy instrument in aviation is highly questionable by virtue of the possibility to evade to other countries for refuelling (Wit et al., 2005 and Wit and Dings, 2002).

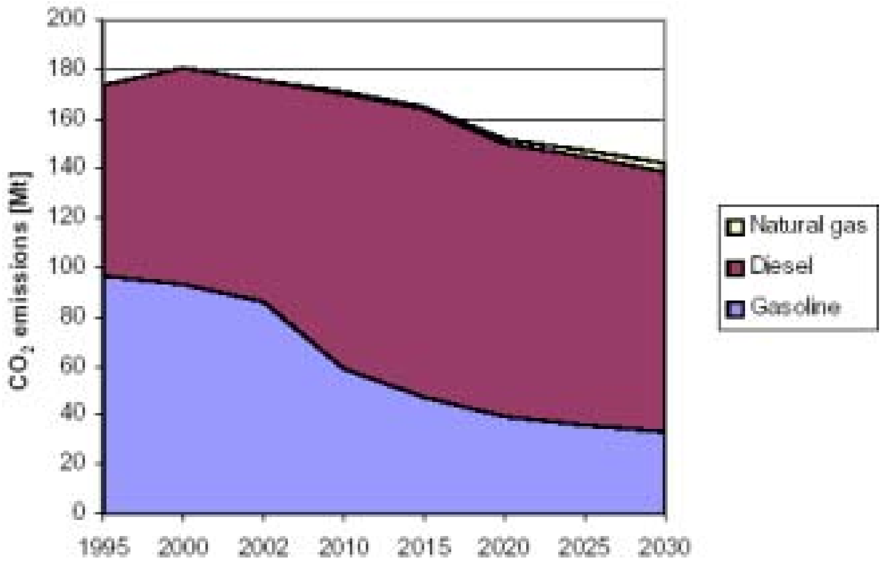
2.1 History and outlook on road traffic

In the nineties the improvement of specific fuel consumption in cars caused by progresses in engine mechanics were excelled by trends towards higher motorised and heavier cars, additional conveniences, higher limit demands in other pollutants, as well as a increase in performance ("upsizing"). Therefore and due to the high enhancement in the freight road transport, emissions of CO_2 caused by road traffic in Germany increased by 5.4 % between 1990 and 2004.

But there is a very different development in freight and passenger road transportation. While the emissions of the former increased due to eastward enlargement of the European Union, where Germany move more and more in the centre of important flows of trades, by about 20 %, whereas the latter decreased by 4 %. Progtrans (2007) predicted a further increase in freight road transport of 100 % until 2050. Nevertheless passenger transport still causes about 68 % of national CO_2 emissions.

The TREMOD model estimated increasing kilometres travelled by car by around 25 % between 2000 and 2020 (Ifeu, 1999). Zumkeller et al. (2005) stated that car motorization will still increase, but mileage in road transport will stay constant or even decrease. As cars become more and more efficient a decrease in energy consumption appears reasonable (EWI and Prognos, 2005). Furthermore as usage of new fuels with less CO_2 emissions (bio-fuels, gas, etc.) is increasing, overall emissions in road traffic will significantly decrease by about 25 % until 2030 (see figure 2). Only the TREMOD model (Diaz-Bone et al., 2001) forecasts a further increase of CO_2 emissions caused by road traffic until 2020 (Ifeu, 1999) – even though efficiency gains in passenger cars below 100 g of CO_2 per km are assumed to be technical feasible and realistic for new cars in 2020.

Figure 2: Development of CO_2 emissions of road traffic in Germany between 1995 and 2030.



Source: EWI and Prognos, 2005

2.2 *Why emission trading?*

As already depicted the aim *reduction of CO_2 emissions in the transport sector* could be archived by a few instruments (among others emission trading). To what extend the composition of arrangements is economically authorised can be (hypothetically) pre-proved, according to Rennings et al. (1997, p. 20) in the style of Grossekettler (1991). This evaluation of policy instruments can be accomplished by virtue of four criteria as aim conformance, system conformance, cost efficiency, and institutional controllability.

A short comparison of instruments

Whereas the past politics in Europe concentrated primarily on regulations, fees, and taxes (e.g. fuel tax, a supplementary "Eco-Tax" for fuel and energy in Germany as well as taxes on passenger cars) today informational and voluntary instruments become more and more important. So e. g. the Association of European Automakers (ACEA) assured voluntarily to reduce the average CO_2 emissions to 140 g per km (these emissions are obtained in the new European driving cycle without consideration of the consumption for air-conditioning and further electric consumer as steering boosters, seat heater, etc.) for new authorised cars till 2008. Similar self commitments are also disposed from Japanese and Korean automakers. But these commitments are far from being fulfilled, thus the Council of EU-Ministers passed a low act which regulates CO_2 emissions for new sold cars of 120 g per km till 2012. All of those previous instruments show however certain weakness especially when concerning the warranted reduction aims of the Protocol of Kyoto.

Taxes do not formulate any aim and self commitments have deficits in formulating absolute aims; they can only formulate specific aims. Covenants in environmental issues which are based on specific aims contain a risk concerning the ecological achievement of this aim: since an unexpected high action level – say unexpected growth in macroeconomic, sectoral or corporate specific way – may lead to unscheduled ecological surplus loads, even if complied with specific target values. Additional is the ACEA agreement applied only to new licensed cars; this causes a long time lag until the self commitment penetrated the whole market. The environmental effectiveness is also jeopardised as self commitments are normally not legally binding. If the aim is failed it is impossible to achieve it by mandatory instruments. Furthermore their instrumental design is not exposed thus effectiveness remains vague; and additionally information of accumulated costs are hardly available – not to mention open to the public. Thus recapitulating the process is highly intransparent and doubtful.

Instruments in police law curtail actors in their technical options to lower emissions. The outcome of this is inefficiency. Police law is rather well employed in acute averting a danger, what is completely wrong in the slow growing problem of climatic change, where CO_2 lingers and accumulates in the atmosphere over a long period. Furthermore it evenly distributes thus there is no local or regional hot spot.

Economic instruments such as taxes and certificates do not restrict the choice between different prevention options but consistently price the utilisation of the nature. On this price every emission source can orientate itself. They can choose to pay taxes (to buy certificates) or to invest in measures to avoid emissions. Normally it is also linked with a high flexibility in time: emitters can optimal accommodate the point in time of their investments to their specific conditions (e.g. in enterprise or household). Indeed with a fiscal solution the ecological effect is difficult to calculate and therefore a precision landing on the default aim is hardly possible (as information about prevention costs in an economy are unknown or/and a changing business environment – as e.g. the rate of economic growth and of technical progress – couldn't be foreseen). A further adjustment of taxes seems to be essential. By contrast a solution with certificates assesses the amount of greenhouse gas emissions and leaves the certificate price undefined.

An advantage of all economic instruments is their affability to innovations. Every emission reduction, which can be implemented with lower costs than the obtained certificate price (respectively tax rate), is a possibility for the emitters to higher their gains. For that reason a dynamic incentive to search for new competitive possibilities to reduce emissions arises.

However, transportation is characterised by an extreme high number of mobile emission sources. Measurements and controls – as assumption for aim conformance of all these emission points – would guide to massive costs for administration and therefore let the system of an emission trade slide to the end. These high costs (transaction costs) are often used to argument against an implementation of trade with certificates in the transport sector (see e.g. Brockmann et al., 1999, pp 100). This argumentation assumes however implicit that a regime with certificates always asses on the emission source. This is however not necessary as CO_2 emissions are strongly dependent on fuel demand, which remains to be controlled.

Implemented policy instruments for reducing CO_2 emissions in Germany

Since 1985 the tax on cars depends on their pollutant category. A further instrument is implemented in April 1999: The Eco-Tax ("Ökosteuer") was introduced, which increases fuel by 3.07 €-Cent per liter (0.15 US$ per Gallon) and it was increased by further 3.07 €-Cent each January until 2003 (up to 15.35 €-Cent per litre (0.76 US$ per Gallon) fuel).

In 2005 a toll for heavy vehicles (>12 t) on federal highways between 0.09 and 0.14 Euro per kilometer (dependent on axis-thrust-loads and pollutant category) was implemented. In the next years the average value from 0.124 Euro will be raised to 0.15 Euro per kilometer which should be accompanied by a simultaneous decreasing of taxes of carriers. Additionally all fuels in 2007 have to be without sulphur according to the recently passed Energy Tax Law ("Energiesteuergesetz"). This includes an organic fuel quota law, which specifies a quota of organic fuel in diesel (which has a stake in fuels for transportation of about 28 %) of 4.4 % and in liquid fuel for spark-ignition engines of 2 %. These quotas will rise in the following years. Additionally organic fuel will be taxed. Only organic fuels of the second generation ("Biomass-to-Liquid Fuel") will be out of taxes. Since November 2004 the estimated CO_2 emissions per kilometer has to be displayed for all sold cars. Thus for fuel consumption and hence CO_2 emissions exists not yet any strong limitation in contrast to many other pollutants (NO_X, particles, CO, HC).
Additionally some informatory instruments were used to change the modal split. Zinn et al. (2003) and Hunecke et al. (2005) showed that this shift is not possible with monetary instruments only, as households do not react accordingly to higher fuel prices (low elasticity of demand). Only with strong price raises and only with respect to the long run shows empirical effects. Due to this fact instruments should be differentiated on the diverse road user types (Schubert, 2004). Thus when a (open) certificate market is implemented, side subsidies from the transport sector to other sectors are realistic outcomes, as willingness to pay is very high in the transport sector (price elasticity of demand is very low).

As depicted above, certificate trading scheme in the transport sector convinces by virtue of aim conformance, system conformance, and cost efficiency. Especially with regard to the "fair" reaching of the forced aim argues for its implementation. But as reactions (e. g. exorbitant fuel prices) and unexpected avoiding behavior of participants (e. g. shortages of organic oil in supermarkets) could be so extremely differential a simulation of the market remains necessary before introducing the instrument. For this multi-agent based models are highly convenient, as they could be calibrated very differentiated and individual. Furthermore they can cope with (in passenger transport often recognized) subjective biased cognitions and non-rational decisions. But before starting to establish a model, the design of the trading scheme should be clarified.

3 An exemplary certificate market for the transport sector (scenario 1)

In the Protocol of Kyoto a national limit for emissions was accepted by more than 150 states. The way how this aim is achieved by the participating states is optional. The European Union decided for introducing the ETS for selected sectors. So far the transport sector is neglected and if it should be included, its design remains at first vague. The following decisions are strongly connected to this issue and should be discussed: liable agents (up- vs. downstream), tradability of certificates (open vs. closed market structure), character of aim (absolute vs. specific budget) and allocation mode (grandfathering vs. auctioning). In the following paragraph these decisions are (exemplarily) made to create a first scenario to examine potential impacts.

Stronzig et al. (2002) depicted (at least) 36 possibilities to design an emission trading scheme in the transport sector. From this variety it is easy to exclude some approaches from the further consideration by considering different reasons.

Interestingly although the transport sector seems to become a net payer of the certificate system, objective to this must not occur, as estimated abatement costs in transport differ strongly. The partial equilibrium model PRIMES –105 Euro per ton for transport (CE Delft, 2006). Furthermore other authors also argue for negative abatement costs – particularly when considering the welfare effects of the economy (Greene and Schafer,2003, NRC, 2002, Department of Transport, 2003, and T&E, 2005). They argue that the overall costs for abating CO_2 emissions are (much) lower than its profits. According to this abatement is favorable and cheap in the transport sector especially when considering the low additionally capital costs of 15 % compared with the additional fuel price savings (-35 %). However, comfort, image and safety issues are certainly neglected in this calculation – what explains the negative value of abatements costs. An example (without safety risks) is the new Volkswagen POLO BlueMotion with a surcharge of about 500 Euro for saving of about 0.7 liters per 100 km – after about 60’000 km (with German diesel prices of about 1.19 Euro per liter) the additional investment should be balanced without considerations of rising fuel prices. Contrariwise to these studies assuming a more or less consumer shift to smaller cars, positive abatement costs between 15 up to 540 Euro per ton are calculated by EC (2004) and ACEA (2006). These calculations differ according their valuation of behavioral changes of the consumer.

Thus for households prestige and other reasons play a leading part in the decision of purchasing new cars, as empirical price elasticities tend to be substantially smaller than the income elasticities of demand – a carbon tax would have very limited effects. Goodwin et al. (2004) conclude that the price-elasticity of total transport demand can be -0.6 in the long run and the income-elasticity of demand is a factor 1.5 to 3 higher. One reason for relative low price elasticity is that buyers of new cars generally only consider the first three years of fuel savings, and not the fuel savings over the entire lifecycle (NRC, 2002; Annema et al., 2001).

As fuel consumption is direct correlated with the CO_2 emissions (Heister und Michaelis, 1991, p. 59) it is equally effective to introduce a down- (liability by e.g. car drivers) mid- (liability by e.g. car producer) or up-stream (liability by e.g. fuel companies) approach. Solely the transaction costs are much lower by using an up-stream approach. For that reason in scenario 1 an up-stream approach is chosen where the oil companies are liable for holding certificates for every sold liter of fuel. Furthermore there are many other possibilities of liable agents when considering dimensions of market participants, energy consumption of modes, and mobility purposes.

Concerning the tradability of certificates it is assumed that the willingness to pay for fuels in transport is very high, thus this is also true for CO_2-emissions. It is obvious that, on the one hand, without a big change in the demand structure of motorized road users, certificate prices in a closed trading scheme would be enormous. On the other hand, in an open trading scheme the transport sector would not change its emissions but rather use the high willingness to pay to buy certificates in other sectors ('cross-financing of mitigation'); which is conform with economic efficiency. When opening the certificate market it is useful to use the already implemented ETS. For this, all other above mentioned decisions are made according an applicable integration to the ETS rules to avoid a bias between different companies. Thus the certificate trading scheme in scenario 1 include an absolute aim (concerning the sold amount of fuels) and (mainly) a free allocation of certificates (grandfathering). For shippers this could be done revenue neutral in lowering other (excise) taxes.

4 Multi-agent modeling of German transportation

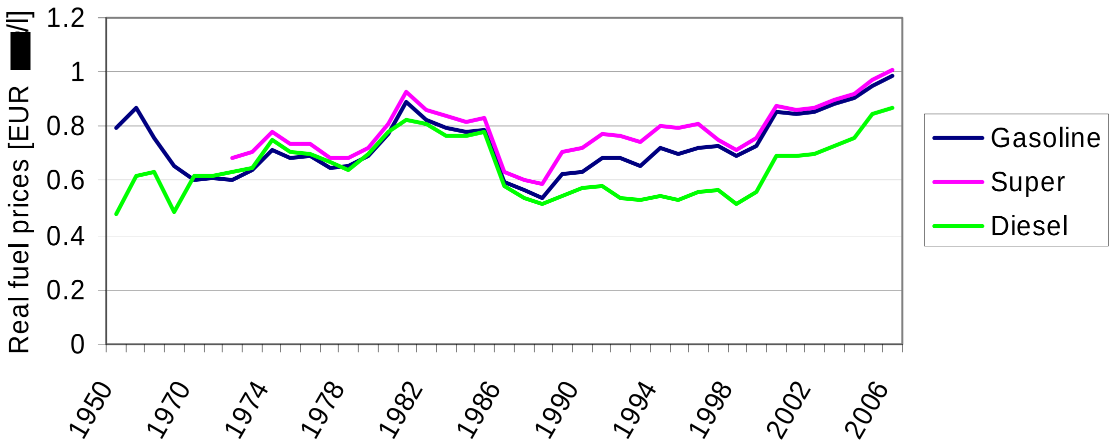
This chapter presents a multi agent-based approach to the simulation of the road transportation sector. The concept of multi agent-based simulation seeks to overcome some of the weaknesses of conventional modeling approaches by building a simulation from a player's perspective which helps to integrate aspects like individual player strategies, imperfect information or subjective decisions (Wooldridge, 2002). The approach of agent-based simulation draws on the concepts of several disciplines such as economy/game theory, social and natural sciences and software engineering (Wooldridge, 2002). The variety of approaches to agent-based simulation has led to a variety of definitions concerning the term "agent". One definition which is often quoted in the field of multi-agent systems or distributed artificial intelligence is given by Wooldridge and Jennings (1995) stating that agents are characterized by *autonomy* (ability to operate on its own), *social ability* (ability to interact with other agents), *reactivity* (ability to respond to a perceived environment) and *pro-activeness* (ability to act on its own initiative in order to reach envisaged goals). However, a review of multi agent-based simulation platforms shows that the agents used in these simulations in many cases apply weaker definitions of the term "agent" (Drogoul et al., 2002).

Models of transportation could be net based or behavior oriented. The first alternative, which concerns especially with route choice, congestions and bottle necks in local networks, is mostly applied in transportation research (among others Balmer et al., forthcoming). The latter alternative (behavioral orientated) is preferred in this model as mode choice is mainly affected by social status and attitudes.

4.1 Conceptual framework of a multi-agent model

With the following model possible impacts to households and carriers due to an implementation of CO_2 certificate trading schemes should be analyzed. Generating reaction functions of the agents is challenging as all individuals react different to the policy instruments and factors of influences are so manifold. Additionally in Germany no significant (real) price raise in the last decades happened, where one can calibrate the model (see figure 3). There are often many other impacts to households whereby individuals change their mileage. In the following model the assumption is made, that a household has some main influences in its modal choice behavior due to its type (single household, family etc.), its region and its attitude (especially its network). These features lead to reduction functions of households which are rather similar within a cluster and only differ in an additional (equal distributed) error term, which constitute other factors of households.

Figure 3: German fuel prices from 1950 to 2006 in real terms.



Source: Destatis, 2007

4.2 Main necessary agents and their features

As already mentioned for an impact assessment of policy instruments in the transport sector a behavior based model will be adequate. For an overview it could be advisable to separate the issues in different markets. For abating CO_2 emissions in the road transport sector four markets are relevant: In the passenger transport (i) as well as in freight transport (ii) participants can reduce their CO_2 emissions in changing their individual modal split or in reducing their mileage. In the long run, they also may buy more efficient cars (iii). Furthermore a CO_2 certificate market (iv) for trading free certificates should be included (see figure 4 below). Considering the agents there are first of all households (demanding fuel and new passenger cars), shipper, haulier and carrier (demanding fuel and new freight cars), car maker (providing new cars) and fuel companies (selling fuel and trading certificates).

But for the reaction patterns of the households the main influences on decisions regarding their traffic behaviour are questionable. In Germany some studies detected attitudes as main influences (Hunecke et al., 2002, Götz et al., 2003, Zinn et al., 2003, Hunecke et al., 2005). These studies also segmented participants according their attitudes and expectations. Certainly there are many regressors responsible for those decisions. For Germany there is representative panel data for most "objective" parameters as income, distance to work, distance to the next bus, tram and train stop, many car features, characteristics of the household, etc. – but neglecting their personal attitudes. These could only be estimated in looking to their trip diaries, where every trip is quoted with length in time and space, purpose etc.. Furthermore companies demonstrate additional environmental attitudes when they have an environmental report (according ISO 14,000), some patents in ecological issues or a sustainability report (Seijas Nogareda and Ziegler, 2006). Notwithstanding the current model consider these aspects solely by an equal distributed error term.

5 Preliminary results by a prototype model

For a first estimation a prototype java based model is designed and accomplished, which includes only different households as traffic participants and a preliminary open CO_2 certificate market with an absolute reduction aim (see scenario 1). The households, shipper, haulier and carrier are already based on empirical data, but the CO_2 reduction path (amount of certificates) and the duration (10 years) are at first hypothetical. In this prototype model only basic structures are considered (see figure 4). Individual impacts to households and transport-companies through an implementation of a CO_2 certificate market are in the focus of this model. So far households (and carriers) can either abate CO_2 emissions in reducing their mileage of passenger car (truck) or in buying more efficient cars. In demanding more fuel households and carriers force fuel companies to buy certificates on the CO_2 exchange market. The resulting CO_2 price is marked up to the fuel price of the next day.

Global parameters are days (1-264 per year), years (1-10), households (1-50,000), fuel types (super 95, super plus 98, gasoline 91 and diesel), fuel companies (1-3), and vehicles in households (1-6).

The root of the model consists of a loop which represents an average exchange market day and which is repeated 264 times a year. In those days some traffic participants arrive at the petrol pump and take a look to the actual prices. According to this they might adjust their mileage. Once a year they decide whether to buy a new (or used) car or remain driving the old one (see Annex). In the evening fuel companies consider to buy certificates or not. In doing so they are free of the amount – except the last day in the year where they have to balance their account of certificates (trading period is a year). When fuel companies sell their certificates the CO_2 certificate price of the other markets (industry and energy) decline (excess on certificates); if they buy certificates ($zDemand_t > 0$) this will higher the price for the others (shortage of certificates) (by $co2PriceTransp_t$); and if no transaction is conducted the CO_2 price from the EEX (European Energy Exchange) remains constant. This correlation is simplified by

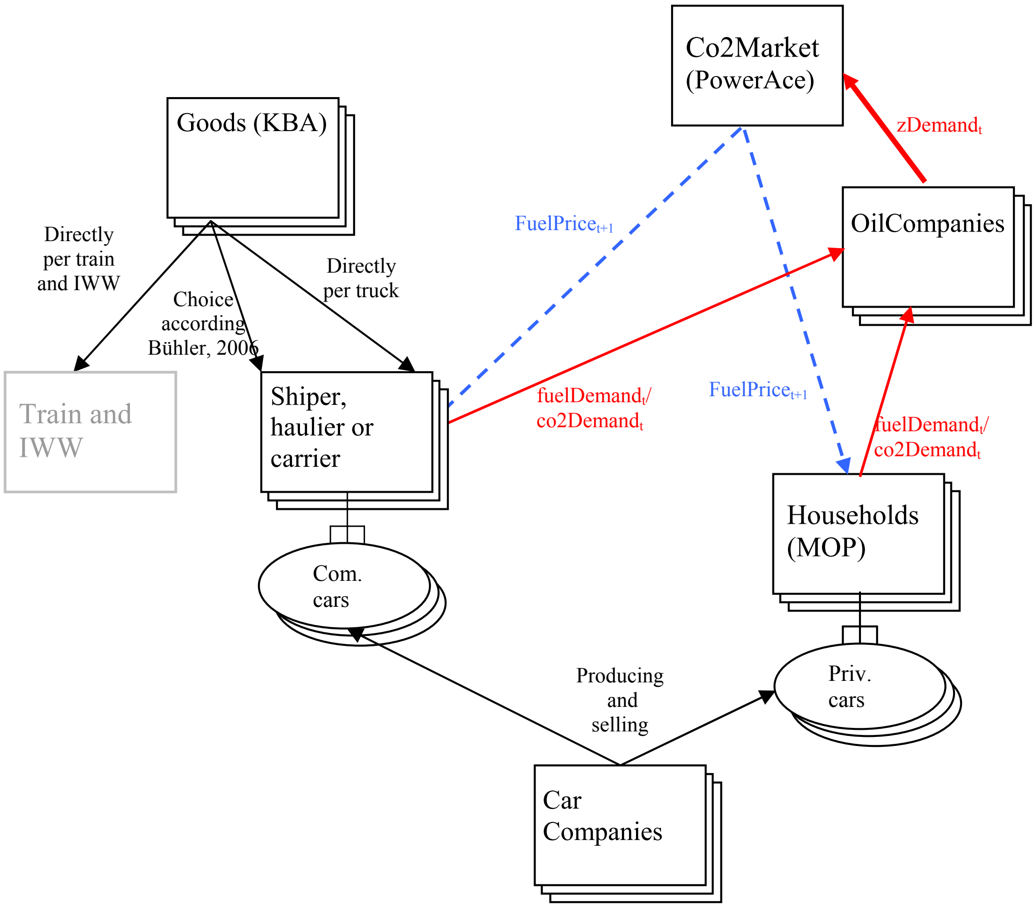
$$co2PriceTransp_t = zDemand_t \cdot 0.001 \qquad (1)$$

As already mentioned, this surplus of the CO_2 price is added to the fuel price for the next day.

Households are defined by the following attributes: *household types* (small household with employee (1-2 persons), small household without employee (1-2 persons, a. o. retired persons), household with children and household without children and more than one adult), *region types* (more than 100,000 inhabitants and housing in the city centre, more than 100,000 inhabitants and housing in the suburbs, 20,000 – 100,000 inhabitants, 5,000 – 20,000 inhabitants and below 2,000 inhabitants); they differ with respect to their *share of leisure trips* (based on mileage), and according their specific reaction function, which is based on the former attributes (see Annex). The vehicles are defined by their specific fuel type (super, gasoline or diesel), their specific fuel consumption, year of construction, mileage (in the base year) and their cylinder capacity. The CO_2 market shows specific constant base fuel prices, CO_2 prices (from EEX), specific CO_2 prices (resulting through the additional trading of the transport market) and a dropping rate depicting the reduction of CO_2 certificates per year. Furthermore fuel companies have a determined constant sale share (1: 0.4; 2: 0.4 and 3: 0.2) and a self determined daily certificate demand.

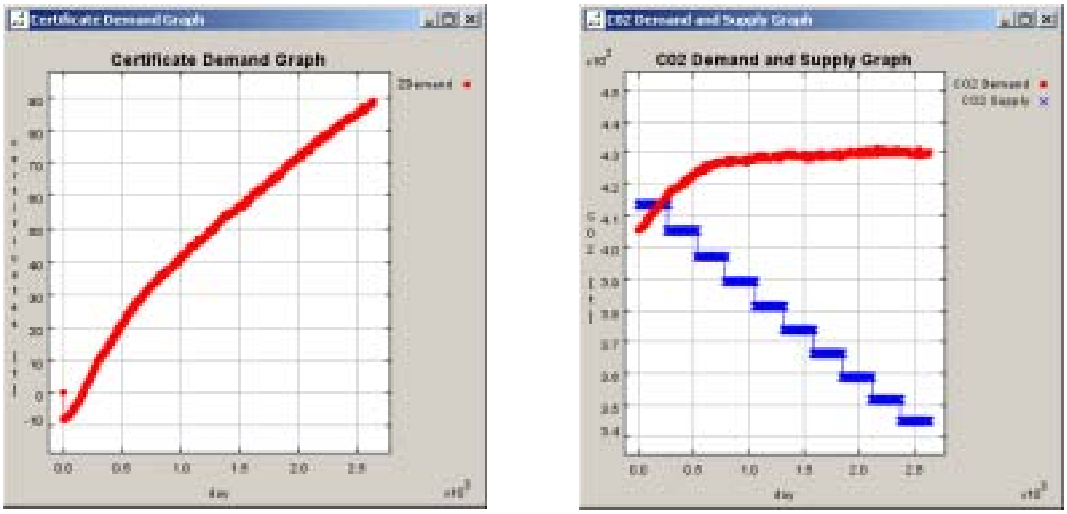
Inputs into the model are transport panel data from a mobility panel survey (German Mobility Panel (GMP), Zumkeller et al., 2004), which include some characteristics of more than 20,000 traffic participants since 1994. These data are used for creating realistic household agents and for calculating reaction functions of households (price elasticities) by a linear regression dependent on the different household and region types. The coefficients of the regression are used to design the reaction functions, which are equipped with a further equal distributed error term afterwards to underline there individuality. Further data input into the model comes from the EEX-CO_2-Exchange market (prices), the German Federal Motor Transport Authority (goods), Bühler (2006) (elasticities for freight transport). For the first period in the model the CO_2 emissions of road transport are calculated (their CO_2 demand) in multiplying their yearly mileage by the corresponding specific emission value for fuel. In this prototype model the CO_2 certificate supply in the first period is 2 % higher than the calculated CO_2 demand of the households. This supply decreases every period by 2 %. Thus in the first period no change due to emission trading happen.

Figure 4: Class diagram of the prototype model.



Road freight transport is implemented by a twofold decision path (see figure 4). For some transports no real modal choice opportunity is seen. This is true for distances below 100 km, expensive, perishable very havy goods or for big amounts of goods. Only the two latter are carried by train or ship all other goods in this list most likely by truck. The third class of goods could be carried by the one or the other mode. For these cases a (costdependent) allocation can be applied by a modal chioce logit model by Bühler (2006). For the investment strategies of the shiper, haulier and carrier fleet the formula by Blauwens et al. (2002, p. 166) is applied.

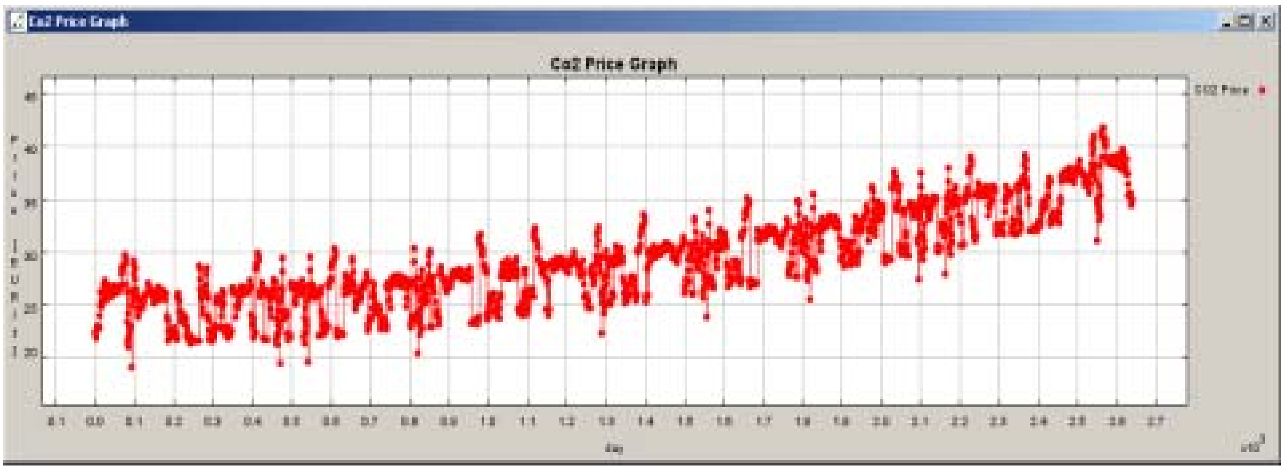
Figure 5: Simulation results: reactions of households facing limited CO_2 certificates in periods 1 to 10.



For the implementation a JAVA based model was established and upgraded by the JAVA library REPAST (2007). The preliminary output can be described by the CO_2 demand resulting from the fuel demand of the households, the CO_2 supply (thus the number of certificates allocated to the transport sector), the exchanged CO_2 certificates and the corresponding CO_2 certificate price (see figure 5 and 6). In the following example the certificate price increases in ten years to about 100 Euro per t CO_2 (figure 6). This is due to the amount of certificates bought by the fuel companies.

Surcharging the whole amount of 100 Euro per t CO_2 to the fuel price means a surplus of about 0.25 Euro per liter fuel. This means ceteris paribus an average surcharge for the next 10 years of about 1.7 % p.a. for German fuel prices which shouldn't change the mileage of households as long as their attitude persists as in this business as usual scenario.

Figure 6: Simulation results: CO_2 certificate prices in periods 1 to 10.



Recapitulating one can say that the impact of the decisions of household is small in the business as usual case. One can argue that the certificate system is only for getting the transport sector to pay for their emissions and not to really abate. Further political instruments should be developed which could be assessed in further multi agent-based models.

6 Conclusions

Due to the dangers from global warming and the commitments from the Protocol of Kyoto, policy instruments to reduce CO_2 emissions in the German transport sector are nowadays unavoidable. This is especially true as the transport sector is the only sector which rose its CO_2 emissions in the last decade and contributes almost a fifth of the German emissions. New instruments should be considered as existing instruments have fallen far short of reaching a crucial trend in reversal of emissions caused by transportation so far. This is especially true for road transportation. One "new" instrument is an emission trading scheme including the transport sector. As a result of the direct connection between emissions and fuel consumption, the emission trade has not to approach essential to the emission source – here vehicles – but rather to any optional point in the energy flow chain of fuel (e.g. oil company, petrol station, etc.). This lighten its implementation considerably.

The emission trading scheme convince in three (system and aim conformance and efficiency) of four criteria (institutional controllability). A first suggestion of a certificate trading scheme is depicted (scenario 1). This is an open up stream model charging the fuel companies in an open system (trade with the existing ETS is allowed), with free allocation of certificates and an absolute reduction aim. It is shown that a behaviour based multi agent model is convenient to handle this impact assessment. It should include the following agents: households, shipper, hauliers, carriers, car makers and fuel companies.

Furthermore a prototype model (working partly with empirical data) was developed and applied. The results confirmed firstly the expected CO_2 prices for a trading scheme in the level of 0.05 Euro per liter today and might arise up to 0.25 Euro per liter when CO_2 certificate prices quintuple. The model shows that if attitudes of traffic participants persists the mileage and fuel consumption remain constant and the transport sector will act as a net payer in the emission trading – reduction of other sectors will be paid on the petrol pump. Recapitulating, the impact in the business as usual scenario is rather small and further political instruments should be implemented and scrutinized in multi agent simulation models. If however transportation demand changes, a double dividend could be expected: Despite people still coming from A to B cars are less expensive and much more efficient (neglecting social prestige, comfort etc.).

Further research insists especially in developing the prototype model. Furthermore as many features of traffic participants could not be quantitative determined additional questionnaires would be desirably.

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Annex

Reaction of households in the model

Every day households can change their mileage, *Diffkm*, according the changed fuel prices, *diffPrice*, confronted (which include the CO_2 prices). This is done according the following reaction function which is the outcome of an OLS-Regression with the GMP data of all repeaters in the panel:

$$\text{Diffkm}_i = e^{\text{hhConst}_i * (\text{diff Price} - 1) + \text{rtConst}_i * (\text{diff Price} - 1) + \text{normConst} + \varepsilon} \quad (1)$$

With *hhConst* (type of household), *rtConst* (type of city/country) and *normConst* ("normal" behaviour in the accounting period or exceptions as holiday, illness or car in garage) according table 1. ε is a equally distributed error term between –0.2 and 0.2.

Table 1: Factors of the reaction function of households

HH-Typ/ Raumtyp/Norm	***hhConst***	***rtConst***	***normConst***
0	–	–	0
1	-0.518491	0.1931093	-0.000157221
2	-0.920595	1.478599	–
3	-0.4106846	0.5619931	–
4	-1.57978	-0.3157597	–
5	–	0	–

Besides this daily mileage change once a year the household wondering whether to buy a car. In doing so he decides for purchasing a car according the following Logit model.

$$\begin{aligned} \text{newCar}_{n,i,k} &= -3.347186 + 0.4098371 \cdot \ln(22 \cdot \text{mileage}_{n,i,k}) + 0.0000796 \cdot \text{cc}_{n,i} + \\ &0.3464239 \cdot (n + 103 - \text{yoc}_{n,i,k})^{1/2} - 0.0886111 \cdot \text{business}_{n,i,k} + \varepsilon \end{aligned} \quad (2)$$

If *newCar* > 0, than a car is purchased this year, if not the household keep its car. *cc* is the cylinder capacity and *yoc*, the year of consumptions. The Boolean variable *business* shows whether the considered car is mainly used for business trips (1) or not (0). ε is again an equally distributed error term between –0.2 till 0.2. If the household decided to buy a (second hand or a new) car, the year of construction of the new bought car is determined according to:

$$\begin{aligned} \text{yoc}_{i,k,n,t} &= -2.257545 + 0.4312058 \cdot (\text{yoc}_{n,i,k,t-1} - n - 103) + 0.0003543 \cdot \\ &(22 \cdot \text{mileage}_{n,i,k}) + 0.0004222\ \text{cc}_{n,i} + 103 + n \end{aligned} \quad (3)$$

Where the regressand $yoc_{n,i,k,t}$ is the year of construction of the new vehicle (for the next periods) and the regressor $yoc_{n,i,k,t-1}$ is the year of construction of the "old" car in this period. The specific fuel consumption of the new car is dependent on the share of leisure trips (*leisureShare*), the cylinder capacity, the fuel consumption, and the business boolean:

$$fuelConsumption_{n,i,k,t} = 4.611647 - 0.0702151 \cdot leisureShare_{n,i} - 0.0000506 \cdot cc_{n,i,k} + 0.4626268 \cdot fuelConsumption_{n,i,k} - 0.0863185 \cdot business_{n,i,k} \quad (4)$$

The corresponding cylinder capacity is calculated according to …

$$cc_{n,i,k,t} = 667.3129 + 127.057 \cdot fuelConsumption_{n,i,k,t} \quad (5)$$

All those equations are results from statistical regressions with the GMP data.