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MOZERT - MODELLING PERSONAL CARBON ALLOCATION SCHEMES AND ANALYSING THEIR IMPACTS ON HOUSEHOLDS AND ENERGY SYSTEM

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Introduction

Ambitious targets in climate policy (especially in a long term Post-Kyoto perspective) are faced with disillusioning interim results, concerning actual achievement of these targets. It is therefore worth questioning whether the instruments applied in climate policy are sufficient. It appears to be necessary to become engaged in the development, discussion and analysis of novel approaches. One basic shortcoming of state-of-the-art climate policy is that clearly quantified targets for the reduction of greenhouse gas emissions shall be achieved with “unpredictable” instruments (as investment incentives, standards, CO2 taxes or information campaigns), in the sense that the actual emissions reductions effect of these instruments is difficult to predict. From this point of view, certificate based instruments allowing a direct regulation (a cap) of the amount of emissions are attractive.

The core objective of this paper is to carry out a qualitative analysis of different personal carbon allocation schemes (PCA schemes) and to present the methodology for simulating the impact of such schemes, the conceptual basis for a „climate-policy simulator”. This simulator for investigating the effects of different personal carbon allocation schemes on the socio-economic situation of households and the energy system is currently being developed by a consortium financed by the Austrian “Klima & Energiefonds”. Examples for the carbon allocation schemes considered include Cap & Share and TEQs, which can be applied complementary or alternatively to “classic” emission-trading, as currently implemented within the EU-ETS. Methodically we use a multi-paradigmatic modelling approach by combining top-down (System Dynamics Modelling) and bottom-up modelling approaches (TIMES energy system model, Agent-based Modelling).

Current studies in Ireland (Johnson et al. 2008) and England (Roberts and Thumim 2006) show, that personal carbon allocation schemes are a topic of societal relevance which is also of interest for political decision makers. The German Aachen Foundation Kathy Beys is promoting the CO2-card as an important policy instrument (www.co2card.de). The Australian initiative “carbon equity” (www.carbonequity.info) writes on its home page “The idea of carbon rationing is a better response than carbon taxes, and here's how it will work.” The international resonance shows that the topic is of relevance with possibly increasing importance. The project MOZERT aims to give a considerable impulse in this respect.

In order to ensure a climate policy regime can effectively lead to a cap and stepwise reduction of greenhouse gas emissions, the question comes up to what extent the reduction target can be reached by increased application of energy efficient technologies, transition to renewable (resp. at least less fossil carbon-intensive) energy resources or behavioural changes (energy-saving behaviour, curtailments in consumption of energy services). The relative importance of each of these options determines if the transition is going more or less smoothly. The behaviour of different actors (in the sense of investment and consumption behaviour) influences the relative contribution of each of these options to reach the goal of a less fossil carbon intensive society.

MOZERT integrates multiple modelling paradigms, because the analysis of research questions and problems in relation to society-human-environment interaction benefits from the use of different methods and modelling paradigms. Due to this multi-paradigmatic approach the advantages of the different methods can be gained and the disadvantages, at least to some extent, can be reduced. (Scholl, 2001; Villa and Constanza, 2000; Vangheluwe et al. 1996). While quantitative analyses concerning the aggregated system behaviour can be conducted relatively easily by top-down approaches, it is nevertheless possible on the other hand to go for more detailed bottom-up considerations in parts of the system, which show emergent self organisation phenomena within these subsystems. The striking advantage of applying this combination of approaches is that emergent phenomena (on a macro-level) driven by actions and interactions of social actors (on a micro-level) will be investigated by multi agent-based modelling and simulation.

The computer simulations conducted within the scope of the MOZERT project shall demonstrate how, within different scenarios defined by a particular choice of a certificate-based instruments and other scenario parameters

- the mix of energy sources by applications/energy services,
- the diffusion of energy efficient and renewable energy technologies, and
- the socio-economic situation of households

is prone to develop in the course of time.

The main results presented in this paper are the detailed concept for the climate-policy simulator consisting of a socio-economic model describing actors and relations as well as an overall model architecture and it’s detailed sub-models. The paper will furthermore present the results from qualitative studies comparing the different personal carbon allocation (PCA) schemes.

Qualitative assessment of PCA schemes and standards

Within the last ten to fifteen years, different suggestions have been made which also integrate individuals as participants into emissions-certificate trading systems. An overview of such suggestions is given for example in Johnson et al. (2008) or Roberts and Thumim (2006). These approaches have in common, that all citizens (in most cases adults) are endowed with an equal emission right. This results in an equal allocation of emission certificates per person. However, there are considerable differences between these schemes in detail. In the following, these certificate-based approaches which include individuals in their allocation scheme are summarized under the general term personal carbon allocation schemes (PCA-schemes) and assessed qualitatively.

One of these approaches, Cap and Share, is working/operating as follows (FEASTA 2008, see fig.1): Similar to other systems of emission trading initially a limitation for the totally allowed amount of emissions (a so called “Cap”) is determined, which is gradually reduced over a given set of years. The emissions covered by this “Cap” can cover the total CO_2 emissions of a geographical area (state/nation, or a larger area/ greater geographic region, up to theoretically the whole earth) or a certain portion of the total emissions (e.g. the portion which is not covered by the EU emission trading system). The emission certificates are passed on to all adult citizens of this geographical region in equal shares. (The passing to all adults in equal shares also is called “sharing out emissions rights”, therefore the term “Cap and Share”.) The certificates for one year do not necessarily have to be handed out annually, they could as well be handed out in a higher frequency, e.g. quarterly. Within any given year, the citizens have the possibility to sell the obtained certificates within one year to intermediaries (e.g. banks) according to an - over time fluctuating - market value. These intermediaries hence sell the obtained certificates to enterprises, which import fossil energy carriers or directly extract them domestically. Only these enterprises need emission certificates in further course. The amounts of CO_2 which are contained in the fossil energy carriers sold by these enterprises and which are released during combustion have to be covered by emission certificates. Thus, at the end of a control interval (usually one year) each enterprise has to prove that the purchased certificate amount is sufficient to cover the emissions of the fossil energy carriers sold. At the end of the control interval finally the certificates are cleared. The certificate costs are added to the prices for fossil energy carriers and hence take effect on all consumers (households, enterprises, public sector). However, only households are compensated for the increasing prices of fossil energy carriers by the earnings from certificate sales.

Hence the scarcity rent of the enterprises, which introduce fossil energy carriers into the market, is confronted with a scarcity rent on the end consumer side due to the introduction of the certificates. Thus end consumers are partly compensated for rising energy prices. The development of the certificate prices over time will be depending on supply and demand for the certificates, and thus depending on the strictness of the limit (the "Cap"), but also on the speed of adaptation of all energy consumers towards a less carbon-intensive society.

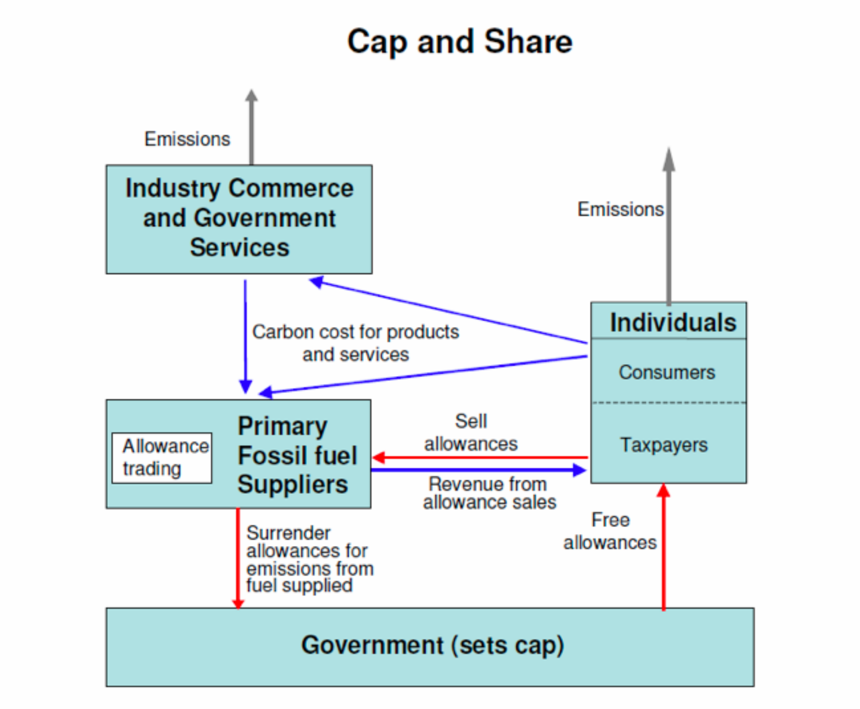

Figure 1: "Cap and Share" in principle; red: flow of certificates, blue: flow of money, grey: emissions, certificate trade only within the "primary fossil fuel suppliers", Source: AEA Energy & Environment (2008), p. 13

Several proposals of personal carbon allocation (PCA) schemes are currently being promoted by think tanks, environmental activists, researchers and politicians. A closely related proposal to Cap and Share is called "Cap and Dividend" which was developed and is promoted in the USA (www.capanddividend.org). „Cap and Dividend"(also referred to as the „Sky Trust") is similar to „Cap and Share", as in this scheme only those enterprises, which import fossil energy carriers or extract them directly inland, need certificates equivalent to the emissions caused by the fossil energy carriers sold by these enterprises. These enterprises have to purchase the certificates via auctions, the auctions' revenue is reimbursed to citizens in equal shares (in contrast to "Cap and Share" citizens hence do not receive emission certificates).

A system that is somewhat more complex in terms of feasibility and degree of involvement of individuals, is called "Tradable Energy Quotas", abbreviated TEQs (Fleming 2007). This system is more transparent from the individuals' or households' point of view, as households obtain explicit information about their CO2 emissions and hence a more direct feedback concerning their behaviour. Under a TEQs-regime CO2 accounts are set up for all energy consumers (individuals, organizations as enterprises, public and other institutions). (Adult) consumers are endowed with emission certificates for free and to equal shares, according to their direct emissions for mobility, heating and electricity (e.g. about 40% of all emissions), organizations of all institutional sectors other than households (enterprises, government, NPISH) have to purchase the remaining certificates via auctions. The earnings from these auctions could be disbursed in equal shares to individuals or be used for public investments to speed up the energy transition, whatever may be decided by the government.

Individuals get a CO2 account and obtain a CO2 card, i.e. a separate card or a credit card with CO2 credit/debit functionality. At the direct purchase of fuels the corresponding CO2 amount is charged from the CO2 account linked to the card (or the CO2 certificates have to be purchased at the point of sale directly, in case no card is present/existent). In the same vein, at the payment of electricity, gas or district heating bills, the corresponding CO2 amount is charged from the CO2 account. In the case of under-consumption, individuals can sell spare certificates, in the case of over-consumption they have to buy them. Hence a market for CO2 emission certificates is created, with individuals as well as enterprises and other organizations participating. TEQs also could be implemented as measure for a relatively flexible “electronic rationing/scaling down” (e.g. in the case of a shortage of energy carriers such as crude oil) (Fleming 2007, p. 25f.)

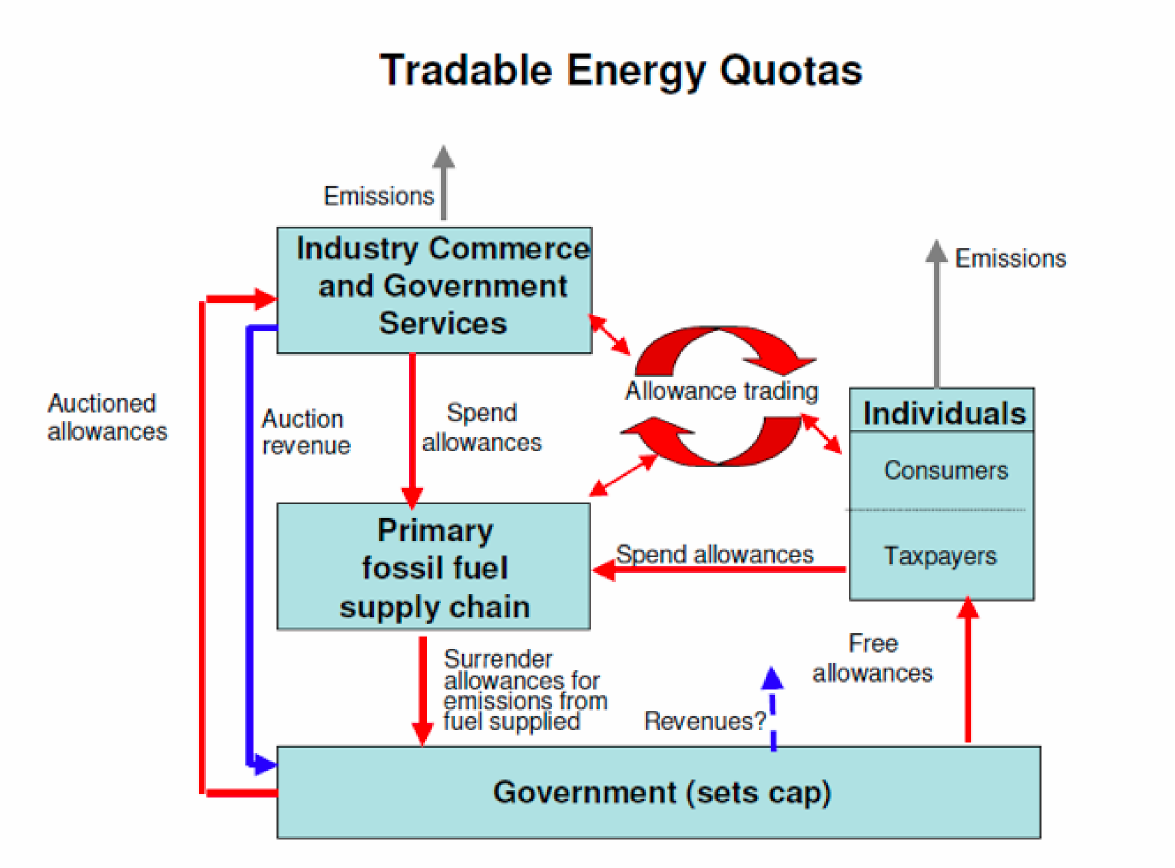

Figure 2: Scheme for „Tradable Energy Quotas“; red: certificate flows, blue: money flows, grey: emissions, Source: AEA Energy & Environment (2008), p. 16

Other personal carbon allocation schemes suggested in literature are PCR (Personal Carbon Rationing), RAPS (Rate all Products and Services) and the „Ayres Scheme“. Personal Carbon Rationing and the „Ayres Scheme“ are quite similar to TEQs, unlike TEQs Personal Carbon Rationing only covers the emissions which are directly caused by households (including private air travels). On the other hand, within RAPS (Rate all Products and Services) all products and services are tagged with a CO2-label where all CO2-emissions accumulated during production are the basis for calculation. In the foreseeable future, this comprehensive CO2-accounting is considered to be practically unfeasible, respectably only feasible with very high effort.

Diverse research work on PCA schemes has been conducted and is still ongoing, as documented e.g. in the workshop “Personal Carbon Trading (PCT): Bringing together the research community” organised by the UK Energy Research Centre (UKERC 2009). Activities regarding PCA schemes are mainly taking place in English-speaking countries (UK, Ireland, USA). In German-speaking countries the Kathy Beys Foundation in Aachen is promoting and explaining the ideas of personal carbon trading and gives an overview of different concepts of PCA schemes (www.co2card.de). Also the research done in the project “MOZERT” which is explained in this paper is trying to put the topic of PCA schemes on the scientific and climate policy agenda.

Based on a SWOT (strengths-weaknesses-opportunities-threats) analysis conducted by AEA Energy and Environment (Johnson et al. 2008) we did an extended qualitative assessment of PCA schemes and other climate policy instruments (carbon taxes, direct regulation, voluntary instruments) as part of the project MOZERT. Fig. 3

shows the results of this evaluation in relation to the following criteria (extending the work of AEA Energy and Environment):

- environmental effectiveness (to which extent can the fulfilment of carbon emissions reductions targets be assured?)
- equity / fairness
- implementation and maintenance costs
- complexity
- public engagement
- public acceptability
- compatibility with the EU-ETS

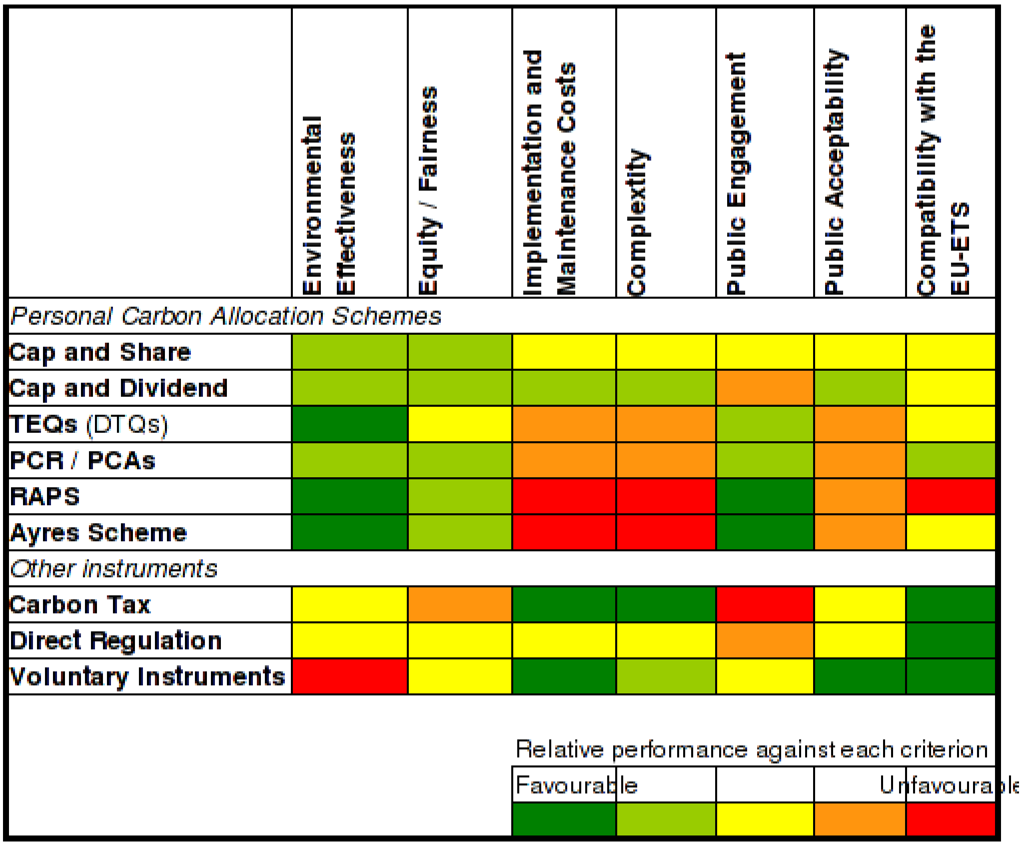

Fig. 3: Qualitative assessment of PCA schemes and other instruments, Source:Own compilation based on a SWOT analysis conducted by AEA Energy and Environment (Johnson et al. 2008)

Environmental effectiveness

Schemes that establish emission caps, like PCA schemes, can assure the fulfilment of carbon emissions reductions targets as long as control and sanction mechanisms are sufficient. This cannot be guaranteed with the other instruments (carbon taxes, direct regulation, voluntary instruments). Schemes that cap carbon emissions of all fossil fuels used in a given geographic area can be assessed as particularly effective.

As PCR (Personal Carbon Rationing, as proposed by Mayer Hillman and Tina Fawcett (Hillman 2004)) only covers individual emissions it is evaluated as less effective. Schemes which provide more information for individuals and eventually other participants set probably higher incentives to take up relevant measures (earlier) that reduce carbon emissions (dark green in figure 3, second column). Because of this a smoother transition and lower respectively less volatile carbon and subsequently energy prices may be expected.

That is why “Cap and Share” and “Cap and Dividend” are evaluated as less effective as they do not provide as much and specific information as schemes like TEQs or PCR. With high prices for certificates the danger exists that the cap is softened, which reduces the effectiveness of a given scheme (see figure 3). The question if caps have to be kept in any situation (“hard cap”) or if otherwise softening of the cap (“soft cap”) should be allowed is discussed controversially.

Equity / fairness

Due to the allocation of certificates in equal parts to each participating individual an inherent equity / fairness principle is implemented within PCA schemes. Persons and households with lower income normally also consume less fossil fuels and thus cause fewer carbon emissions than average. This would lead to a positive income effect for these individuals and households because they could sell more certificates and thus gain an additional income. On the other hand, if poor individuals or households have over-average emissions (because they live in badly insulated houses and need to travel much by car because they live in a remote area) there could be a negative income effect for these groups.

Carbon taxes do not have such a positive distributional effect in general (unless there is some additional compensation mechanism or the CO2 tax revenues is redistributed to individuals). Since in the TEQs-scheme not all certificates are allocated to individuals (they are partly allocated to firms and other organisations) this scheme is seen as less equitable compared to the other PCA schemes.

Costs and complexity

The assessment regarding the criteria costs and complexity yield similar results as more complex instruments are expected to cause higher costs (for implementing and running a scheme). PCA schemes which need bigger changes compared to the status quo (but provide more information) cause higher costs. These complex schemes are TEQs, PCR, and even more complex RAPS and the Ayres scheme (red colour in figure 3). Setting up carbon accounts and facilitating inter-personal certificate trading is required within these schemes.

Although costs for a TEQs- or PCR-scheme in the UK are estimated to be in the considerable range of 1 to 2 billion Pounds Sterling (DEFRA 2008b), this has to be seen in relation to the whole GDP and the potential benefits (1 to 2billion Pounds Sterling is 0,06 to 0,12 % of the GDP in the UK). Other instruments like carbon taxes or voluntary instruments are comparatively cheap. Regulations may be more costly due to control needs.

Public engagement and acceptance

PCA schemes like TEQs, PCR, RAPS or the Ayres Scheme involve the public to a high degree – individuals not only receive carbon certificates but also information on their carbon consumption, individual carbon accounts are set up and inter-personal certificate trading is possible. On the other hand, Cap and Dividend provides the lowest extent of involvement for individuals: they receive their dividend on the one hand, on the other hand they are confronted with higher energy prices because certificate costs are priced into final energy prices. Cap and Share is situated between these two poles regarding public involvement.

High public engagement need not to go hand in hand with high acceptance. Empirical investigations regarding the acceptance of different climate policy instruments (PCA-scheme similar to TEQs, carbon tax, EU-ETS) showed that the PCA-scheme has more the tendency to polarise the population (DEFRA 2008c, IPPR 2009). There are concerns regarding data privacy, and limits for individual activities are feared. Beyond that PCA schemes tend to be regarded as complex and the willingness to deal with a new system might be low. The acceptance for an instrument like Cap and Share or Cap and Dividend might be different due to their different characteristics. An information policy that addresses the above mentioned concerns is important when introducing a PCA-scheme.

Furthermore it shall be mentioned that each policy instrument that leads to bigger changes compared to the status quo is confronted with problems of acceptance: a carbon tax with a sufficiently high tax rate is not easily to implement, either.

Compatibility with the EU-ETS

PCA schemes in their pure form (meaning: in the form they were intended to function by their inventors) are not compatible with the EU-ETS, as it is implemented now, in a strict sense.

This is due to double counting of emissions within parallel systems which are not totally matched to each other. For instance, Cap and Share covers all emissions caused by using fossil fuels, a part of these emissions is also covered by the EU-ETS.

We assume that parallel certificate systems only make sense if they cover distinct emissions / sectors.

The combination of a PCA-scheme with the EU-ETS thus needs a modification of the systems in the form that:

a) EU-ETS dominates, PCA-scheme adapts to EU-ETS, in the sense that it only covers emissions not covered by the EU-ETS

b) PCA-scheme dominates, EU-ETS is adapted, in the sense that it only covers emissions not covered by the PCA-scheme

c) Both systems are modified. A new hybrid scheme is created having characteristics of both schemes.

Option a) is only not considered for RAPS (Rate all Products and Services). For the other PCA schemes it would be conceivable although the total system complexity is higher and the effectiveness of the PCA-scheme is reduced compared to the case it would be solely introduced.

Option b) means that only a strongly reduced EU-ETS would remain which is hard to imagine at least until 2020 under realistic policy assumptions.

With other instruments (carbon taxes, direct regulation, voluntary instruments) compatibility with the EU-ETS is easier to achieve, for instance with a carbon tax that covers only those emissions not covered by the EU-ETS.

Socio-economic model of actors and relations

The overall socio-economic framework of the project MOZERT consists of the following actors:

- An agency, that allocates CO2 certificates to the market.
- Private households. Consume and choose from a set of energy relevant actions
- The public sector. Collects taxes and pays subventions and transfers but is also a relevant consumer of goods and thus chooses from a set of energy relevant actions
- The commercial sector. Supplies either energy relevant actions or other goods
- The energy sector. Supplies primary and end-use energy
- Intermediate traders as e.g. banks (not modelled)

The figure below illustrates the interactions between all the actors within the MOZERT modelling approach using the example of introducing “Cap & Share”. Thus companies in the energy sector have to purchase the amount of certificates that equals the amount of energy they sell within the country.

The **agency** gives away the certificates for free to private households. **Private households** spend their money on transport, housing and (other) consumption. They:

- pay taxes to the **public sector** and receive transfers
- receive wages and buy goods from the **commercial sector**
- sell certificates to the companies in the **energy sector**

All actors can influence their energy consumption by choosing from a set of energy relevant actions (e.g. switching to a more efficient technology, changing behaviour,…). This way the actors can change their energy costs and their demand for certificates.

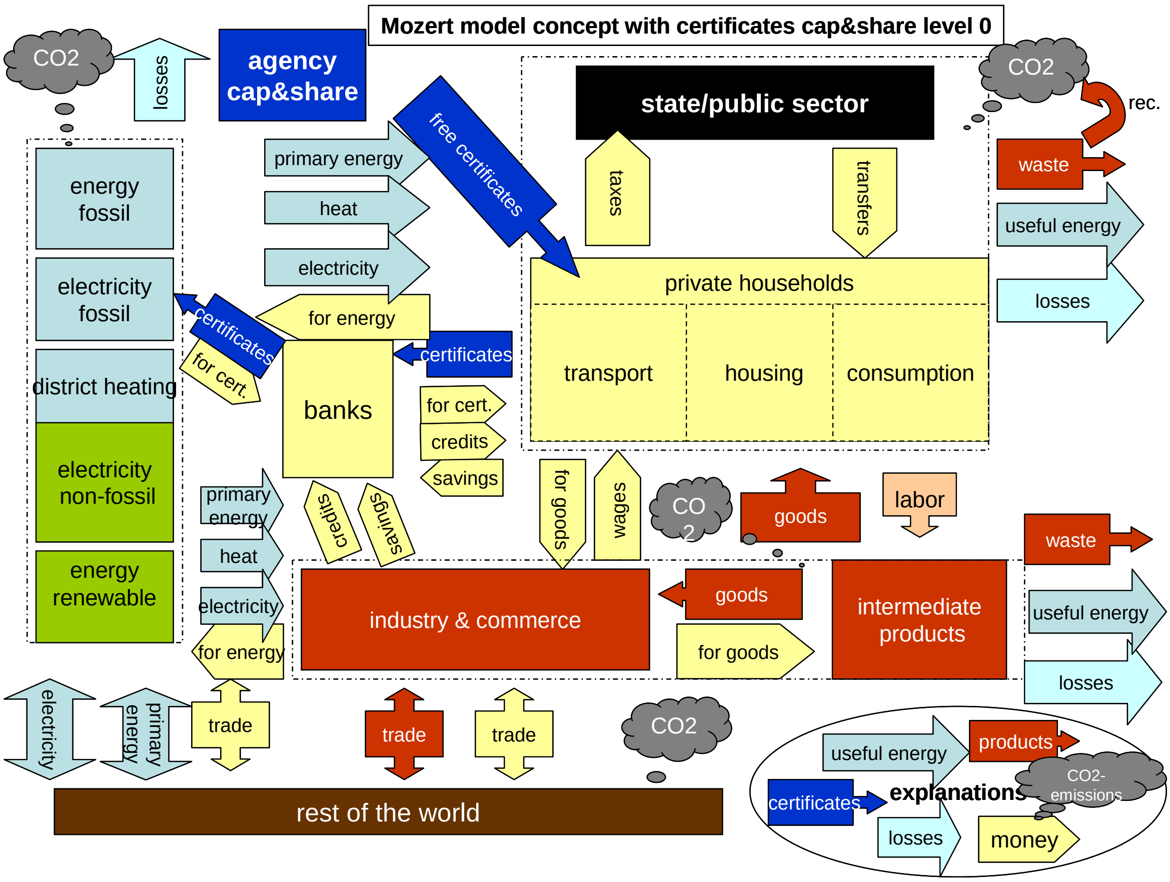

Figure 4: Interactions between the MOZERT actors in "Cap & Share"

Foreign trade

In an open economy there is exchange of all kinds of goods (including energy) with the rest of the world. In MOZERT the following scenarios with respect to foreign trade were defined:

- one region: the whole world as one region introduces the certificate system, there is no foreign trade. This is the starting point for modelling in MOZERT
- two regions 1: Europe introduces a certificate system, the rest of the world does not. There is foreign trade caused by different prices in the two regions
- two regions 2: Europe and the rest of the world introduce a certificate system. There is foreign trade.
- small country 1: Austria (small country) introduces a certificate system, the rest of the world does not. There is foreign trade.
- small country 2: Austria (small country) and the rest of the world introduce a certificate system. There is foreign trade.

GDP and growth

The gross domestic product (GDP) is the main economic parameter that influences other variables like income, employment, investment and savings. The main economic relations within the economy are described with input output tables.

Economic growth in the MOZERT model framework is driven by the following dynamic:

1. Technological progress in the commercial sector (exogenously given in MOZERT)
2. Prices for goods decrease due to lower production costs
3. Demand for good rises
4. Production capacities have to be increased
5. Demand for labour increases
6. Wages or employment increases
7. Incomes of households rise
8. Consumption rises

9. GDP rises (economic growth)
1. Technological progress in the commercial sector…

The certificate market

Two basic market mechanisms are considered:

- The auction of certificates: there is one actor on the supply side and many actors on the demand side. Supply is given.
- The trade of certificates: there are many actors on supply and demand side.

The market for certificates can be divided into two chronological markets:

- On the primary market certificates are allocated to the market (e.g. certificates are given for free to households or auctioned to companies).
- On the secondary market trade of certificates takes place between different actors depending on the certificate system that is implemented.

Multi-paradigmatic Modelling approach of MOZERT

Within the last 10 years a trend to so-called multi-paradigmatic modelling approaches can be clearly seen. The analysis of research questions as well as problems related to society-nature interaction can profit from a research approach that is not bound by paradigms and methodologies. Apart from other challenges, such an approach for problem-oriented research must be able to deal equally with structural (e.g. System Dynamics Models - SD) and behavioural models (e.g. Multi-Agent Systems - MAS) of society-nature interaction. A too tight engagement with one method often produces a blockade to use new approaches. Scholl (2001a) mentioned that the major differences between the modelling paradigms mark their relative strengths and weaknesses. MAS, for example, is weak in that the agent rules should be explored out from a complex aggregate behaviour. This means if only aggregated information respectively data is available it is very difficult or almost impossible to extract the underlying agent rules producing this behaviour (the patterns on the macro scale). One of SD's major weaknesses is that emergent phenomena from micro scale, which often occur within social systems, cannot be properly explored from an aggregated feedback system. SD therefore does not provide appropriate tools for studying self-organization processes from the micro-scale to the macro-scale. A combination of both methods helps to overcome the weaknesses of both methods. Scholl further argued that both modelling methods may well complement each other in ways that are unimagined from today‘s perspective (Scholl 2001a).

About ten years ago pioneering work on the combination of System Dynamics and Multi-Agent Systems simulation was conducted by Akkermans and Scholl (Akkermans, 2001), (Scholl, 2001a) and (Scholl, 2001b). Pourdehnad, Schieritz and Milling (Pourdehnad et al., 2002), (Schieritz, 2002) and (Schieritz and Milling, 2003) have worked on principal methodological issues when combining the two simulation paradigms. Schieritz and Größler presented a prototypical implementation of a combined SD and MAS simulation model; an application from the area of supply chain management (Schieritz and Größler, 2003). Lorenz and Jost (Lorenz and Jost, 2006) argued that applying different approaches should be more easy if adequate multi-paradigm modelling tools are available.

Since these early days of multi-paradigmatic modelling specialized software as e.g. Anylogic and MASGISmo has been developed integrating different paradigms, whereas each of them provides different features and varying levels of accuracy of applying the paradigm. In the following MASGISmo, a Java programmed multi-paradigm modelling platform, will be discussed in more detail, as this platform was mainly developed by a member of the project-team and is used within MOZERT. A discussion of other important multi-paradigm software platforms can be found in (Gebetsroither, 2009).

MASGISmo (Multi-paradigm Agent-based, System Dynamics and GIS modelling platform) was developed at the AIT (Austrian Institute of Technology) under the lead of Ernst Gebetsroither during several projects over a longer period of time. Starting point was a connection of the System Dynamics Software Vensim , which was established in the year 2003 with a GIS software called ArcView (ArcMap) from ESRI (Gebetsroither and Strebl, 2004). The connection programmed in Visual Basic for Application worked well, but it had some main disadvantages e.g. it was not possible to integrate MAS modelling. Within a project funded by the AIT called Adaptive Forest

Management, experiences working with RepastJ to establish a MAS model -- for a forest succession growth simulation - was gained and in the end led to integrate all GIS, SD and MAS into one platform (more details can be found in (Gebetsroither, 2009) or (Gebetsroither et al., 2005)). MASGISmo uses data from Geographical Information Systems (GIS) and integrates RepastJ as well as Vensim, a specialised SD modelling software. Additional certain GIS features are programmed in Java. To the professional software Vensim a simulation bridge has been established, therefore the SD models can be built with the use of Vensim. A graphical user interface (GUI) was developed to integrate all features from the different parts. The most important components are those related to the GIS features, to Vensim and to RepastJ.

The General model architecture of MOZERT:

A combination of different computer simulation methods can be achieved in different ways. In our project we apply top-down methods together with bottom-up methods. The System Dynamics approach, developed at the MIT in the 1960ies, is a top down approach looking at the overall structure of the system. With the TIMES model the energy system can be simulated, taking into account detailed technical and economic aspects. Both modules of the integrated system model, as shown in figure 5, deliver aggregated results with relatively small effort. When a system is near an equilibrium, top-down approaches are very efficient to simulate the system behaviour. Complex systems with a high level of self-organisation potential, systems far away from an equilibrium as social systems often are, on the other hand need bottom-up approaches, which can cope with inherent self-organisation processes. Within MOZERT MAS is used to simulate the self-organization between households.

The overall model consists of the three sub-modules (see figure 5):

- Energy system (implemented with the Austrian TIMES energy system model, a comprehensive energy flow model based on linear programming developed by project partner Austrian Energy Agency in 2009)
- Households and certificate market (implemented by applying an MAS approach)
- Commerce and Industry (implemented by applying the System Dynamics approach)

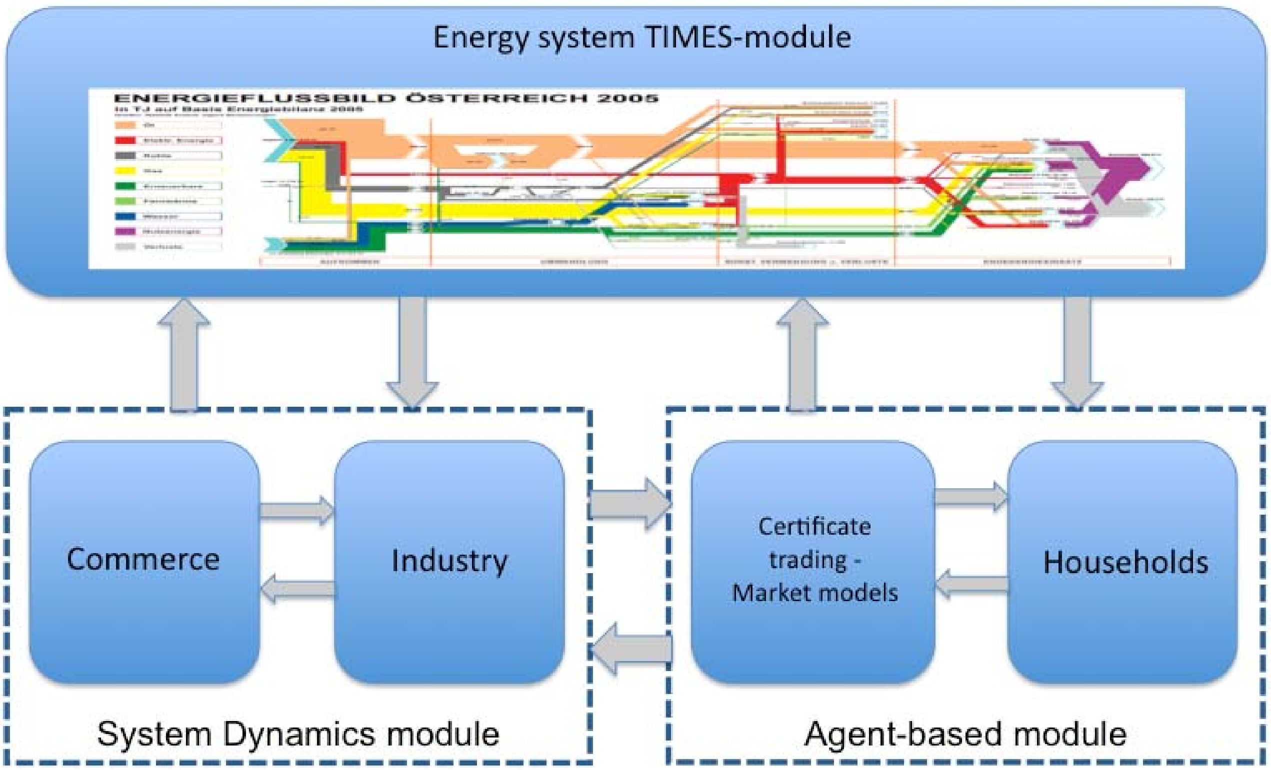

Figure 5: The overall model integration scheme

System Dynamics sub-module for Commerce and Industry

SD is a modelling approach to understanding the behaviour of complex systems over time. What makes it different from other approaches in studying complex systems is the use of feedback loops and the Stock and Flow concept. These elements help to describe how even seemingly simple systems display baffling non-linearity. System dynamics are not breaking up the world of interest into smaller and smaller pieces, they are looking at it as a whole. The approach is based on a formulation of ordinary differential equations (Sterman, 2000). These ordinary differential equations are solved with the help of numerical analysis methods, as Euler or Runge-Kutta, because analytic solutions would be far too difficult. The graphical representation is one of SD's benefits. The approach has become famous for its use in the world models from the Club of Rome (Meadows et al., 2004). The SD approach will be used within the project to model the consequences of the decisions by the individual households (results from the MAS model) influenced by certain frame conditions from the energy system, modelled with TIMES, from a top-down perspective within Commerce and Industry. A detailed simulation of the Commerce and Industry sector would be far beyond the possibilities within MOZERT and is also not necessary to analyse the impacts of different personal carbon allocation schemes for the socio-economic situation of households.
For example decisions in private households to renovate their living space for energy saving or the change to energy consuming equipment will affect the industry and commerce sectors. These influences can be considered using Input-Output analyses of the national economy. The following scheme shows very simplified the general integration of effects from households.

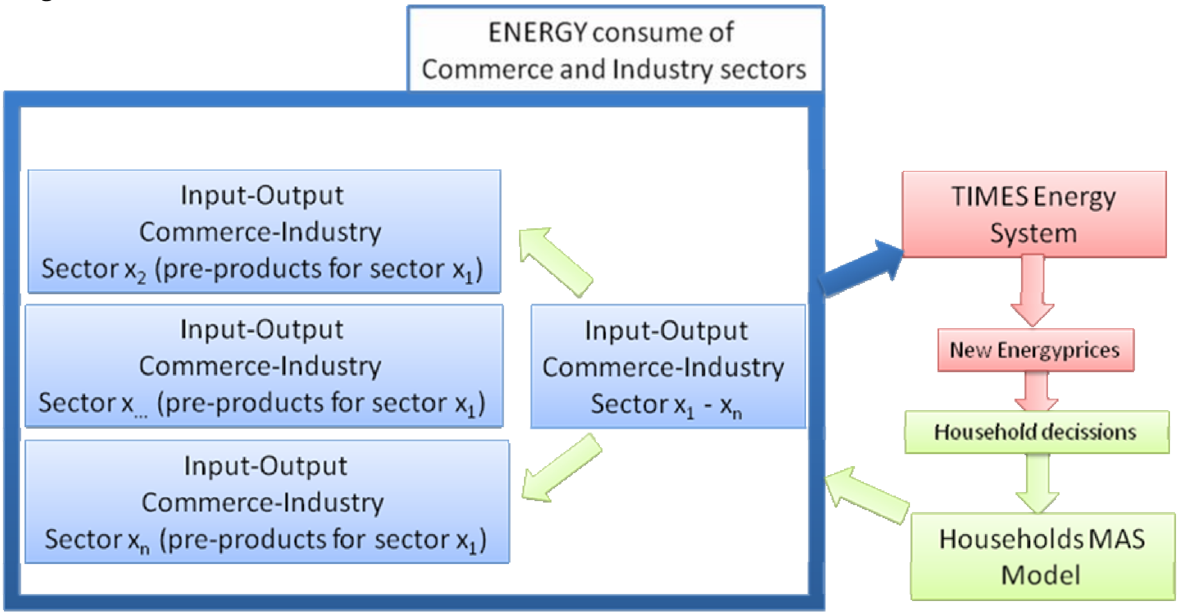

Figure 6: Simplified integration scheme of SD module for Commerce-Industry within the overall model

With the use of the Input-Output matrices the network of dependencies between various Industry and Commerce sectors can be mapped. Thus the pre-products can be estimated which are necessary to produce the demanded products from the households. A correlation with the sectoral energy statistics delivers an approximation of the necessary energy to produce these products. This energy demand itself is an important input for the TIMES energy system model, which calculates the energy prices and thus affects the decisions of the households in the future (see figure 6).

The agent-based module of households and the certificate market - MAS

Multi-Agent Systems (MAS) simulate the dynamics within a system due to the behaviour of individuals (agents), which act considering information from their environment and objectives they want to achieve. How and when they act is defined within the agent rules, agents may also interact with other agents showing group behaviour and self-organisation phenomena. The household sector and the certificate market which are modelled using the MAS approach are characterised with a high degree of self-organisation. The early stage of solar panels introduction in the market can be seen as an example of such self-organisation processes, whereas do-it-yourself construction groups have been catalysing the industry which started later on to produce the solar panels. Such self-organisation processes could not be analysed with top-down approaches as system dynamics.

Agent-based modelling is an appropriate approach to incorporate differences in decision making of lifestyle groups resulting in varying possibilities for actions they can perform. In our agent-based MOZERT-model households are classified by agent groups differentiated according to their life-style. We use the lifestyle types based on the work of Schulze (SCHULZE 2005), which are medium to old people with higher education representing the "niveau-milieu", medium-to-old people with low education aggregated in the "harmony-milieu", young people with low income in the "entertainment-milieu" and the "self-fulfilment-milieu" of young people with high education which can be disaggregated into two sub-milieus, either consumption-oriented ore driven by intangible values (see figure below). In MOZERT each Schulze milieu is represented by an agent type reflecting a certain lifestyle with key parameters like income, age, educational background, living area and other factors.

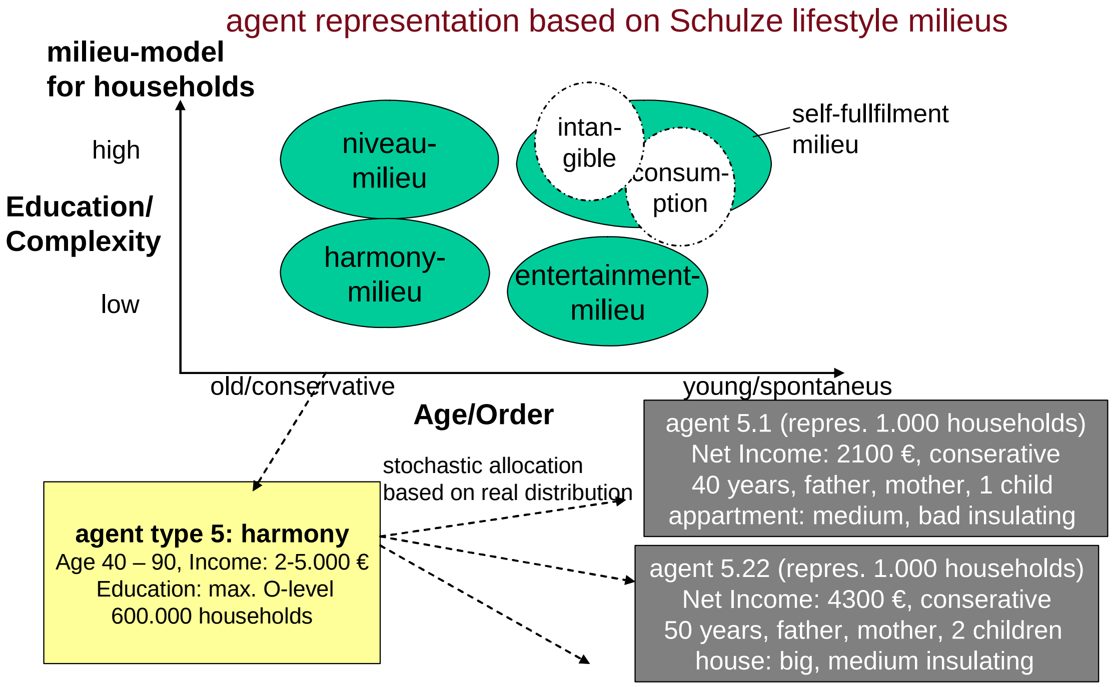

Figure 7: Agent representation based on lifestyle milieus of Schulze (SCHULZE 2005)

An agent type represents a lifestyle and a certain bandwidth of characteristics of a class of individual households. Stochastically MOZERT creates agent instances representing specific households with a certain income, education, age, etc. Each agent instance represents about 1.000 households which in our model behave identically. This is the resolution of the model which can be increased (e.g. 100 households per agent instance or decreased e.g. 5.000 households). All the agent instances of MOZERT combined represent the best fit to the real distribution of households in Austria based on data from Statistics Austria.

For households data like individual household equipments and specific lifestyle we use an existing database developed by SERI (Sustainable Europe research Institute, http://www.energisch.at/) in a project also financed by the Austrian "Klima- & Energiefonds". This set of data based on interviews of a representative set of 1024 Austrian households is randomized to 3800 agent instances without loosing the intrinsic correlations of the data.

The introduction of personal carbon allocation schemes in the system, will trigger different reactions within the different agent types. Each agent type has a specific agent logic hard-coded. It consists of a given set of activity options like e.g. "buying an electric car", "insulating the house" or "consuming less". Further on each agent type has specific rules which may lead to different decisions in the same situation. Depending on the social group and lifestyle people are willing to pay more or less than objective economically meaningful for a certain item depending on their personal values, behaviour of their social group etc. In the case of a buying decision for an electric car environmentally conscious people are willing to pay more for an electric car than a gas-operated car. In other social groups an electric car is a no-go and would not be purchased even if economically making sense.

As shown in the picture below each agent instance has a certain agent logic depending on the agent type. The logic consists of agent rules and activity options as well as knowledge an agents actual income, energy prices and its status personal carbon certificates. An agent instance also has knowledge about present inventory and consumption like energy consumption, equipment, house insulation, cars, etc. (see fig. 8).

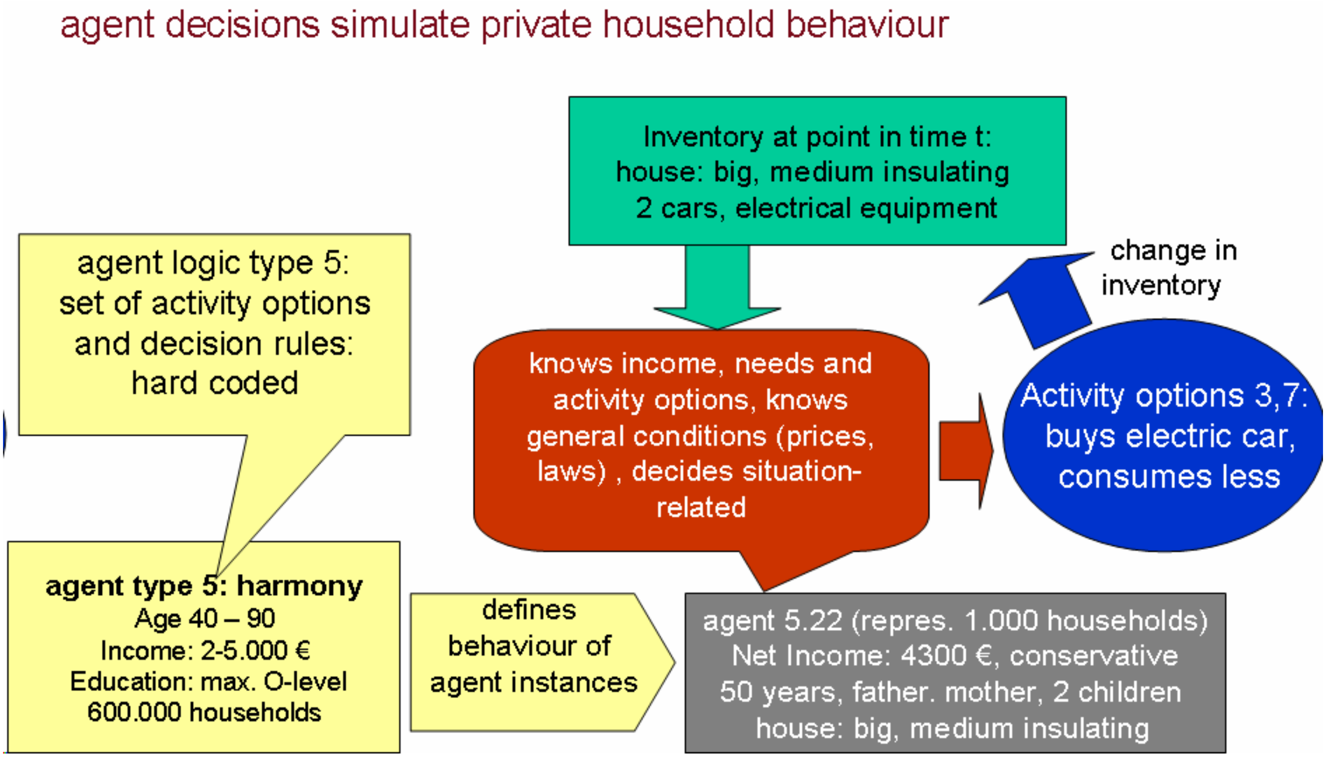

Figure 8: Agent representation based on lifestyle milieus of Schulze (SCHULZE 2005)

Normally an agent instance consumes the same way as within its last period, but changes in boundary conditions like an energy price increase, the end of life of a heating system or budget problems cause the agent to either

- invest in a new inventory like an electric car, house renovation with better insulation, energy-efficient electrical equipment or
- alter the agents behaviour by changing the modal split (less usage of cars) or holiday behaviour, consuming less or more, changing to organic food or cheaper food, reducing the heating temperature in the apartment etc..

In the model this means that an agent instance responds to new circumstances by choosing one or two of its activity options, which again may change the inventory of the agent instance.

The BDI components

To model decision-making of an household we use cognitive agents based on the BDI-architecture. The BDI agent concept implements the principal aspects of Michael Bratman's (BRATMAN 1999, RAO 1995) theory of human practical reasoning (referred to as Belief-Desire-Intention, or BDI).

The architectural components of a BDI system are:

- Beliefs: Beliefs represent the informational state of the agent, what an agent knows about the world (and may change in time due to learning): In our concept this is represented by a list of activity options which may differ between agent types.

- Desires: Desires represent the objectives the agent would like to accomplish. An examples of a desire in MOZERT is: Maximize your personal utility.
- Intentions: Intentions represent desires the agent intends to fullfil. In MOZERT this is the sub-set of activity options optimally fulfilling the agents desires in a non-contradictory way.

To provide the agent with beliefs we created a set of energy relevant activity options which have an influence on energy usage and CO2-emissions. These are actions in the segment of housing like “build or buy a new passive-house” , “insulate your house”, “change the heating system”, etc. The second segment is transport, e.g. “buy a more energy-efficient car”, “make more use of public transport”, “make more or less flights during holidays”. Additionally the agent may choose actions in nutrition like “eat more organic food” or “eat more/less”. Actions may be either investments into technology or changes in behavior.

The component “Desires” is the core of the decision making of an agent. In this component the set of possible or “believed” actions is ranked based on the agents main desire which is maximizing his/her personal utility. For this we calculate the personal utility of each activity option in the present situation. The first part is a pure rational calculation of the investment and the utility created by it. Future cost reductions due to a more efficient technology are discounted and compared with the investment necessary. This is the “rational” or “objective” part of utility.

But this is only one part of decision-making. Humans are also directed by values and other “subjective” issues. Van Raaij and Verhallen (Van Raaij 1983) differentiate between general and specific attitudes influencing our behavior. General attitude may be “conscience about climate change”, specific attitude “degree of accepted personal responsibility” or “personal convenience/comfort of a behavior”. A lower room temperature results in less costs without any investment but may be seen as reducing comfort. This is mainly represented by a certain wtp-value (willingness to pay) which may differ between agent types. This factor represents the subjective side of decisions and has been evaluated in many studies (Banfi (2010), Achtnicht, M. (2010), Sammer (2006), Gerpott (2009), Hansla (2008), Murphy (2005), Potoglou (2007)). We use wtp-values from these studies to add a subjective side to the decision-making of the agents. The sum of the “objective” and “subjective” utility gives the total utility of each activity option which is used to rank all possible options from the “Believe” component by the utility to the individual agent.

The last component of decision-making, the “intentions” component” calculates the optimal set of activity options for each agent under the present circumstances. Conflicting options are sorted out and fitted to the personal boundaries of an agent like “credit amount possible”. At the end of this decision process the agent acts by executing this optimal set of activity options.

Dynamic agent properties and the certificate market

Agents in MOZERT are no static objects but evolve dynamically and individually: They grow older over time which may lead to a change in life-style. They become parents increasing the house-hold-size and they die. They may also change their income and their belongings.

Agents may also alter their subjective opinion towards an activity option in case many others have bought this item (e.g. electro-cars). All these characteristics lead to dynamic agent behaviour in the model which is closer to reality than static top-down models especially in times of change.

Along the household sector the certificate market is also simulated with the use of agents. The advantage is that in this way different market frame conditions can be compared. Are there just few buyers and sellers, e.g. if all the certificates will be sold by an organisation (a bank) for the private households or are there large numbers of buyers and sellers? This will change the market behaviour and the price building process.

Conclusions

Reproducing and imitating the behaviour of complex real-life systems is the speciality of modelling. System Dynamics (SD) and more recently Multi-Agent System (MAS) Modelling have proven to be very valid to fulfil this task, at least to a certain extent. In the last ten years more and more voices within the modelling community have been raised, calling for a combination of these two approaches. A new area of integrating different modelling methods into a multi-paradigmatic approach seems to emerge lately.

Thus the application of a multi-paradigmatic modelling approach for the analysis of the project's key questions is innovative. Only in recent years, this modelling approach has been increasingly featured, however up to now it has been applied rarely. A combination of a top-down approach (SD modelling) for parts of the economy, TIMES modelling for the energy system and a bottom-up approach (MAS modelling) for a detailed coverage of the self-organisation mechanisms as well as the behaviour of relevant actors, has not yet been used in this context. Regarding the complex problem being researched in MOZERT, such an innovative methodology clearly shows it's advantages over classical approaches. Within MOZERT we are able to simulate the specific behaviour of households in a transparent way. Agent-based modelling is an appropriate approach to incorporate differences in decision making of lifestyle groups. In our agent-based MOZERT-model households are classified by agent groups differentiated according to their life-style types.

Regarding PCA-schemes our qualitative assessment brought us some insight into the different schemes and their possible advantages and disadvantages. The next steps towards an understanding of the possible outcomes of an introduction of such a scheme are quantitative scenarios comparing different PCA-schemes and their impacts on people and the energy system. The first phase of MOZERT has enabled us to build such a simulation tool to study this question in detail. In the next months the results of these investigations will be published, which will greatly improve the current scientific debate on PCA-schemes by providing quantitative results and comparisons of the benefits and costs of the different schemes. Based on these detailed scenarios we are also going to be able to provide clear policy recommendations to political decision-makers and opinion-leaders concerning a better (smoother) transition to a low carbon economy.

To model decision-making of an household we use cognitive agents based on the BDI-architecture. The BDI agent concept implements the principal aspects of Michael Bratman's theory of human practical reasoning and is well-suited to model households decision-making process. To provide the agents with options we created a set of energy relevant activity options influencing energy usage and CO_2-emissions. Thus we are able to model effects in the main end consumer segments housing including heating and electricity as well as transport. Activity options may be either investments into technology or changes in behavior.

To model the subjective side of the agent decision-making we use wtp-values based on a study on human behaviour literature within the project. Areas for future work have been identified in our literature review on human behaviour. In the context of climate-mitigation we miss comprehensive studies covering the uptake of new technologies like electric-cars and energy-related investments, as well as behavioural changes. For this very reason we had to use a combination of data from various studies to program our agents. This should be improved for future projects.

Agents in MOZERT are no static objects but evolve dynamically and individually. Agents may also change their opinion towards an activity option based on leader-follower mechanisms. All these characteristics lead to dynamic agent behaviour in the model which is closer to reality than static top-down models especially in times of transformation.

The results of the overall project MOZERT are to produce knowledge about the effects and dynamics of the different certificate based instruments, to generate supporting data for decision-makers in Austrian and European climate and energy policy. The insights gained with the help of the climate-policy simulator could contribute to make climate protection effective, successful and actually sustainable.

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