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Transitions and transition management in the surface passenger transport system : a system dynamics model.

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Abstract

In order to evolve towards a more sustainable society, fundamental changes need to take place in the domains of energy, transport, housing, economic production,… Few theoretical frameworks are available, which can bring order in the complex flow of events. However, the idea of socio-technical systems (Geels, 2002) achieves just that. By looking at societal transitions as the outcome of interactions between different levels and different dimensions in a socio-technical configuration, the future challenges and options for sustainable development become more clear. Geels (2002) even has a point when he defends the use of case-studies in order to better understand the different dimensions of technological transitions. However, by describing quantitative models as too narrow, too much based on extrapolation and too top-down, he fails to acknowledge the future added value of system dynamics in the development of scenarios and in the scientific learning process concerning societal transitions. This paper will present a system dynamics model concerning the possible transitions in the surface passenger transport system. The goal of the model is not to make predictions for the next 50 years, but to increase our understanding of what such models should look like. In the final paragraph, a simulation game will be played in order to clarify the concept of transition management.

1. Surface passenger transport[1]

In the final decade, the total amount of kilometers travelled by private vehicles in Flanders (Belgium), has increased by approximately 30%. At the same time, the load factor decreased from almost 1,5 in 1990 to less than 1,4 in 2001. In other words, people increasingly perceive the automobile as an all-purpose, flexible and individual mode of transport. In terms of the number of vehicles per 1000 people, Flanders equals the average for the European Union. Countries like Germany, Italy, Luxembourg and Austria have somewhat higher values. Some 14,3% of all households possess no automobile, while 27% of all households have 2 or more automobiles. As expected, households with higher average incomes are more likely to possess more than one automobile. When we do not make a distinction between the different activities that force people to move, 66% of all trips are made by car, while some 27,4% of all trips are either done by bike or by foot. When we consider only the trips to work, these numbers become 70% and 15%.

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[1] The data in this paragraph can be found on http://aps.vlaanderen.be

For the trips to school, the values are respectively 42% and 34%. In terms of the number of person-kilometers, 88,4% of all travelled kilometers is made by car, while the remaining number of kilometers travelled are done by train (6,6%) or bus (5%). Compared with the other countries of the European Union, Flanders has the most dense road and rail network. In other words, an enormous transport infrastructure has been built in the past. The number of train passengers has remained more or less fixed during the last 2 decades, while the average distance travelled has steadily increased. This is in agreement with past investments in capacity, which has remained unchanged in the last decade. Transport accounts for an important share in the total amount of household expenditures. Some 13% of the disposable income is spent on transport.

The current surface passenger transport regime generates a lot of negative externalities. Because of the fact that almost all light-duty vehicles burn gasoline or diesel in their internal combustion engine, transport is an important source of CO_2, CO, NO_x, SO_2 and Pm emissions. For instance, during the last decade, CO_2 emissions from surface transport have increased by more than 25%, while the other emissions were somewhat less or even decreased (e.g. CO and SO_2). A positive trend in the last decade was the rapid decrease of lead emissions. However, emissions of copper, chromium, nickel and zinc remain significant. With the increase in the number of passenger vehicles and the number of total passenger kilometers travelled, traffic congestion steadily worsened in the last decade. In some parts of Flanders, people can sometimes spend some 1 or 2 hours in huge traffic jams, decreasing the difference somewhat between the average time needed when doing the movement by car and the average time needed when doing the movement by public transport. These traffic jams are concentrated in 2 peak moments during the day: one when people go to school and work in the morning and the other when they return in the evening.

At the moment, these negative externalities are not yet perceived as highly problematic by the public opinion. While some 61% of the respondents states that the speed of traffic is too high in certain neighbourhoods, only 37% agrees with the statement that the traffic noise is too high and only 26% is hindered by the smell of traffic. Further, as expected, it are mostly young people (<24 years) who prefer to take the public transport instead of the private and flexible mode of transport delivered by the automobile. For the other age categories, the percentages are low (less than 20%). A lot of people, independent of the age category, also state that they prefer to take the bike or go by foot when only a small distance needs to be travelled. A lot of people also state that they want to use the automobile less often (over 60%) and some 40% is even prepared to pay an additional environmental tax. In other words, we can conclude that pressure from the public opinion has not yet reached sufficiently high levels, though it is without doubt that beneath the surface, fundamental changes are gradually taking place.

In order to achieve certain societally desired goals, different policies could be implemented (IEA, 2001; Vancronenburg, 2004a). For instance, the government could focus its attention on on-road fuel efficiency regulations: driver education, vehicle maintenance and inspection programs, vehicle retirement programs,… Technical optimizations of the current internal combustion engine vehicle could also be pursued: the use of on-board technologies (e.g. diagnostic equipment, information and automated systems) that improve fuel economy, reduce tire rolling resistance, 'new generation' engines such as hybrid-electric systems, streamline the vehicle's shape and reduce its frontal area, reduce the vehicle's weight through material substitution (e.g. aluminium, plastics and lightweight composite materials), reduce engine friction through the use of advanced lubricants and synthetic oils,… Another class of policies can focus on the road capacity: new lanes, the use of advanced technology for managing incidents and sensing traffic conditions that allow faster responses to break-downs and accidents on the road and that can deliver real-time information on traffic conditions, directions and identification of alternative routes to drivers,… Researchers in the Netherlands are also studying the potential of 'quieter roads', i.e. smoother road surfaces which will reduce tire vibration. By 2010 the Dutch government aims to reduce noise levels from the country's road surfaces by 6 decibels in this way (Glaskin, 2004). In the same category, congestion could also be reduced by influencing the amount of traffic during peak hours. For instance, incentives could be given to businesses which create telework opportunities for employees. Currently, 11% of all companies in Flanders offer the opportunity of teleworking. This number is higher in companies with more than 200 employees (42%). Another class of policies considers general taxes (e.g. road pricing and parking tax) and fuel economy taxes (carbon tax, rebates based on fuel economy, mobility rights, modification of the tax structure from fixed travel costs towards more variable travel costs,…). Currently, a lot of research and development is also being carried out on advanced vehicle propulsion technologies (fuel cells and electric batteries) and on new automotive fuels (e.g. methanol and ethanol, biodiesel, LPG, CNG and LNG, DME, hydrogen,…). The government could set performance-based sales requirements for advanced vehicle technologies, offer incentives (e.g. rebates, low-rate loans,…) for the use of on-board reformers, support and promote demonstration and pilot projects, invest in well-to-wheel infrastructure,… In the short term, none of these advanced technologies and new automotive fuels will become commercially available or competitive with the internal combustion engine on gasoline and diesel (IEA, 1999). Finally, the government could also decide to invest in the quality of public transport: invest in transit infrastructure, improve and offer new public transit services, use a GPS to provide more accurate and real-time information to passengers, institute signal priority and more reserved lanes for buses, invest in paratransit public vehicles that are flexible in their scheduling and route choice, invest in on-demand transit systems that allow commuters and other travellers to reserve a transit service for a particular time or destination,…

The description of the surface passenger transport system clearly demonstrates the complexity of the issue. It is impossible to state in advance which policies are promising, given a set of criteria on which the outcome of the policies will be evaluated, and which are worthless. Without a theoretical framework it is also very difficult to obtain a clear picture of the interactions between the different technologies and fuels, societal values and user preferences, governmental standards and regulations, taxes, infrastructure,… Will the future surface passenger transport system be characterized by merely system optimizations, gradually increasing the performance of the currently dominating technologies and fuels, or will we witness a gradual change in the context of the surface passenger transport regime, resulting in a transition towards a new dynamically stable state. And what will this new state look like? Will the automobile remain an all-purpose vehicle, fueled perhaps by hydrogen or biofuels, or will it rather be perceived as an important chain in a customized mobility system in which all modes of transport (automobile, bus, train, bike,…) are integrated with each other? Could the transition towards a customized mobility system result in smaller automobile driving ranges, such that, for instance, battery electric vehicles become a promising option for the future? And which trajectory will the transition within the surface passenger transport system follow? How will the interactions between the different technologies and the dimensions of the socio-technical configuration be played out? A theoretical framework is required in order to answer these research questions.

2. Socio-technical systems

Through a study of the literature, Geels (2002) has documented the strengths and weaknesses of several research domains, which study technological transitions. The first class of theoretical frameworks concern the point-source approaches with fields that stress the life cycle concept (Utterback and Abernathy, 1975), the branch of economics that focuses attention on contingency and path dependency (Arthur, 1988), the study of Large Technical Systems (Hughes, 1983; Mayntz and Hughes, 1988; Summerton, 1994 and Coutard, 1999), actor-network theory (Callon, Law and Rip, 1986) and the Social Construction of Technology approach (Bijker, Hughes and Pinch, 1987). These point-source approaches, however, have the following weaknesses (Geels, 2002, p38-39):

> "Point-source approaches focus mainly on the emergence and diffusion of new technologies. Because of their focus on new technologies, they tend to neglect the existence of old technologies, and do not say much about technological replacement. Because there is no attention for wider contexts, technological diffusion is understood mainly in terms of internal mechanisms (e.g. scale effects and decreasing costs, learning processes, network externalities, momentum, the dedicated work of system builders). There is little attention for external processes which create opportunities for breakthrough and diffusion".

The second class of theoretical frameworks concern the replacement approaches. Here we find economic models which stress the importance of substitution processes (Grüβler, 1998), frameworks which try to demonstrate that technological changes take place as a sequence of punctuated equilibria (Anderson and Tushman, 1990), the branch of economics (evolutionary economics) which tries to apply the idea of Universal Darwinism (Dawkins, 1983) to the workings of the firm and sector (Nelson and Winter, 1982; Dollimore,

2002) and theories concerning long-wave economic cycles (Freeman and Soete, 1997; Freeman and Louça, 2001). Through his case-studies, Geels (2002) has demonstrated that the replacement approaches quite often underestimate the complexity of wider societal transformations. For instance, in his case-study concerning the transition from horse-and-carriages towards automobiles, he clearly shows the falsity of Grüβler's statement that "the car industry grew initially by replacing horses" (Grüβler, 1998, p64). The bicycle at the end of the 19th century had already demonstrated the potential of private and flexible transport and had already initiated the desire for massive road building, while the electric tram, also at the end of the 19th century, had already made people accustomed to higher speeds. In other words, the bicycle and the electric tram were important stepping stones in the transition from horse-and-carriages towards automobiles. The replacement approaches have further also no attention for the emergence of new technologies and neglect the role of changing user preferences and other wider societal changes in transition processes.

Geels (2002) consequently fits the insights from the literature study into a multi-level perspective (Kemp, 1994; Schot, Hoogma and Elzen, 1994; Rip and Kemp, 1998; Kemp, Schot and Hoogma, 1998) in order to obtain his own multi-level perspective of socio-technical systems. I have used his theoretical framework for the surface passenger transport system in Flanders (Figure 1).

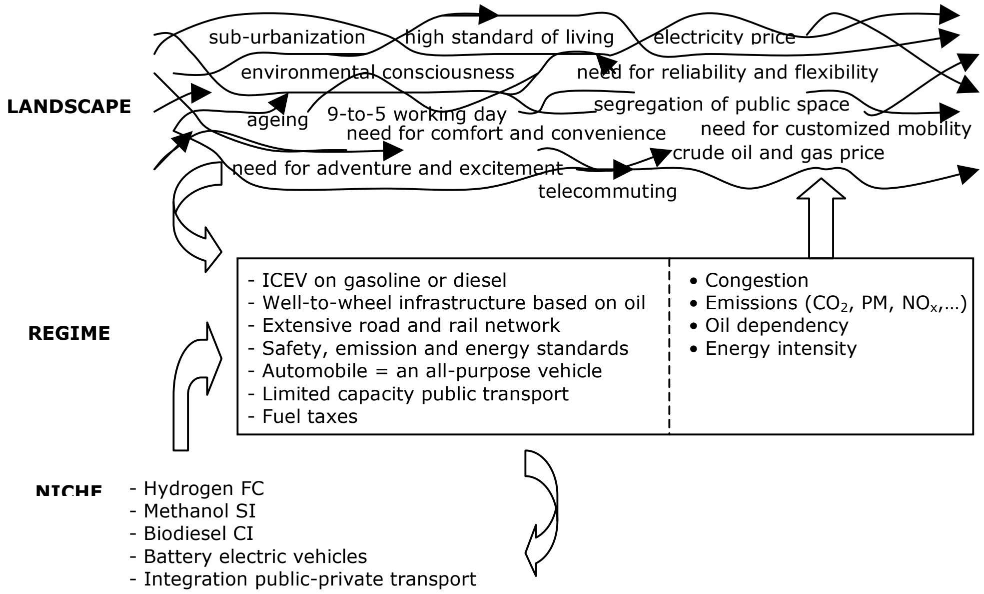

Figure 1: The surface passenger transport system

The current surface passenger transport regime is dominated by the automobile with internal combustion engine, fueled by gasoline or diesel. The share of public transport in total passenger kilometers travelled is almost negligible. However, as already stated above, the regime generates a lot of negative externalities: a high energy consumption, a high oil and gas import dependency ratio, a lot of emissions and a lot of congestion (both urban congestion and congestion on motorways). These negative externalities form internal regime tensions. If these internal regime tensions become linked with landscape pressures (e.g. increase in environmental consciousness, ageing, need for reliable and flexible transport, the desire to live in large suburban houses,…), then the reigning regime becomes faced with major challenges. If it is unable to cope with these challenges, the regime will open up and become more fluid. Windows of opportunity for new and advanced technologies, which are currently still residing in small niches, emerge, such that they can steadily increase their market share and gradually transform the current regime into a new configuration. However, the current regime can also play a more active role to safeguard its future survival. Figure 2 demonstrates the still possible gains in fuel consumption of the internal combustion engine vehicle (ICEV). These gains are the result of the use of advanced tyres, material substitution, drag reduction, engine friction reduction,…

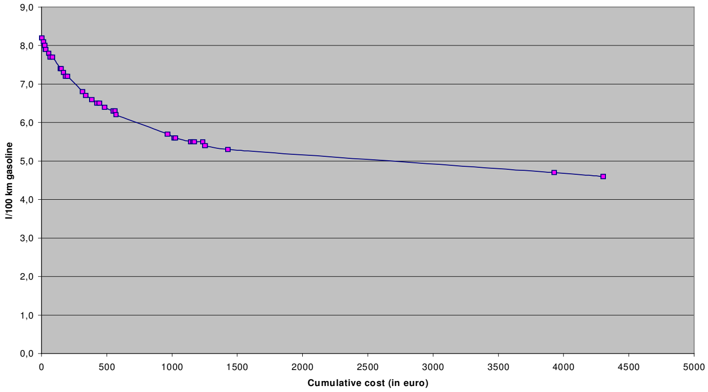

Figure 2: Optimization of the ICEV (IEA, 2001)

In the same sense, several strategies can be thought of, which make it possible for the current regime to cope with the challenges faced. In other words, the reigning regime is a moving target, again and again trying to decrease the generated internal regime tensions. Kemp and Rotmans (2001, 2002) call these strategies system optimization strategies. They improve the situation in the short term, but in the long term, it becomes technologically, economically and socially harder and harder to achieve the needed efficiency gains. On the other hand, when the current regime is unable to cope with the internal regime tensions and landscape pressures, new technologies can diffuse from their niche level towards the regime level and transform the whole regime configuration. Strategies which stimulate the emergence and diffusion of new and advanced technologies are called system innovation strategies (Kemp and Rotmans, 2001, 2002). For instance, fuel-cell vehicles, in which the consumed hydrogen is produced by renewable energy resources, or battery electric vehicles integrated in a system of customized mobility, will result in major gains in terms of energy consumed, CO_2 emitted, oil dependency, congestion,… It is interesting that in this story, we recognize the ‘Shifting the burden’ archetype (Senge, 1990). This is visualized in figure 3 in which Geels’ theoretical framework is integrated with another theory concerning transformations in human systems (Holling et al., 2002).

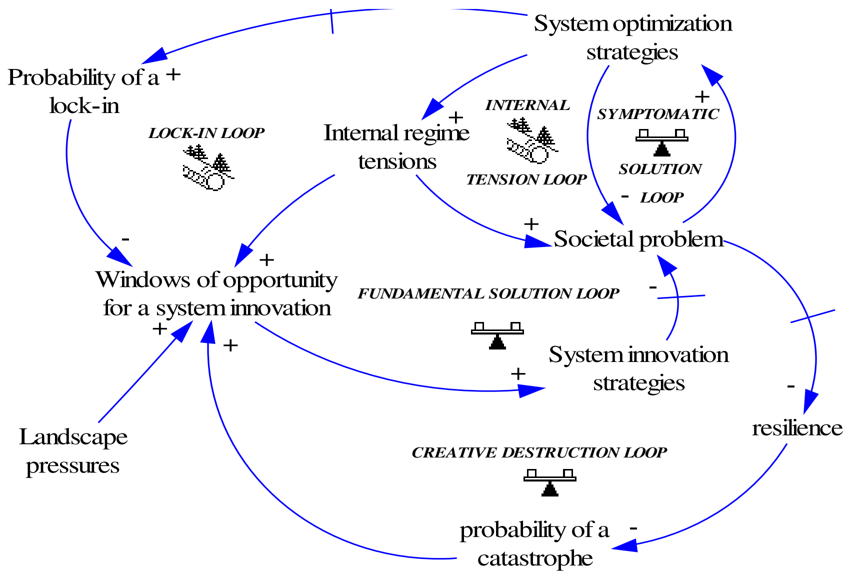

Figure 3: System optimization versus system innovation strategies.

3. How to study transitions in socio-technical systems?

When contemplating about the proper research strategy for studying transitions in socio-technical systems, Geels (2002, p18) makes the following statement:

> "[…] technological transitions (TT) are a complex phenomenon, consisting of many interacting elements and linkages. Investigations of this kind of phenomenon require a research strategy that is both rich in context and can track complex developments over time. Yin (1994) argues that case studies are the only methodology to study a phenomenon in relation to its real-life context and to understand causal links in complex situations where many variables interact. […] According to Yin (1994), case-studies have a distinct advantage over other research strategies when a 'how' question is being asked. […] Case-studies are well suited to tell such rich stories in terms of dynamics and interacting processes. They are necessary, because of the qualitative multi-level perspective I use. It is the interaction and alignment between processes at multiple levels which offer understanding of TT. The focus is on the interlocking of multiple processes and activities, not on linear cause-and-effect relationships."

Later, he states that quantitative exploration methods "lost popularity in the 1980s, due to the second oil crisis and the economic depression. There was disillusionment because the forecasts had not foreseen important turning points" (Geels, 2002, p406). Consequently, he identifies several problems of quantitative methods (Geels, 2002, p407-410):

- Forecasting methods are reductionistic and are characterized by a lack of attention for qualitative aspects.
- Forecasting methods are too much based on extrapolations and the assumption of incremental change. There is too little attention for discontinuity and radical change.

- Forecasting methods focused too narrowly on specific topics, without looking at the broader system.
- Many technology scenarios assume a set of technologies on the supply side, characterized by generic aspects such as price, performance and a historically calibrated ‘learning curve’. On the demand side, a homogeneous set of consumers is assumed with fixed preferences, sometimes complemented with government regulations as part of the selection environment. The development and diffusion of technologies are assumed to be economically driven: technologies with higher cost/performance ratios win higher market shares.

> “This conceptualisation is not wrong, but limited for several reasons. Firstly, technological development on the supply side is influenced by firm strategies, social and industrial networks, learning processes. Secondly, there are many different market niches, made up by different user groups, with different problems, preferences and willingness to pay. Thirdly, consumer preferences do not remain constant indefinitely. Social and cultural processes on the demand side will lead to changes in the selection environment” (Geels, 2002, p408).

- Many technology-scenarios look at (emerging) technologies independently. Technical trajectories are analysed and characterized with learning curves as if they were independent. In reality, however, these trajectories influence each other. Interactions between technologies may be competitive, but also more complementary and symbiotic. New technologies may stimulate each other and have positive interrelatedness. Furthermore, the exploration should not only look at technologies and markets, but also at possible changes in user preferences, policy, cultural changes, infrastructure.
- Scenarios can have a ‘macro-bias’. This means that the dynamics and outcomes of the scenarios depend too much on macro-aspects (e.g. economic growth, environmental awareness, oil price). The ‘logic’ of the scenarios is top-down in the sense that processes and actions at the meso- and micro-level are determined by macro elements. It is no surprise that environmentally friendly technologies become dominant in scenarios with high environmental awareness and high economic growth. Such scenario outcomes are externally determined, by national and international forces.

Consequently, Geels makes two interesting recommendations. These recommendations were also made by ICIS (2000b) in their study concerning the state of the art in environmental modelling and scenario analyses:

> “To cope with the problems, there are several directions of improvement. The first improvement is to include more qualitative elements in future explorations (e.g. consumer attitudes, regulatory issues, world politics), even when this leads to methods which are ‘looser’. […] With regard to technological development this means that attention should not just be given to aggregate variables such as price and performance, but also to aspects such as actor strategies, social networks and learning processes” (Geels, 2002, p410).

> “The more traditional forecasting methods have been unsuccessful at forecasting turning points because they merely replicate past experience rather than capture adequately the causal relationships and environmental factors which contribute to major structural change. Although there will probably never be a reliable way of actually forecasting turning points, it is possible to forecast the conditions which may make an abrupt change more likely” (Huss, 1988, p379).

What are the implications of all this for system dynamics? I agree with Geels (2002) and ICIS (2000b, 2000c) that past quantitative models – system dynamics models in particular – were rather restrictive and that, indeed, a lot of past system dynamics models had the flaws, which Geels (2002) mentions. I think 2 mistakes laid on the basis of this. First of all, system dynamics is perhaps the only method available which can successfully increase our understanding concerning dynamically complex problems (Senge, 1990; Sterman, 2000). By taking a more broad approach, it has learned us that the boundaries of perceived wicked problems should be extended. In this way, system dynamics resonates very well with the remarks made by Geels (2002). However, which variables should we include in our system dynamics models? For example, ICIS (2000a) correctly state that in order to understand the dynamics of a certain societal problem, 3 dimensions should always be represented in any system dynamics model: the economical, environmental and social dimension. However, which variables within those dimensions are important for the understanding of societal transitions. The literature on system dynamics can not answer this question, nor can actually any scientific literature on a specific topic (e.g. global warming, congestion, pollution,…). The literature on societal transitions can, however, by looking at several socio-technical transitions and trying to identify several dimensions which were important driving forces in all these transition processes. Supporting on the literature on Strategic Niche Management (Schot, Hoogma and Elzen, 1994; Kemp, Schot and Hoogma, 1998; Hoogma, 2000; Hoogma, Kemp, Schot and Truffer, 2002), Geels (2002) identifies 7 dimensions of a socio-technical regime: technology, infrastructure, symbolic meaning of a particular technology, social networks of value chain (supply, production), knowledge (science, craft), sectoral policy (laws, regulations, standards, subsidies) and functional domain (market niches, user preferences and competences). In his case-study concerning the transition from horse-and-carriages towards automobiles, Geels (2002) clearly demonstrates the importance of such ‘soft’ variables as the desire for fun, excitement and adventure, the belief in progress through technological innovation and the desire to live in suburban communities. I wonder if those variables would have been included in any systems dynamics model, studying possible transitions in the surface passenger transport system. In other words, theoretical work on socio-technical systems and system dynamics are strongly coupled. System dynamics modellers, studying the conditions for possible future transitions in a certain societal domain, require theoretical spectacles in order to decide which variables are important for the study of societal transitions and should thus be included in the model, and which variables could be neglected, keeping the model manageable. These theoretical spectacles are being built by the valuable contributions of scientific researchers in the field of socio-technical systems. However, there is also, of course, an important feedback loop. System dynamics can also make a valuable contribution to the research concerning socio-technical systems. For instance, by constructing models based on socio-technical principles, it can offer more consistency and analytical rigour than merely pure story-telling. It is undeniable that some expected trajectories are actively incorporated into the model. For example, if people's environmental consciousness increases, then it is more likely that the government, through standards and taxes, increases the pressure on the reigning regime, making it for niche technologies more easy to diffuse towards the regime level. People will also more quickly make the transfer from automobile towards public transport, whenever the quality of public transport is sufficiently adequate. However, the strength of system dynamics models is that they always keep surprising us, suddenly generating a behaviour which we were not expecting. The socio-technical scenario concerning customized mobility which Geels (2002) presents, has no such surprises. This was to be expected, because system dynamics modellers have long known that only fully built simulation models can master the dynamic complexity of wicked problems. Geels (2002) is unable to interfere in a consistent manner the dynamics from the complex structure he presents. Further, system dynamics can also analyse more thoroughly the importance of contingency, path dependency and hysteresis of transition processes and can ask what-if questions to explore other outcomes which would also have been possible. All these insights can either be used in scenario analyses, perhaps supplemented with more 'soft' and qualitative approaches such that the scenarios are sufficiently rich, or can flow directly into the theoretical research concerning societal transitions. This paper explores the potential of the first promise, while another paper (Vancronenburg, 2004b) has transformed the 'Shifting the burden' archetype (Figure 3) into a stock-and-flow diagram in order to explore the different conditions for a system optimization versus a system innovation.

The second mistake concerns the perception of the goal of a system dynamics model. Geels (2002) focuses the attention on forecasting as the goal of a quantitative model. However, Rotmans and de Vries (1997) and ICIS (2000c) have clearly highlighted the different uncertainties with which every modelling process is confronted. These uncertainties are not restricted to exogeneous variables, which could then be 'solved' by sensitivity analyses. Value diversity, the need to incorporate different perspectives into the modelling process, the influence of excluded variables and feedback loops on the dynamics of included variables, the need to consider several causal and functional relationships between variables, the sudden emergence of 'surprises',… make it all very difficult to keep believing in forecasting as the goal of a system dynamics model. This statement should perhaps be relaxed somewhat and be placed in its proper context, because when forecasting is out of the question, why build quantitative models then in the first place? I think we should be very sceptical concerning the final outcome of our system dynamics models, especially concerning the final state of variables, but even about the resulting characteristic patterns, speeds and directions of change. However, in our system dynamics models we can identify the conditions in which certain feedback loops will dominate, while others remain dormant. We can increase our understanding concerning the negative feedback loops, which inhibit change and form a major barrier for new and promising technologies in the niches. These insights should result in rules-of-thumb which identify the possible emergence of future bottlenecks, which warn us of possible dangers (e.g. lock-in or lock-out) when a certain policy is implemented, which identify promising options which should consequently be studied in societal experiments,… In other words, it are the rules of thumb which should be discussed with decision makers and not the model with its graphical outcomes which should be presented as a truth machine. These rules of thumb should result in a dialogue between the different stakeholders to test their plausibility and to stimulate a societal learning process in order to identify policies and societal experiments which could steer society towards democratically desired goals.

4. A system dynamics model concerning transitions in the surface passenger transport system

The goal of the system dynamics model, presented in this paper, is to explore the potential of applying the insights from the research on socio-technical systems into the model. Attention is focused on the theoretical aspects of this endeavour. This has given rise to some simplifications. For instance, the model makes a distinction between only 2 modes of living: urban versus suburban living. At year 2000, the initial time of the model, 6 million people lived in suburban communities, while 4 million people lived in urban communities. The model does also not make a distinction between different socio-economic categories (e.g. low-income versus high-income, single versus married, with or without children, a distinction according to age,…). The population will also remain at 10 million people during the whole time period. The model, however, does consider the influence of ageing on the surface passenger transport system. This has been modelled by making use of an ageing factor. Further, only 2 types of trips are considered: short distance trips versus long distance trips. For suburban communities, the average distance of short trips is fixed at 5 kilometers, while the average distance of long trips is fixed at 30 kilometers. For urban communities, the values are respectively 2 and 30 kilometers. The model does also make no distinction between the different activities by which people spend their time (e.g. work, school, shopping, recreation, social contacts and family visits,…). The number of daily movements which people make because of these activities, remains fixed during the whole simulation and equals 4. This is in agreement with Schoemaker (2002). In other words, in the model, the number of daily movements is divided between short and large distance trips, independent of the activity which is eventually performed. At first sight, all these simplifications may seem to be too extreme. However, they made it possible to focus attention on those interactions which I was mostly interested in, namely the potential of system dynamics to study the interactions between different technologies, the interactions between internal regime tensions and landscape pressures and the windows of opportunity they create for the diffusion of niche technologies, the importance of the absence of a well-to-wheel infrastructure for the use of new automotive fuels, the importance of 'soft' variables like people's perception of what a house needs to be or of what the function of an automobile is (e.g. an all-purpose vehicle versus a chain in a customized mobility system),…

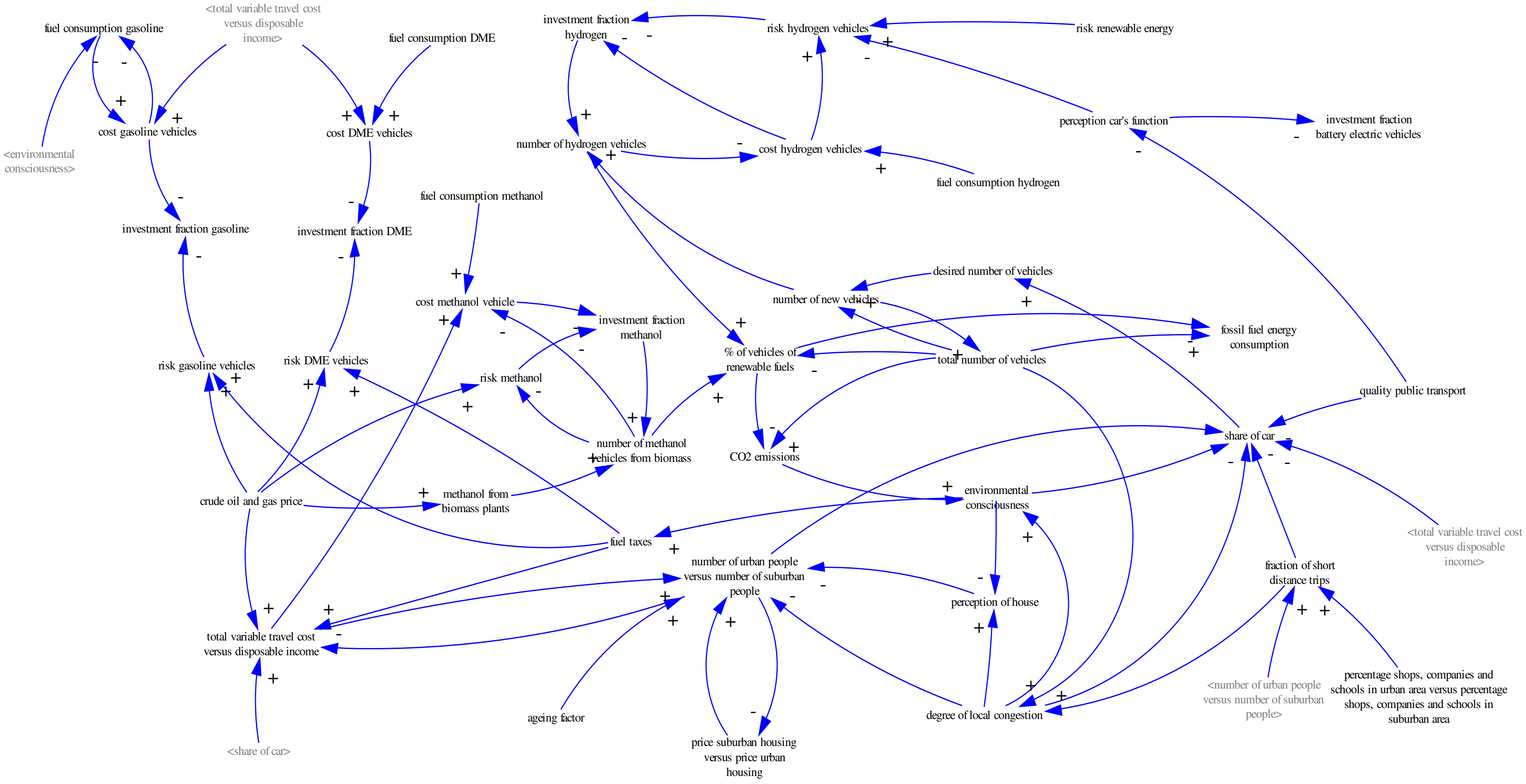

Figure 4: Mental model of the surface passenger transport system

If I would have made a more realistic distinction between the different categories and activities mentioned above, the data requirements would firstly have been enormous. Secondly, the magnitude of the model would also have increased a lot, making it less and less likely that the dynamics would have been understood. Further, the added value of this additional detail complexity would also have been very limited, given the goal of this research endeavour. Along with the fact that system dynamics stresses the need to extend model boundaries in order to understand the dynamics of a system, I believe that the model simplifications, mentioned above, are justified. Further, the simplifications are also not arbitrary. For instance, common sense describes that people in suburban communities, because of lower population densities, must travel more to do their shopping. Schoemaker (2002) further illustrates that almost half of all movements is shorter than 3 kilometers, while only 4% is longer than 50 kilometers and merely 1% is longer than 100 kilometers. In other words, in terms of the number of movements, short distance trips certainly dominate. This was also demonstrated during the description of the most recent statistics concerning the surface passenger transport system in Flanders. There we mentioned, for instance, the rather large shares of the bicycle and walking in the modal split. However, the fraction of these modes of transport in total kilometers travelled is negligible. Supporting on these simplifications, the system dynamics model is constructed (Figure 4).

Every time step (i.e. 1 year), 5% of all people moves. They make a choice between an urban versus a suburban living. The urban carrying capacity is 6 million people, while the suburban carrying capacity amounts to 7 million. The ratio of the number of urban people versus the number of suburban people is determined by the ageing factor, the price of suburban housing versus the price of urban housing, the degree of local congestion, the perception of what a house should look like and the total variable travel cost versus the disposable income. Older people require a more urban environment, with compact and accessible homes, in the neighbourhood of shops and social care institutions, and with good public transport facilities. When the number of urban or suburban people approaches the respective carrying capacity, the difference in the price of suburban houses versus urban houses increases. When the share of car use rises, i.e. more kilometers are being travelled by car, the total variable travel cost increases. The total variable travel cost can also increase due to higher fuel taxes or higher well-to-wheel costs before taxes (e.g. oil and gas price, electricity price). The ratio of the number of urban people versus the number of suburban people is also determined by the degree of local congestion. If the congestion in urban centres increases, more and more people will opt for a suburban living. Finally, the perception of what a house should look like also influences the number of urban people versus the number of suburban people. Currently, people desire large houses, whenever it is financially feasible. It is possible to imagine the gradual emergence and diffusion of new perceptions, which, for instance, prefer smaller homes in a friendly urban neighbourhood. When the degree of local congestion is high, this shift in perception will not take place, because of the fact that people have not come into contact with a quiet and cohesive urban climate due to high traffic. An increase in environmental consciousness, itself the result of increasing public worries due to high CO_2 emissions and a high degree of local congestion, can also result in a shift in the perception of houses. In the model, the location decisions of companies, schools, shops and recreation centres track the changes in urban versus suburban living. In each time step, 10% of all companies and schools needs to make a decision concerning a suburban or an urban location, while for shops and recreation centres this number equals 20%. The location of companies, schools, shops and recreation centres versus the ratio of the number of urban people versus the number of suburban people determines the weight of short distance trips in the total amount of trips made. If the location of companies, schools, shops and recreation centres differs strongly from the ratio of the number of urban people versus the number of suburban people, the amount of short distance trips will be limited. When the fraction of short distance trips decreases, the share of the car in the total number of movements will increase, because of the reduction in the share of the bicycle, walking and public transport. However, the share of car can also decrease due to an increase in the quality of public transport - which translates itself into shorter travel times by public transport - and by an increase in the total variable travel cost versus the disposable income. When the number of urban people decreases, the share of car will increase due to the currently limited potential of public transport in suburban communities. The share of the car in the total number of trips determines the desired number of vehicles. The difference between the desired number of vehicles and the available number of vehicles determines the number of new vehicles. The average lifetime of an automobile in the model is 10 years. This is consistent with the WEO2002 (IEA, 2002). The total number of vehicles further determines the total amount of fossil fuel consumption and CO_2 emissions. However, if the share of vehicles on renewable fuels increases, then the total amount of fossil fuel consumption and CO_2 emissions will decrease. An important decision in the model consists the investment in new and advanced vehicles. In contrary to figure 1, this model will only consider 4 types of fuel: gasoline, DME, methanol and hydrogen. In other words, diesel, biodiesel, LPG, CNG and LNG are not considered in the model. The reason for this is that the incorporation of these additional fuels in the model would increase the complexity of the model, but would not make a very valuable contribution concerning our understanding of the transition process in socio-technical systems. As long as the risk of the internal combustion engine vehicle on gasoline remains low, car manufactures will keep investing in these vehicle types. This choice is rational, given the enormous sunk costs in infrastructure and knowledge, the uncertainty concerning the technical and commercial potential of new and advanced vehicles and the climate of vested interests. However, the risk of the gasoline vehicle can start increasing due to a rise in the oil price and/or an increase in fuel taxes due to increased pressure on the government from the more environmentally conscious public opinion. The risk of DME vehicles is more or less analogues with that of gasoline vehicles, given the fact that DME is processed from natural gas. An increase in the gas price or an increase in the fuel taxes on DME will also enlarge the risk of DME vehicles. However, even if the risk of DME vehicles is limited, as long as the risk of gasoline vehicles remains small, car manufacturers will not initiate the production of a new type of automobile. Methanol can be obtained from natural gas and biomass (especially cellulose) (IEA, 1999). As with DME, so long as the methanol is obtained from natural gas, the risk of methanol vehicles will start increasing whenever the gas price increases. An increase in the gas price will favour the production of methanol from biomass, expanding the capacity of methanol from biomass plants. As more and more methanol from biomass vehicles are produced and as the capacity of methanol from biomass plants expands, the risk of methanol vehicles decreases. An important variable, especially when studying future transitions in the surface passenger transport system, concerns the risk of hydrogen vehicles. In the model, hydrogen vehicles can take on 3 forms: hydrogen fuel cell vehicles and gasoline and methanol vehicles with on-board reforming. If there is no available capacity for the production of hydrogen, car manufacturers will first increase the production of gasoline and methanol vehicles, in which the gasoline and methanol is reformed on-board towards hydrogen. The choice between methanol and gasoline depends on the respective costs of both types of vehicles and on the availability of sufficient methanol. This is determined by the capacity of methanol producing plants. At the moment, the cost of hydrogen fuel cell vehicles is very much higher than the cost of gasoline, DME and even methanol from biomass vehicles. However, learning effects due to increasing production should lower the cost of hydrogen fuel cell vehicles in the future. The risk of hydrogen vehicles is also determined by the fraction of renewable energy in the generation of electricity. If, for instance, most of the generated electricity is from coal or natural gas, then hydrogen production will already be less interesting, given the high energy intensity of hydrogen production and the large amount of CO_2 emissions throughout the whole well-to-wheel infrastructure. An increasing share of renewables in total energy production would reduce the risk of hydrogen fuel cell vehicles. Finally, an increase in the quality of public transport can result in a shift of perception of what an automobile should look like and what it’s proper function should be. If the public transport system is extended and the quality is improved, the automobile could become more and more to be seen as an important component in a system of customized mobility. In other words, a shift in the perception of the automobile’s function can result in a demand for smaller and more compact vehicles, which can eventually stimulate the production of battery electric vehicles, which are especially suited for this market niche. However, if the perception of what an automobile should look like and what an automobile should be able to do starts to differ more and more from our current perception of the automobile’s role, car manufacturers will be reluctant to invest in a totally new automobile design, such as the hydrogen fuel cell vehicle. In other words, a shift in the perception of the automobile’s function will result in a rise of the risk of hydrogen fuel cell vehicles. Within specific risk constraints, the number of new vehicles will be divided over the respective vehicle types according to cost considerations.

5. Simulation results

Two different scenarios are run to present the dynamics of the system dynamics model. In the first scenario, no investments in public transport are made. In the second scenario, the quality and capacity of public transport are gradually improved. In terms of the total number of vehicles and the partition of the total number of vehicles over the respective vehicle types (e.g. gasoline, DME, methanol from natural gas, methanol from biomass, hydrogen from gasoline, hydrogen from methanol and pure hydrogen), the outcome of the 2 scenarios is somewhat different (Figure 5 and 6).

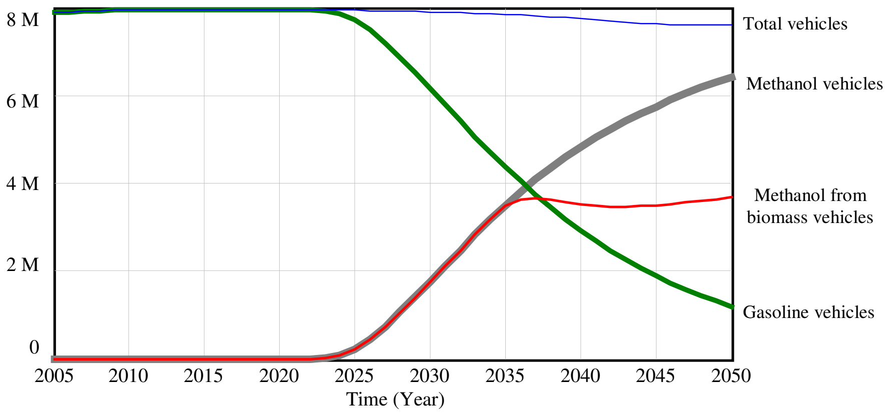

Figure 5: Total number of automobiles and partition over the different vehicle types (No public transport scenario)

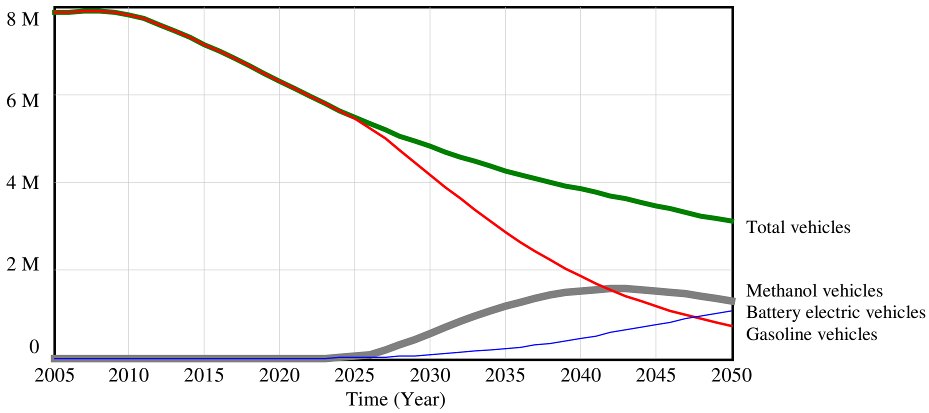

Figure 6: Total number of automobiles and partition over the different vehicle types (Public transport scenario)

In the ‘No public transport scenario’, the total amount of vehicles remains more or less the same. From 2025 onwards, gasoline vehicles start to decrease. The share of methanol vehicles in the total number of automobiles increases as a result. Until approximately 2035, all methanol is produced from biomass. However, after 2035, land for biomass becomes increasingly scarce, making it impossible to fulfil all demand for methanol from biomass. The share of methanol from natural gas starts increasing after 2035, making the methanol vehicle option less and less interesting. Hydrogen vehicles, pure or with reforming on-board, do not emerge in the ‘No public transport scenario’. DME vehicles are also not represented. In the ‘Public transport scenario’, the total number of vehicles decreases continuously during the whole simulation period. After 2025, the decline in the number of gasoline vehicles is faster than the overall decline in the total number of vehicles. The gap is filled up by methanol vehicles, where all the methanol is produced from biomass, and by battery electric vehicles. As with the

'No public transport scenario', hydrogen and DME vehicles are not represented in the scenario.

One of the factors, determining the partition of the total number of automobiles over the respective vehicle types, concerns the risk of the various vehicle types. This is represented in Figure 7 and 8.

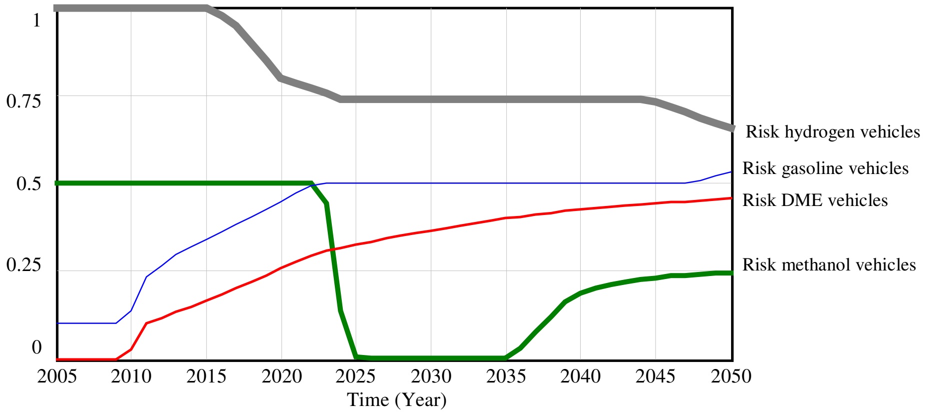

Figure 7: Risk of the different vehicle types (No public transport scenario)

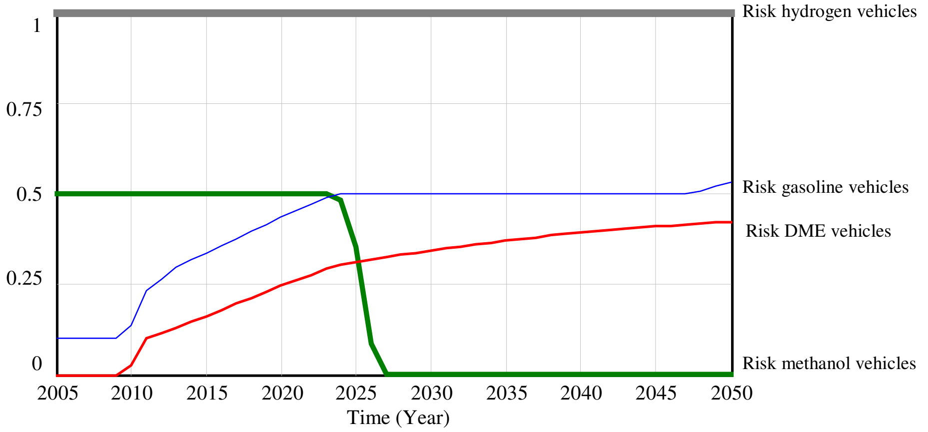

Figure 8: Risk of the different vehicle types (Public transport scenario)

In the 'No public transport scenario', the risk of gasoline and DME vehicles increases steadily due to the rise in both the oil and natural gas price and in the fuel taxes on gasoline and DME. The risk of methanol vehicles starts decreasing after 2020, when the number of methanol from biomass plants rises due to the increasing demand for methanol from biomass vehicles. This results in a decrease of uncertainty concerning the commercial and technical potential of methanol from biomass vehicles. After 2035, the risk of methanol vehicles starts increasing again due to the shift from methanol from biomass towards methanol from natural gas as a result of the increasing scarcity of land for cellulosic crops. The risk of hydrogen vehicles remains very high for the whole simulation period. As long as almost no hydrogen vehicles are produced, the uncertainty concerning the commercial and technical potential of hydrogen vehicles remains very high, resulting in massive barriers for its emergence and diffusion. This is a real starting problem for a new and advanced technology. I have not opted for an exogeneous increase in the number of hydrogen vehicles, because then the transition would have been exogeneously initiated and driven. For instance, I could have chosen for an independent increase in the number of hydrogen vehicles in another geographical area or in other market niches not included in the surface passenger transport regime (e.g. trucks, buses, vans,…), such that domestic car manufacturers could use the outcome of these learning processes and could start the production of hydrogen vehicles with a smaller unit cost as a result of the fact that a fraction of the experience curve has already been run down. Within the model, the decrease in the risk of hydrogen vehicles needs to be generated internally. In the 'No public transport scenario', windows of opportunity for hydrogen vehicles are created as a result of the rising risk of gasoline and DME vehicles and the still high risk of methanol vehicles until approximately 2020. Because of these increasing internal regime tensions, along with no real pervasive barriers against hydrogen vehicles, domestic car manufacturers start to explore the potential of the hydrogen option. However, with the transition towards methanol from biomass vehicles, the hydrogen option becomes less and less interesting. This results in a lock-in of the methanol from biomass option and a lock-out of the hydrogen option. In the 'Public transport scenario', a more or less similar picture can be observed. However, 2 differences attract our attention. First of all, in contrast to the 'No public transport scenario', the risk of methanol vehicles starts not increasing again at the end of the simulation period. This is because in the 'Public transport scenario' no shift from methanol from biomass towards methanol from natural gas takes place. Secondly, the risk of hydrogen vehicles remains at its maximum during the whole simulation period. This is because in this scenario no windows of opportunity are created for the hydrogen option.

One of the goals of the system dynamics model was to study the importance of 'soft' variables for transitions in the surface passenger transport system. Three variables are considered in the model: perception of a house, perception of an automobile's function and environmental consciousness (Figure 9).

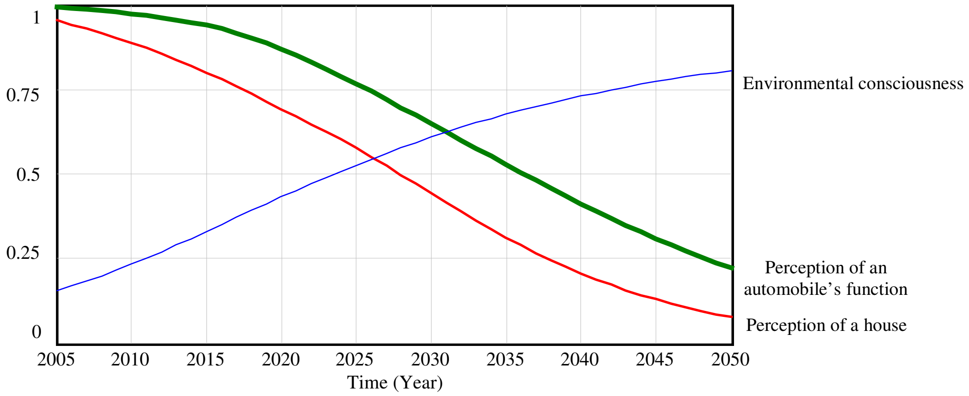

Figure 9: Environmental consciousness, perception of an automobile's function and perception of a house (Public Transport scenario)

In the 'Public transport scenario', 3 shifts in perception take place. First of all, as a result of CO_2 emissions and local and motorway congestion, average environmental consciousness of the population starts increasing. After enough momentum has been gathered, the shift becomes irreversible and feeds on itself. At the end of the simulation period, people have a very different opinion about nature's intrinsic worth. Further, both the perception of what a 'good' house should look like and what a 'good' automobile should be able to do, changes fundamentally in the 'Public transport scenario'. At the end of the simulation period, people do not require the large houses in suburban communities anymore as they currently do. Instead, a house should be compact and located in a nice and friendly urban neighbourhood. The same can be said concerning people's perception of what an automobile should look like and what an automobile should be able to do. As a result of massive investments in public transport, the automobile becomes to be perceived as an important chain in a customized mobility system where each mode of transport has to fulfil its proper function. The required driving ranges of the automobile decrease, creating more and more windows of opportunity for the emergence and diffusion of battery electric vehicles. At the same time, because of the shift in people's perception of what an automobile should be able to do, it becomes less and less interesting for car manufacturers to invest in hydrogen fuel cell vehicles. The surface passenger transport system becomes gradually locked in into a customized mobility system in which battery electric vehicles have an important role to play. The outcomes for the 'No public transport scenario' are more or less similar, except for people's perception of an automobile's function. Because of the absence of a high-quality public transport system, the automobile remains to be perceived as an all-purpose mode of transport, suited for short as well as for long distance trips. As a result of this, the battery electric option becomes locked out.

An important variable concerning CO_2 emissions, fossil fuel consumption and congestion, is the share of the automobile in the total amount of trips made. In figures 10 and 11, the share of the car in short and long distance trips for urban and suburban households is presented.

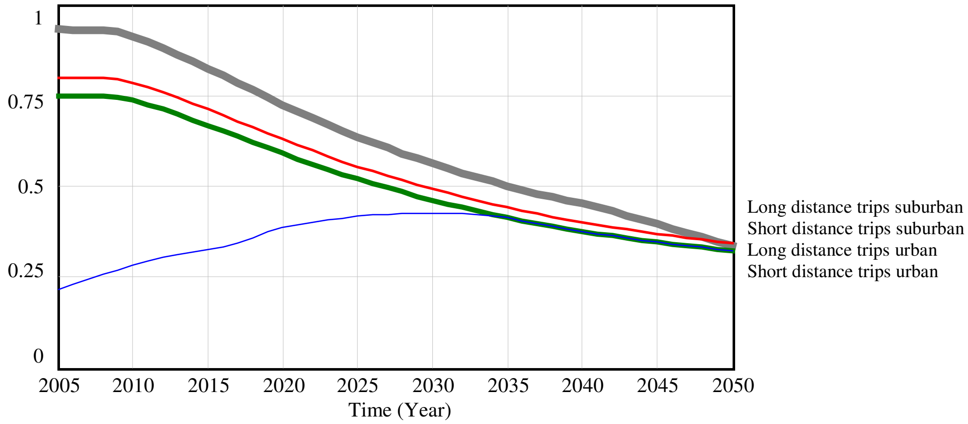

Figure 10: Share of car in short and long distance trips for urban and suburban households (Public transport scenario)

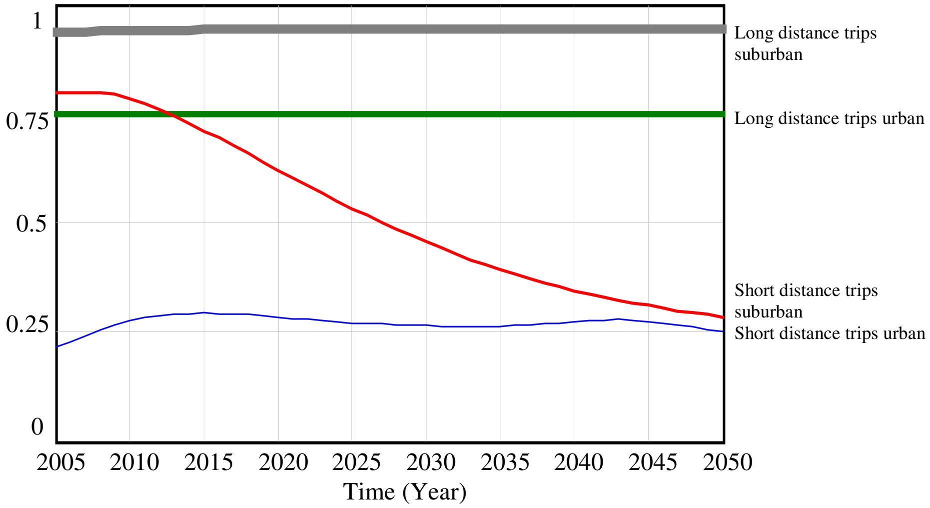

Figure 11: Share of car in short and long distance trips for urban and suburban households (No public transport scenario)

The 'Public transport scenario' shows a marked decrease in the share of the car. As a result of massive investments in the capacity and quality of public transport, more and more people are willing to consider the public transport option. This is the result of a decrease in the average travel time of public transport, an increase in the comfort offered, a rise in the number of people who can benefit from the public transport infrastructure (especially more and more suburban households come in range of a public transport entry-point), a rise in people's environmental consciousness, an increased focus on the enjoyment of biking and walking,… On the other hand, in the 'No public transport scenario', for long distance trips, there are no alternatives for the automobile due to the poor performance of the public transport system. In this climate, the share of the car decreases only very little.

In urban communities, the share of short distance trips in the total amount of trips made, decreases slowly. In suburban communities, the direction of change is opposite, namely a small increase. This is a result of the fact that companies, schools, shops and recreation centres track the location patterns of households. As a result, the mismatch between the location patterns of households and those of companies, schools, shops and recreation centres that was present initially, is gradually decreased, influencing the respective weight of short distance versus long distance trips. These weights along with the share of the automobile in the total amount of trips made, determine the total amount of person-kilometers made by car, by public transport and by bike or foot (Figure 12 and 13).

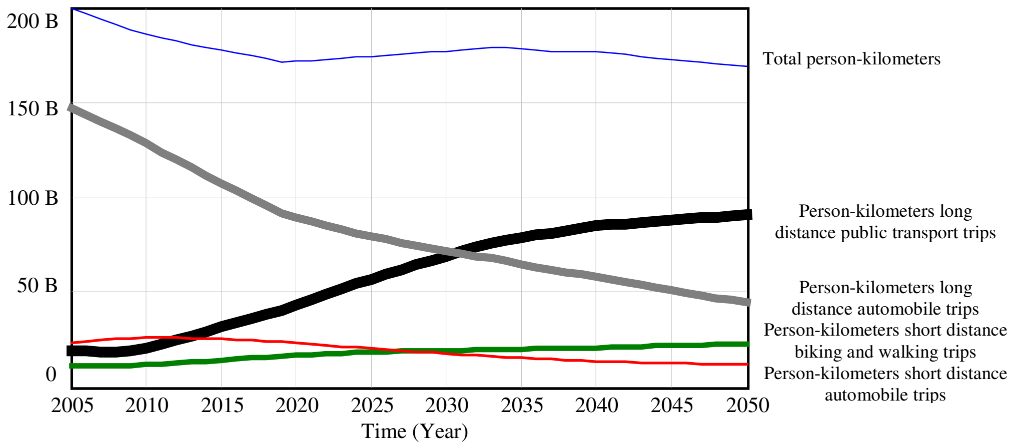

Figure 12: Total person-kilometers and person-kilometers by automobile, public transport and bike and foot (Public transport scenario)

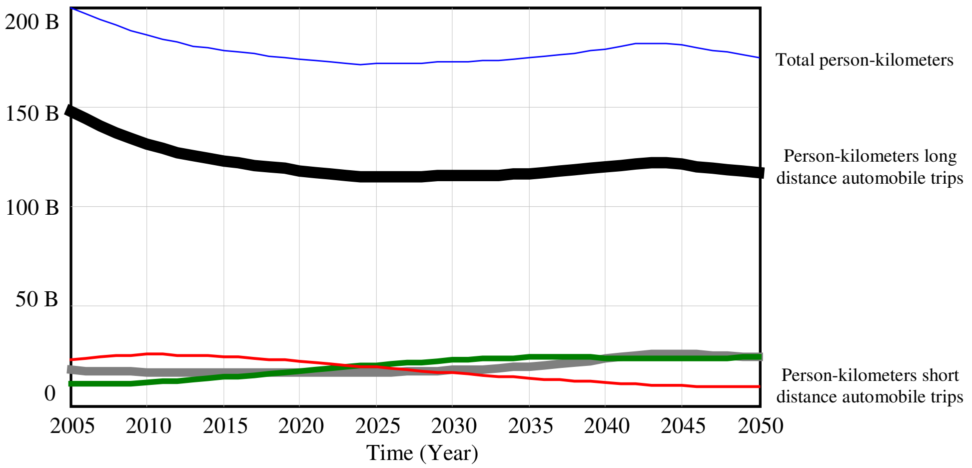

Figure 13: Total person-kilometers and person-kilometers by automobile, public transport and bike and foot (No public transport scenario)

In both scenarios, the total amount of person-kilometers remains more or less the same and is mostly the result of changes in the number of urban people versus the number of suburban people. In the 'Public transport scenario', the share of automobile person-kilometers in the total amount of person-kilometers decreases, while the weight of public transport person-kilometers expands. In the 'No public transport scenario', the automobile keeps dominating in the total amount of person-kilometers.

The result of changes in the share of car, the fraction of short distance trips in the total amount of trips made, the number of urban people versus suburban people, the emergence and diffusion of different vehicle types in the total number of automobiles and improvements in the efficiency of gasoline vehicles on the total amount of CO_2 emissions and the degree of local congestion, is presented in Figure 14.

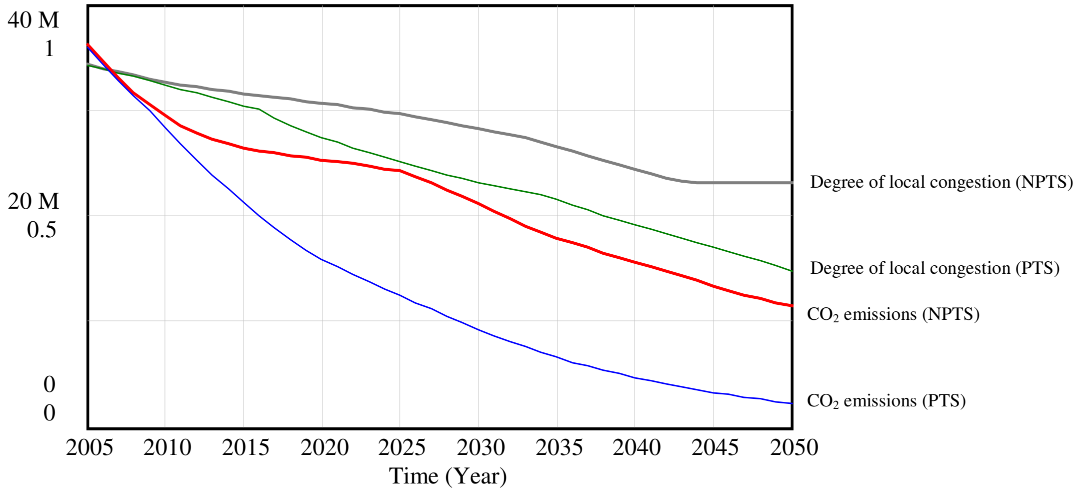

Figure 14: Total CO2 emissions and degree of local congestion for the 'Public transport scenario' (PTS) and for the 'No public transport scenario' (NPTS)

In the 'Public transport scenario', the total amount of CO2 emissions and the degree of local congestion are much lower than in the 'No public transport scenario'.

6. Transition management

The insights concerning socio-technical transitions have also resulted in ideas concerning how such societal transitions should be managed. These ideas have been bundled under the name of 'transition management' (ICIS, 2001; Rotmans, 2003). The goal of this paragraph is to illustrate the major building blocks of transition management, without going in too much detail. In order to achieve this, 2 simulation games will be played. In the first game, policies are implemented whenever the change in selected indicators does not move in the desired direction or with the desired speed. No visions are specified in advance and no societal experiments are organized. Stress is put on system optimizations as long as they result in satisfying outcomes. It is only when further improvements in the state of selected indicators become difficult that more innovative policies are considered. In the second game, a set of stakeholders (e.g. government, consumer organizations, non-governmental organizations, car manufacturers, railway companies, electricity generation and distribution companies, automotive fuel distribution companies, knowledge institutions,…) regularly meet during so-called 'development rounds'. In these development rounds, future societal images and goals are specified, scenarios are worked out, policies are selected, the choice for certain societal experiments is made, outcomes from past experiments are interpreted,… From the beginning, i.e. initial time 2000, this forum is organized, resulting in a much more active management approach, as opposed to the one presented in the first simulation game.

In year 2000, for the first simulation game, no additional policies are implemented: fuel taxes on gasoline and DME remain unchanged, no sales based requirements for hydrogen or methanol vehicles are set, no rebates for hydrogen vehicles are offered, no governmental engagement concerning new and advanced vehicle types is made, investments in public transport remain unchanged, no policies are implemented concerning teleworking or flexible working hours and no requirements concerning the percentage of methanol produced from biomass are specified. During the first 2 decades, the business-as-usual attitude of the government seems to be a good decision for the internal dynamics result in significant improvements in the selected indicators. Both the total amount of CO_2 emissions, the degree of local congestion, the average speed on the motorway and the total variable travel cost versus disposable income (TVTC versus DY) improve. However, after 2020, it becomes more and more clear that further improvements require a more active approach (Figure 15).

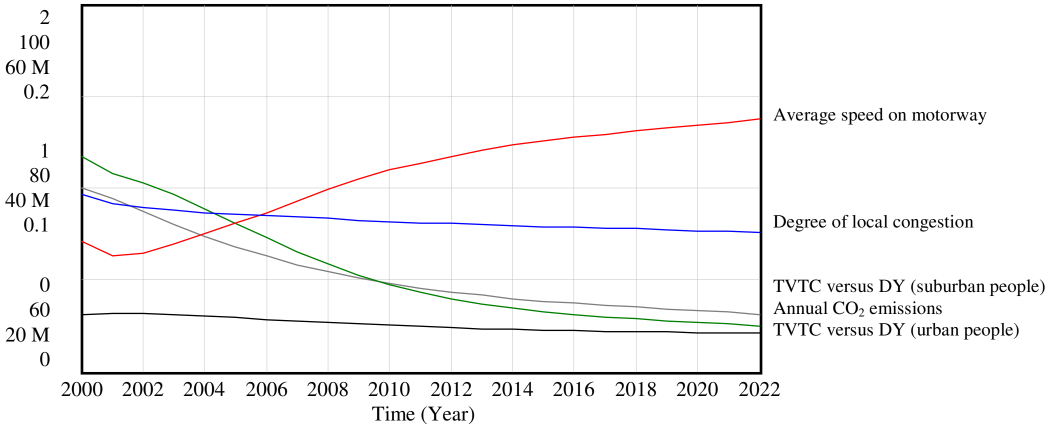

Figure 15: Outcome of selected indicators until year 2022 (Simulation game 1)

In 2022, the government decides to increase the fuel taxes on gasoline by 2% p.a. It also implements some incentives, guidelines and regulations in order to stimulate teleworking and the practice of flexible working hours. The investments in the public transport system are also increased somewhat. In 2026, the government decides to increase the fuel taxes on gasoline further to 5% p.a. (Figure 16).

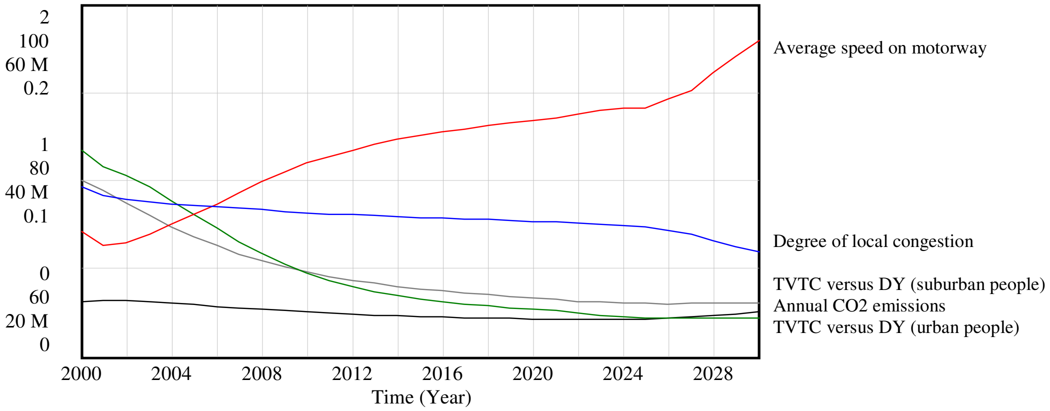

Figure 16: Outcome of selected indicators until year 2030 (Simulation game 1)

The policies work out well. The change in average speed on motorway and degree of local congestion increases. However, the total amount of CO_2 emissions remains more or less unchanged. In order to counter this, the government issues that 5% of new vehicles sold, should run on methanol. In 2034, this requirement is raised to 20% and, additionally, 20% of all methanol consumed, should be produced from biomass (Figure 17).

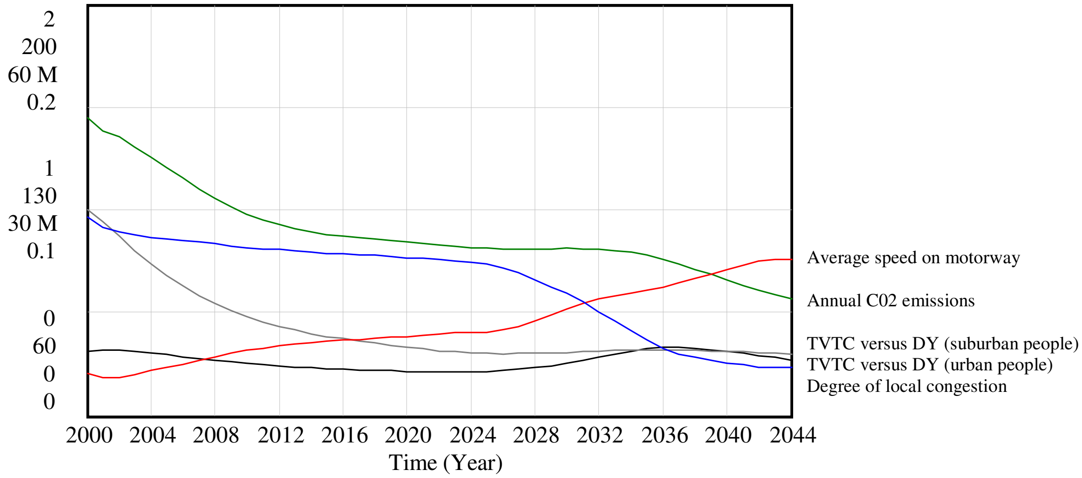

Figure 17: Outcome of selected indicators until year 2044 (Simulation game 1)

Again, the policy works. The decrease in the total amount of CO2 emissions accelerates. However, due to the substitution of gasoline vehicles for methanol vehicles, the land used to grow the cellulosic crops for the production of methanol, quickly expands. In 2044, there is no more land left to grow the cellulosic crops and methanol becomes increasingly produced from natural gas instead of biomass, making the methanol option less and less interesting. In an effort to counter this, the government states that 5% of new vehicles should run on hydrogen. In order to stimulate the emergence and diffusion of hydrogen vehicles, a rebate of 2000 EUR on the purchase price is offered. Not really knowing whether the hydrogen option is feasible, the government decides to diversify its efforts and investments. A large share of total governmental investments also finds its way towards the public transport system. In 2050, the effects of these final governmental policies on the dynamics of the selected indicators have not yet materialized.

In the second simulation game, the government immediately takes the initiative and organizes a first development round in which all important stakeholders within the surface passenger transport system are represented. The goal of the development round is to think collectively about future desired images and to imagine trajectories by which those images could be achieved. Conflict between the different stakeholders is reduced as much as possible. This is obtained through the fact that all stakeholders take each other’s perspective into account. It is decided that the tension on the current surface passenger transport regime should be gradually increased. This is achieved by an increase in the fuel taxes on gasoline and DME by 2% p.a. Not knowing which option is the most promising for the surface passenger transport system, they decide to stimulate several options. For instance, investments in the public transport system are increased and experiments are organized in order to study the potential of certain customized mobility designs. Incentives, guidelines and regulations in order to stimulate the diffusion of teleworking and flexible working hours, are also implemented. The government further states that 5% of new vehicles should run on hydrogen and that 5% should run on methanol, of which 20% should be produced from biomass. Due to the high initial purchase cost of hydrogen vehicles, the government offers a rebate of 2000 EUR for each hydrogen vehicle purchased. In 2004, fuel taxes on gasoline and DME are increased to 5% p.a. (Figure 18).

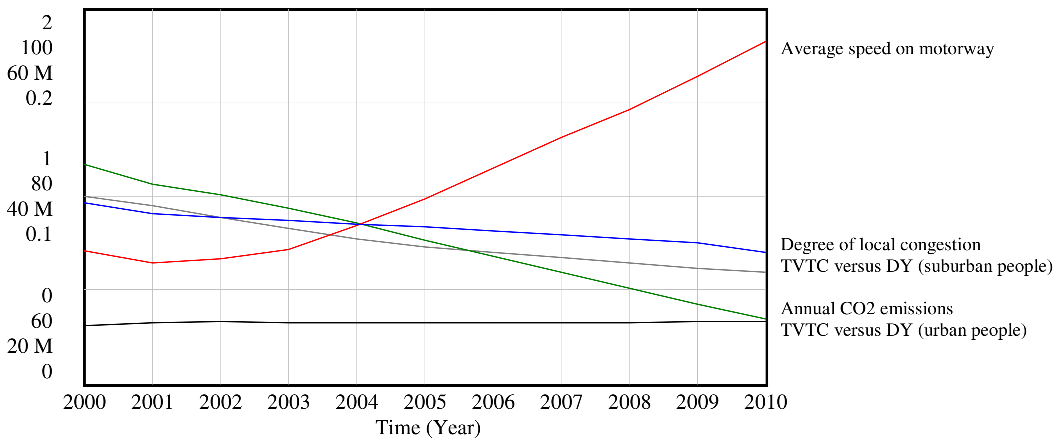

Figure 18: Outcome of selected indicators until year 2010 (Simulation game 2)

During those 10 years, several development rounds have been held, which have evaluated the outcomes of the several societal experiments. It becomes more and more clear that the hydrogen option is the most promising one. In 2010, the different stakeholders decide that 20% of new vehicles should run on hydrogen. The government also makes the necessary promises towards the car manufacturers that hydrogen vehicles will be the vehicle type of the future. In this way, uncertainty and risk is reduced, making it possible for the car manufacturers to make the necessary investments. In 2022, the sales based requirement for hydrogen vehicles is increased to 50%, while the rebate is reduced to 1500 EUR. Finally, in 2030, all new vehicles should run on hydrogen and no rebates are offered anymore (Figure 19).

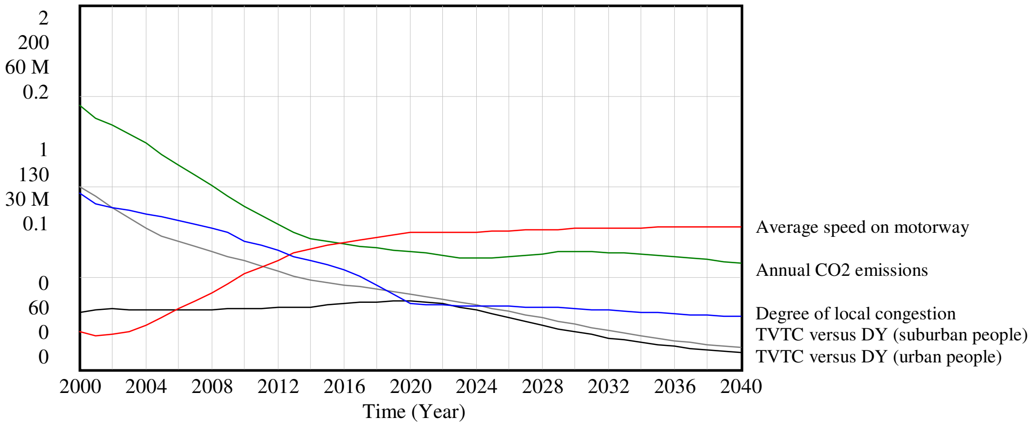

Figure 19: Outcome of selected indicators until year 2040 (Simulation game 2)

Due to the initially higher cost of hydrogen vehicles, the total variable travel cost versus the disposable income decreases less rapidly than in the first simulation game. However, from 2028 onwards, due to the learning effects, the total variable cost versus the disposable income is lower than in the first simulation game and remains so for the rest of the simulation. The annual CO_2 emissions have also decreased much more rapidly in the second simulation game than in the first simulation game. However, from 2030 onwards, it seems that further reductions in annual CO_2 emissions are difficult to achieve. The reason for this is that in 2040 still more than 50% of generated electricity, is coming from fossil fuels (especially natural gas). Given the high energy intensity of the hydrogen production process, no additional improvements in terms of CO_2 emissions are expected. Because of this, the stakeholders decide to improve the public transport system (Figure 20).

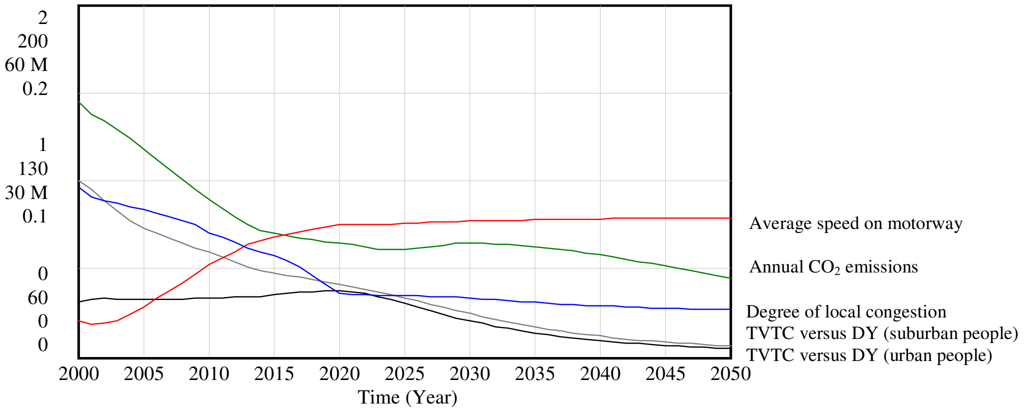

Figure 20: Outcome of selected indicators until year 2050 (Simulation game 2)

These late investments in the public transport system accelerate the decrease in annual CO_2 emissions somewhat. In 2050, the annual amount of CO_2 emissions is a little bit lower than in the first simulation game. However, the cumulative CO_2 emissions over the time horizon are almost 16% lower. The average speed on the motorway is more or less the same, while the degree of local congestion is somewhat higher for the second simulation game. The surface passenger transport system is also somewhat cheaper in the second simulation game.

7. Conclusion and further research

In this paper, the potential added value of system dynamics in the research concerning socio-technical transitions has been explored. The remark has been made that system dynamics requires the theoretical spectacles of the research concerning socio-technical systems in order to make a distinction between important variables and negligible variables. Without it, it would be difficult to justify the eventually obtained causal model. In the system dynamics model which was presented in this paper, the selection of variables has been guided by the theoretical framework developed by Geels (2002). For instance, variables which one would normally not expect in a model concerning the surface passenger transport system (e.g. the perception of what a house should look like, the perception of what the function of an automobile should be, environmental consciousness, governmental engagement concerning new and advanced vehicle technologies,…), were included in the model. Other variables, which normally are incorporated in a quantitative transition model, were also included (e.g. learning curves with their progress ratios). The simulations demonstrated that the model's internal dynamics already result in major improvements in the state of selected indicators, largely the result of changes in fuel consumption, a decrease in the share of the automobile for short distance trips, an increase in the number of urban people versus suburban people,… However, policies are required if one aims for lower levels in the total amount of CO_2 emissions, the degree of local congestion and the total variable travel cost. Potential options in order to achieve more ambitious goals, were illustrated in the paragraph concerning transition management where 2 simulation games were presented. The paper has also demonstrated the potential added value of system dynamics models in any scenario generation process. Quantitative models can introduce analytical rigour and unexpected dynamics in our explorative endeavours of the future.

A second function, which could be fulfilled by system dynamics, concerns offering theoretical insights to the research on socio-technical transitions. For instance, the presented system dynamics model could already be used to study the interactions between landscape pressures (e.g. degree of sub-urbanization, crude oil and gas prices, the fraction of electricity generated from fossil fuels, environmental consciousness,…), internal regime tensions (e.g. oil dependency due to the large share of gasoline vehicles in the total number of vehicles, CO_2 emissions, degree of congestion,…) and niche technologies (e.g. methanol from biomass vehicles, hydrogen vehicles, customized mobility system,…). Further, in this system dynamics model, the share of renewable energy in the total amount of generated electricity was modelled as a trend, based on the WEO2002 (IEA, 2002). However, a second system dynamics model concerning the energy system could be constructed. Consequently, the 2 models, representing the surface passenger transport system and the energy system, could be linked, making it possible to study the co-evolution between the 2 different systems. For instance, in which way are transitions in the domain of the surface passenger transport system coupled to transitions in the energy system? Does the start of a transition in one domain initiates or inhibits the start of a transition in the other domain? Will the final outcome be dependent on which transition starts first? The insights that would result from building system dynamics models of socio-technical transitions would certainly make a valuable contribution towards the theoretical research on socio-technical transitions.

8. References

ANDERSON, P. and TUSHMAN, M. 1990. *Technological discontinuities and dominant designs : A cyclical model of technological change.* Administrative Science Quarterly, Vol 35 : p604-633.

ARTHUR, W.B. 1988. Competing technologies : an overview. Pages 590-607 in *Technical change and economic theory.* Dosi, G., Freeman, C., Nelson, R., Silverberg, G. and Soete, L. (eds). Pinter : London.

BIJKER, W.E., HUGHES, T.P. and PINCH, T.J. (ed). 1987. *The social construction of technological systems : new directions in the sociology and history of technology.* MIT Press : Cambridge.

CALLON, M., LAW, J. and RIP, A. 1986. *Mapping the Dynamics of Science and Technology.* The MacMillan Press Ltd : London.

COUTARD, O. (ed). 1999. *The governance of large technical systems.* Routledge : London.

DAWKINS, R. 1983. Universal Darwinism. Pages 403-425 in *Evolution from Molecules to Men.* Bendall, D.S (ed). Cambridge University Press : Cambridge.

DOLLIMORE, D. 2002. *Universal Darwinism in Nelson and Winter's Evolutionary Theory.* Working Paper.

FREEMAN, C. and SOETE, L. 1997. *The Economics of Industrial Innovation (3rd edition).* The MIT Press : Cambridge.

FREEMAN, C. and LOUCA, F. 2001. *As Time Goes By : From the Industrial Revolutions to the Information Revolution.* Oxford University Press : Oxford.

GEELS, F. 2002. *Understanding the Dynamics of Technological Transitions. A co-evolutionary and socio-technical analysis*, PhD thesis. Twente University Press : Enschede.

GLASKIN, M. 2004. *Hush hour on the highway.* New Scientist, Vol 181, No 2435 : p26-29.

GRÜβLER, A. 1998. *Technology and Global Change.* Cambridge University Press : Cambridge.

HOLLING, C.S., GUNDERSON, L.H. and LUDWIG, D. 2002. In Quest of a Theory of Adaptive Change. Pages 3-22 in *Panarchy. Understanding Transformations in Human and Natural Systems*, GUNDERSON, L.H. and HOLLING, C.S. (eds). Island Press : Washington D.C.

HOOGMA, R. 2000. *Exploiting technological niches : Strategies for experimental introduction of electric vehicle,* PhD thesis. Twente University Press : Enschede.

HOOGMA, R., KEMP, R., SCHOT, J. and TRUFFER, B. 2002. *Experimenting for Sustainable Transport : The approach of Strategic Niche Management.* Spon Press : London.

HUGHES, T.P. 1983. *Networks of power electrification in Western society, 1880-1930.* The John Hopkins University Press : Baltimore and London.

ICIS. 2000a. *Werken met het denkmodel.* ICIS : Maastricht.

ICIS. 2000b. *Cloudy crystal balls. An assessment of recent European and global scenario studies and models.* EEA : Copenhagen.

ICIS. 2000c. *Uncertainty in integrated assessment. A bird's-eye view.* ICIS : Maastricht.

ICIS. 2001. *Transitions and Transition Management. The case for a low emission energy supply.* ICIS : Maastricht.

IEA. 1999. *Automotive Fuels for the Future. The Search for Alternatives*. IEA: Paris.

IEA. 2001. *Saving oil and reducing* CO_2 *emissions in transport. Options and strategies.* IEA: Paris.

IEA. 2002. *World Energy Outlook 2002.* IEA: Paris.

KEMP, R. 1994. *Technology and the Transition to Environmental Sustainability. The Problem of Technological Regime Shifts.* Futures, Vol 26, No 10: p 1023-1046.

KEMP, R., SCHOT, J. and HOOGMA, R. 1998. *Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management.* Technology analysis and strategic management, Vol 10: p 175-196.

KEMP, R. and ROTMANS, J. 2001. *The Management of the Co-Evolution of Technical, Environmental and Social Systems*. Paper presented at 'Towards Environmental Innovation Systems', 27-29 sept 2001, Garmisch-Partenkirchen.

KEMP, R. and ROTMANS, J. 2002*. Transition Management for Sustainable Mobility.* ICIS: Maastricht.

MAYNTZ, R. and HUGHES, T.P. (eds). 1988. *The development of large technical systems.* Campus Verlag: Frankfurt and Westview Press: Boulder.

NELSON, R.R. and WINTER, S.G. 1982. *An Evolutionary Theory of Economic Change.* Bellknap Press: Cambridge.

RIP, A. and KEMP, R. 1998. Technological Change. Pages 327-399 in *Human Choice and Climate Change.* Rayner, S. and Malone, E.L. (eds). Battelle Press: Columbus, Ohio.

ROTMANS, J. and DE VRIES, B. 1997. *Perspectives on Global Change. The TARGETS Approach.* Cambridge University Press: Cambridge.

ROTMANS, J. 2003. *Transitiemanagement: sleutel voor een duurzame samenleving.* Koninklijke Van Gorcum: Assen.

SCHOEMAKER, Theo. 2002. *Samenhang in vervoer- en verkeerssystemen.* Uitgeverij Coutinho : Bussum.

SCHOT, J., HOOGMA, R. and ELZEN, B. 1994. *Strategies for Shifting Technological Systems. The Case of the Netherlands in the Nineteenth Century.* History of Technology, Vol 14: p 173-200.

SENGE, P.M. 1990. *The fifth discipline : the art and practice of the learning organization.* Londen: Century Business.

STERMAN, J.D. 2000. *Business Dynamics : systems thinking and modeling for a complex world.* Boston : Irwin/McGraw-Hill.

SUMMERTON, J. (ed). 1994. *Changing large technical systems.* Westview Press: Boulder

UTTERBACK, J.M. and ABERNATHY, W.J. 1975. *A Dynamic Model of Process and Product Innovation.* OMEGA, Vol 3, No 6: p639-656.

VANCRONENBURG, G. 2004a. *Transitions in the surface passenger transport regime: a prelimenary system dynamics model.* Paper gepresenteerd op Orbel-congres, Jan. 2004, Brussel.

VANCRONENBURG, G. 2004b. *A theoretical synthesis of the insights concerning socio-technical systems and the Panarchy theory: a stock-and-flow model.* Working Paper.

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