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SERIE RESEARCH MEMORANDA

Sustainable Transport and 'Factor Four'

Danielle van Veen-Croot
Peter Nijkamp

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1. Introduction

'Factor ten' and later on *factor four* have become concrete research and policy concepts in current sustainability debates. The idea of *factor four* refers to a doubling of wealth accompanied by a halving of resource and material use. Von Weizsacker, Lovins and Lovins (1997) suggest in their book '*Factor four: doubling wealth, halving resource use*' that this efficiency revolution should succeed within fifty years. Many challenging examples of this concept for the transport sector are mentioned, as for example, video conferences, electronic mail, local products instead of overseas products, high speed trains, and car sharing.

In this paper we discuss whether the concept of *factor four* can be useful in government policy toward attaining a more sustainable transport sector. Therefore, in section 2 we relate the principles of sustainable development to the transport sector. In section 3 we briefly review some underlying trends which explain the present increase in transport. In section 4 we investigate whether the concept of *factor four* can offer practical guidelines for dealing with sustainability in the transport sector. We discuss several strong and weak elements of the concept of *factor four*. In section 5 we combine these findings and construct a strategic framework in which we position the concept of *factor four* in the context of 'sustainable development' and 'industrial transformation' concepts. In this framework four complementary strategies for realising a *factor four* efficiency improvement in the transport sector are distinguished. In section 6 we briefly elaborate on the implications of this conceptualisation for the transport sector. In section 7 we explore several barriers which would prevent us from attaining a *factor four* future for the transport sector. Governments may play an important role in the removal of these barriers. In section 8 we therefore discuss some possible policy strategies in order to attain a *factor four* future for the transport sector. Lastly, in section 9 we draw conclusions and make some recommendations.



2. Sustainable development, transport and *factor four*

Although several authors have attempted to define the concept of sustainable transport, the meaning of the concept of sustainable development for the transport sector is not unambiguous. Although these definitions can help to understand the implications of sustainable development for the transport sector, it remains difficult to define specific requirements for these principles in order to reach sustainability in the transport sector. Therefore it may be better to speak about a *more* sustainable or less environmentally damaging transport system instead of a sustainable transport system.

According to 'the Brundtland report' (WCED, 1987), the general notion of sustainable development is defined as: *'the development that meets the needs of the present without compromising the ability of future generations to meet their needs'*. The meaning of this definition for the transport sector is often explained along the different dimensions of sustainable development.

Gudmundsson and Höjer (1996) have attempted to place transport in the context of sustainable development. In their approach sustainability refers to criteria for long-term stability of the social system, while development is the improvement of the quality of human life, of which consumption for the present generation is an important element. They suggest four principles for sustainable development (See Table 1). S_a refers to the use of renewable and non-renewable resources, the use of ecosystems as waste depository and the preservation of biodiversity. S_b refers to the application of technology embedded in human and man-made capital. Modern society is also dependent on this technology and know-how for its long-term survival. D_a refers to the improvement of quality of life for individuals and D_b is related to the legal, economic, social and physical restrictions individuals face in choosing among different transport options.

Table I. A set of principles for sustainable development

Sustainability	Development
S _n - preserving natural resources for future generations	D ₁ - improving quality of life for individuals
S _h - preserving the option value of human and man-made capital for future generations	D ₂ - ensuring a fair distribution of life-quality

Source: H. Gudmundsson and M. Höjer, 1996

Concerning S_n, transport is an important contributor to the use of natural resources. Transport is almost completely dependent on non-renewable sources, namely oil. Since the early seventies the use of energy for road transport has risen by 103% and for air transport by 93% (European Commission, 1993). Only a few forms of transport use renewable energy for propulsion. The most well-known consequences of the use of ecosystems as waste depository are climate change (emissions of CO₂), ozone layer depletion (CFC) and acidification (NO_x and SO_x-emissions). The emissions of CO₂ caused by the transport sector are nowadays a major environmental concern. Among other things, biodiversity is impaired by transport through the effects of infrastructure which compartmentalise landscapes and form barriers to living organisms by obstructing them from moving within their natural range. The second principle of sustainability, S_h, refers to the components of the transport system which are parts of the human and man-made capital of society. A central idea is that the functioning of the transport system may contribute to the development and enhancement of human knowledge and technological skill in, for example, the discovery and exploitation of new resources and ideas. Thirdly, transport also affects the quality of life in different ways (D₁). Positive effects of transport are access, mobility, more diversity of supply, cheaper goods and services. Negative effects are accidents, noise, impaired air quality, visual intrusion and damage. Finally, the

restrictions individuals have in choosing between different transport options (D,) indicate an unequal physical access to mobility.. Nowadays there are inequalities in physical access to places. services and goods between different groups in the industrialised countries. Especially. in developing countries. anything that limits the provision of basic public transport or makes it more expensive. restrict the access to markets. employment and social facilities for the poor (World Bank. 1996).

Another definition of sustainable transport. as an analytical concept is given in Nijkamp et al. (1977), who define a transport system as sustainable, if it fulfils within a given time horizon the threshold values or standards accepted by governments in international agreements on environmental and climate policies. Here the idea is that a transport system is unsustainable if it can be demonstrated (plausibly argued) that in the longer- run government targets on CO, for example. will not be met.

Recently. Von Weizsäcker, Lovins and Lovins (1997) have published their book '*Factor four: Doubling wealth, halving resource use*'. In this book they describe a more operational approach to achieve a sustainable development, namely by increasing material and energy productivity with a *factor four*. The idea of *factor four* refers to a doubling of wealth accompanied simultaneously by a halving of energy and material use. This essentially means that energy and material productivity should quadruple. The concept of *factor four* can be related to sustainable development because it includes the elements of the principles of sustainable development previously mentioned. The idea of '*halving resource and material use*' refers to preserving the natural resources (S_n). *Doubling wealth* can be seen as a way to improve the quality of life for individuals (D,). In order to reach this efficiency improvement. a large contribution of technological progress is expected, and therefore S_b is important. One underlying notion should be that this revolution is necessary in order to ensure a more equitable distribution of resources between countries in such a way that developing countries are also able to industrialise (D,). In understanding this relation. '*factor four*' can be seen as a innovative and operational way of thinking about sustainability.

3. Trends in mobility and emissions

Transport figures now show a rise in mobility. In Table 2 a few indicators for mobility and environmental pressure are presented.

Table 2. Mobility and environmental indicators in indices for 1993 (1980 = ZOO)

Country	Number of passenger cars	Total passenger car kilometres	Number of goods vehicles	Total kilometres by goods vehicles	CO ₂ emissions by mobile sources
Finland	153	177	170	100	136
France	127	140	198	192	140
Germany ¹	141	143	125	144	134
Greece	228	245	212	189	164
Italy	167	186	195	158	150
Netherlands	127	133	194	200	136
Spain	178	153	204	125	154
Sweden	124	154	166	200	123
Switzerland	140	134	161	160	142
United Kingdom	139	170	150	156	141

¹ only data available for West Germany

Source: OECD Environmental Data Compendium 199.5

Table 2 indicates that the number of passenger cars and goods vehicles has risen drastically, from 1980 till 1993 for the European countries. Moreover, the total kilometres of passenger and goods vehicles increased even more rapidly for most European countries. As a result, the emissions of CO₂ by mobile sources (e.g. motor vehicles) show a sharp rise for the ten European countries, the average rise of CO₂-emissions being 40% from 1980 till 1993.

In Table 3 changes in emissions for the transport sector in the period 1985-1994 for the Netherlands are expressed. According to this table, it can be concluded that large emission reductions are realised for lead, carbon monoxide, benzene and volatile organic matters. It can be marked that the emission of lead is decreased with 90% in less than ten years. This is even more than a *factor four*. This emission reduction is largely achieved by technological improvements.

Table 3. Changes in emissions for the transport sector in the Netherlands for the period 1985-1994

Emissions of	Contribution on total emission in 1985	Change in emissions 1985-1994
lead (Pb)	54%	-90%
carbon monoxide (CO)	61%	-42%
benzene	47%	-39%
volatile organic compounds (VOC)	39%	-33%
sulphur dioxide (SO ₂)	19%	-4%
nitrogen oxide (NO _x)	63%	-2%
particulates	17%	8%
carbon dioxide (CO ₂)	16%	25%
nitrous oxide (N ₂ O)	12%	97%

Source: RJVM, 1995

The emissions of carbon dioxide and nitrous oxide, however, are increased. The increase of CO₂ emissions, responsible for the Greenhouse effect, is a major environmental concern. In this case, by realising a *factor four* improvement, drastic changes in the transport sector are most likely necessary.

Furthermore, the volume of transport will probably further increase. Different trends in western societies will influence mobility patterns. In the 'political' respect, of importance is the ongoing process of political and economic unification of the countries in the European Union (EU). On the one hand, this leads to a more centralised decision-making of important economic, transport and environmental problems; on the other hand, a trend of deregulation and privatisation can be observed: decision-making occurs at a decentralised level. Another important change is the opening of the Iron Curtain. These developments will certainly affect trade and transport needs and patterns (ECMT, 1995; Nijkamp et al., 1994). Additionally, this development leads to competition on a more European and even world-wide scale. This 'economic' trend involves internationalisation and globalisation tendencies which affect traditional competitive structures. Firms are more 'footloose' and move their activities to other parts of the world. The general rise in income per capita also leads to a higher demand for transport facilities, since higher incomes allow consumers to use faster, more expensive modes of transportation. Moreover, tendencies in 'demography and lifestyle' such as individualisation, a leisure based society, a decrease in household size, a higher number of females in the labour force and a continuing rise in commuting distance will lead to an increase in car ownership and car use, an increase in mobility, and more leisure and tourist trips (Nijkamp et al., 1994). According to these political, economical and demographic trends, it seems apparent that transportation volume will rise.

We can conclude that in the past large reductions of emissions responsible for local air pollution have been reached through implementation of technological improvements, but that emissions responsible for global air pollution have risen. According to current mobility patterns, it seems likely that drastic changes are needed in order to reach a *factor four* efficiency improvement for global environmental problems. To bend mobility in a

more sustainable manner. a sustainable transport policy is necessary. Therefore, in the next section we will investigate whether the concept of *factor four* can give some practical guidelines for dealing with sustainability in the transport sector.

4. Strong and weak elements **offactorfour**

As pointed out in the previous sections. *factor four* can be seen as a more operational approach of dealing with sustainability. Furthermore. the concept of *factor four* suggests more specific requirements in order to reach a sustainable development, namely an efficiency improvement of material and energy use with a **factor four**. Von Weizsäcker et al. (1997) propose that in order to reach a sustainable transport system, material and energy productivity must quadruple. Although an efficiency improvement of a **factor four** is rather arbitrary, we suggest that the concept of **factor four** can be seen as an operational 'norm or standard' for sustainable development'.

Although the **factor four** concept is a practical approach to sustainability, there are some shortcomings. The first shortcoming is that the emphasis on the reduction of material and energy use neglects other environmental problems such as visual intrusion, intersection of landscapes and noise annoyance. For the transport sector, these problems are of particular interest. We will argue that in realising a more sustainable transport sector these effects also have to be considered.

The second shortcoming is how this efficiency improvement can be achieved. Von Weizsäcker et al. present many examples of how to raise energy and material productivity, but they do not systematically analyse the methods of realising this increase in productivity. We can make a distinction between two types of efficiency (i) technologies or methods improving material efficiency; and (ii) technologies or methods improving energy efficiency. With regard to the first type of efficiency. Ayres and Ayres (1996)

At first a *factor ten* improvement of resource productivity in the next 30 to 50 years was proposed to attain a sustainable future (Factor 10 Club, Camoules Declaration).

propose four ways of raising the productivity of materials:

1. *dematerialisation*: this refers to a more efficient use of a given material for a given function:
2. *substitution*: this involves the substitution of a scarce or hazardous material by another material:
3. *repair, re-use, remanufacturing and recycling*: for convenience. this way of improving material productivity can simply be called 'recycling'. All of these variants tend to reduce the need for materials. and (indirectly) all of the environmental damage and energy consumption associated with the extraction and processing of materials, including their toxic by-products.
4. *waste mining*: this implies the utilisation of waste flows from (currently) non-renewable resources as alternative sources of other materials needed. This way of improving material productivity simultaneously reduces (i) the environmental damage due to the primary waste stream. (ii) the rate of exhaustion of the second source, and (iii) the environmental damage due to mining the second source.

With respect to the second type of efficiency, we can distinguish two ways of improving energy productivity:

1. *alternative fuel sources*: this refers to the substitution of fossil fuels for alternative fuels such as solar or wind energy;
2. *energy conservation*: this involves measures to improve energy efficiency by implementation of energy conservation technologies.

However. the distinction between energy and material efficiency is not always clear. There could be examples of interdependence between material productivity and energy productivity. On the one hand. dematerialisation and substitution of materials may have a positive effect on energy efficiency. For example. the weight of a passenger car depends on its material composition (iron. steel. plastic, aluminium) and its size. The total weight of a car largely influences the energy efficiency because smaller cars are typically more

fuel efficient than large cars (Eggert. 1990). Therefore. 'substitution of materials' and 'dematerialisation' also influence energy efficiency,. On the other hand. it is unclear in many cases whether recycling improves energy productivity (Ayres and Ayres, 1996). Recycling also entails waste and pollution and it is not always clear whether recycling actually reduces waste and pollution (compared to controlled incineration) or increases them. Indeed. life-cycle analyses have suggested that in some cases, (e.g. packaging materials). incineration with energy recovery is often environmentally preferable to recycling. The interdependence between material productivity and energy productivity makes clear that the benefits of the four ways of improving material productivity are ambiguous. However. case by case. the size and nature of this interdependence largely differs.

The third remark is the heavy emphasis on technological solutions. For realising the increase in material and energy productivity, a large contribution is expected from technological advances. However, a decrease in material and energy use may possibly occur only if these technological opportunities are actually implemented. Findings from Neo-Schumpeterian innovation theory (Dosi et al. 1988) suggest that several barriers to the innovation and diffusion of new technologies do exist. Therefore. we suggest a thorough analysis of these barriers to the implementation of promising technologies within the transport sector.

Fourthly. it is unclear how Von Weizsäcker et al. (1997) are dealing with the volume effects of improving material and energy productivity. Improving material and energy efficiency at the micro-level is not sufficient in order to attain a sustainable economy at the macro-level. The total amount of material and energy use of a region or country would have to be reduced. Volume effects must be taken into account (Herman et al. 1989). For instance. if passenger cars were made more energy efficient, but the total kilometres driven by those cars increased, then the overall effect would be a rise in the use of materials and energy. Therefore. it is more appropriate to examine the use of energy and materials of the total economy. Von Weizsäcker et al. do not systematically consider these

volume effects. To attain a *factor four* efficiency improvement, one also has to take into account the context of production and consumption, socio-economic factors, the spatial structure of regions, lifestyles, etc.

An appropriate concept to deal with these influences on technological development is the concept of 'industrial transformation'. Industrial transformation refers to changing structures of production and consumption, changing modes of regulation of production (social, economic and technological), and changing material and energy transformations (Vellinga et al., 1996). Four elements of transformation can be distinguished: (i) technological transformation, (ii) institutional transformation, (iii) spatial transformation, and (iv) structural transformation. Technological transformation refers to a technological change in production processes and products resulting in a change in materials and energy use, and a subsequent change in the structure of resource use, emissions and waste. Institutional transformation involves changes in government policy, regulations or changes in organisation and management of business enterprises. Spatial transformation is related to changes in the location and scale of production and consumption. Structural transformation results from changing structures of production and consumption.

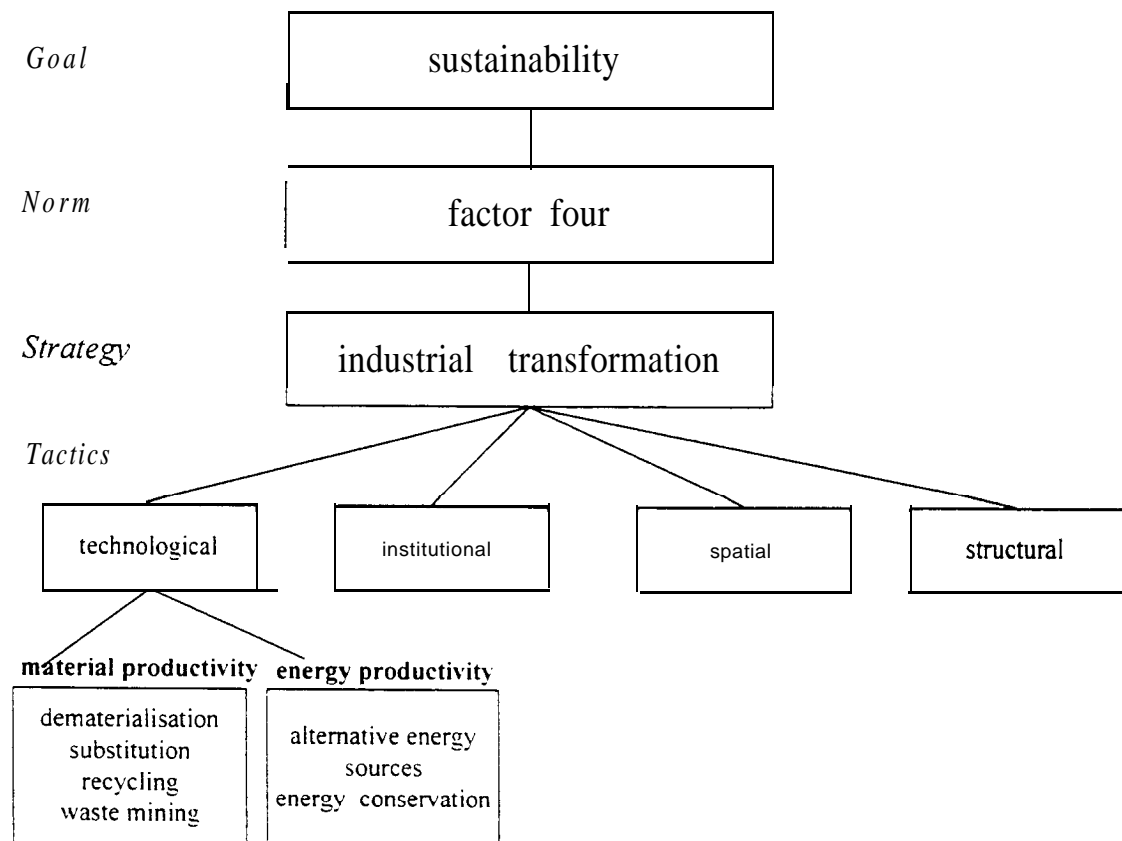
Up until now we have discussed the strong and weak elements of the concept of *factor four*. In the next section we will construct a framework in which we will relate *factor four* systematically to the concepts of 'sustainability' and 'industrial transformation'. This framework can be used for developing strategies for sustainable development in the transport sector.

5. A strategic framework for *factor four*

The primary 'goal' for the direction of progress is a sustainable development. We suggest that *factor four* can be seen as a 'norm' or the standard to reach this goal. *Factor four*

implies the quadrupling of the material and energy productivity. From the preceding section it should be clear that in order to reach an efficiency improvement of materials and energy of an economy with a *factor four*, next to technological opportunities, institutional, spatial and structural changes are necessary as well. We suggest therefore that the concept of industrial transformation can be seen as the ‘strategy’ to reach this *factor four* norm.

Figure 1. A framework for factor four



The four elements of transformation, namely institutional, technological, spatial and structural transformation, can be seen as pathways for realising a *factor four* efficiency improvement. Furthermore, we suggest that the technological opportunities for

improving the material and energy productivity can be seen as ‘tactics’ of reaching a *factor four*. The tactics needed for an institutional, spatial and structural transformation requires more detailed analysis. In Figure 1 the strategic framework is expressed.

For the transport sector this conceptualisation of *factor four* means that a sustainable transport system is marked by an efficiency improvement of energy and material use with a *factor four*. The way to reach this norm is a ‘transformation of the transport sector. Von Weizsäcker et al. (1997) have especially focused attention on particular technological aspects. We argue that institutional, spatial and structural changes also have to be taken into account. In the next section we will further investigate the implications of this conceptualisation for the transport sector.

It should be clear that this strategic framework of *factor four* and sustainability can give key directions for a sustainable transport policy. The institutional, technological, spatial and structural elements of transformation can be seen as complementary strategies in reaching a *factor four* efficiency improvement in the transport sector. However, until now the ‘tactics’ necessary to achieve a technological transformation have been emphasised. We argue that the ‘tactics’ toward achieving institutional, spatial and structural change should be analysed in more detail. In the next section we point out some elements of these tactics. However, we do not claim to make a complete overview of institutional, spatial and structural ‘tactics’. Therefore, further research is necessary.

6. Implications of *factor four* for the transport sector

As mentioned in the previous section, a simultaneous consideration of technological, institutional, spatial and structural changes is needed in order to reach a *factor four* in the transport sector. The implications of this conceptualisation of *factor four* and the transport sector are summarised in Table 4. In Table 4 a distinction has been made between aspects of direct importance for *factor four* in transport, and aspects of indirect importance. The latter refers to the fact that the demand for transport is a derived demand. The demand for

transport depends on developments in the organisation of production and consumption. Therefore, developments in other fields have consequences for the size and nature of transport flows; in for example, the dematerialisation of products, policies on packaging and recycling, globalisation and lifestyle. In this paper we restrict ourselves to the aspects of direct importance.

Table 4. implications of factor four for transport

Industrial transformation	aspects of direct importance of factor four and transport	aspects of indirect importance of factor four and transport
technological transformation	vehicle technology infrastructure technologies alternative fuels	technological development in other fields: • dematerialisation of products • telecommunication / telematics
institutional transformation	transport regulation logistic management of firms	policy and regulation on remaining fields: e.g. legislation on packaging, recycling management in other fields: e.g. internationalisation
spatial transformation	spatial planning location policy	informatisation globalisation shift in trade patterns/ spatial economic structure
structural transformation	modal choice	lifestyle in relation to products relative importance of transport intensive sectors

Technological transformation in the transport sector involves the development of new transportation technologies or the improvement of present technologies, new infrastructure technologies or alternative fuels. Von Weizsacker et al. mentioned different examples of improving energy and material productivity. An example of a new transportation technology is the development of the 'hypercar' which both improves energy and material productivity. At the end of 1991, General Motors introduced a four-passenger carbon-fibre Ultralite concept car with doubled efficiency, high safety and environmental friendliness, great comfort and style. This design could make a car 2-2.5 times more energy efficient than a usual car. The car's redesign requires a shift in material use from steel and other metals to polymer composites (plastics) which will weigh about three times less than today's steel production cars. Von Weizsäcker et al. (1997) suggest that a hypercar could easily weigh two-thirds less than an average US: 521 versus 1,439 kg mass. Another example mentioned by Von Weizsacker et al. (1997) is the Cybertran. Cybertran is a computer-controlled (nodriver), low-occupancy, ultralight rail vehicle. Each car weighs 10,000 lb (one-tenth the weight of conventional trains), including a full compartment of 14 passengers. Cybertran is propelled by electric motors at speeds up to 150 mph on an elevated guideway. Its steel wheels rest on two steel pipes, each welded to a horizontal steel plate. Cybertran is an on-demand transit system, which means that it runs only when a traveller desires it (as with cars and elevators), and it runs as directly as possible to the traveller's destination. The developers of the Cybertran believe that the most useful niche for their innovation is for intercity travel of distances between 100 and 500 miles. Von Weizsacker et al. (1997) suggest that Cybertran's light weight design also makes it more energy-efficient compared to other modes of transport. It requires far less fuel per mile than a conventional car, aeroplane or high-speed train. Other examples of improving material and energy productivity mentioned by Von Weizsäcker et al. (1997) include video-conferences, auctions for second-hand cars, electronic mail, 'local black-currant juice or overseas orange juice', improving the capacity of existing railways, and car-sharing.

Institutional transformation in the transport sector can be divided between government policies and management of firms. The first may mean that government policy is oriented towards promotion of innovation and diffusion of these new transportation technologies. The second element of institutional transformation may induce changes in policy of firms. The two most important possibilities for firms contributions to efficiency improvement of transport are (i) optimisation of transport flows between supplier and buyers and (ii) optimisation of commuter traffic. The first refers to logistic management by which the firm can optimise transport flows. However, logistic management sometimes conflicts with *factor four* goals for transport and could lead to an increase in transport flows. A well-known example is the introduction of the 'Just in time' concept. This logistic concept is directed to a minimisation of the total logistic costs, which often means that storage costs will decrease while transport costs will rise. The increase of transport costs implies a decrease of load factors and a rise in the number of transport trips. Bleijenberg suggests that for a more sustainable transport between firms, load factors must rise. He offers three ways to increase a load factor through logistical changes: (i) by waiting until the load is large enough for a full-capacity trip (less Just in Time), (ii) by combining transport flows, and (iii) by organising a return shipment. For a reduction of commuter traffic, a contribution can be expected from 'tele-working'.

The size of the transport flows largely depends on the spatial structure of production and consumption. therefore spatial transformation is a way to contribute to the attainment of **factorfour** in the transport sector. Spatial transformation refers to changes in location and scale of production and consumption. The informatisation of the economy largely influences the choice of location of firms and individuals (Nijkamp and Ouwersloot, 1997). The impact of this increasing informatisation trend is, however, unclear. On the one hand, the opportunities in tele-working, teleconferencing, etc. would rise; this would imply a decrease in physical transport. On the other hand, a consequence would be that proximity to suppliers, buyers or public transport is of less importance in location choices. This would mean that spatial concepts such as 'compact

city' and 'specialisation and concentration' will decrease in importance and spatial patterns will be characterised by a criss-cross character of mainly traffic and transport relationships. This could mean that the minimum volume of travel demand needed for public transport modes is not reached. Spatial policy of the government can only attempt to influence the locational choices of consumers and producers.

In the case of transport, structural transformation involves the modal choice of consumers and producers. The modal choice is largely dependent on speed, cost and comfort. In passenger and freight transport, speed is a criterion of growing importance. Passengers increasingly prefer the fast transport modes such as road and air transport. Slow transport modes such as public transport and cycling are less popular. However, the latter are the most environmentally friendly modes (Baaijens et al., 1997). The same holds for freight transport. Therefore, nowadays 'slow motion' transport systems are frequently advocated.

In summary, the elements mentioned in Table 4 are pivotal for the necessary efficiency improvement of materials and energy with a *factor* four in the transport sector. Besides the required technological transformation, institutional, spatial and structural transformation are also needed. Government policy fulfils an important role in stimulating these changes.

7. Barriers to achieving a sustainable transport system

Transformation toward a sustainable transport system involves various barriers, several of which can be identified. In Table 5 an overview of possible barriers is given for achieving a 'factor four' efficiency improvement in the transport sector.

Table 5. Overview of barriers to achieving a factor four efficiency improvement in the transport sector

Technological	Institutional		Spatial	Structural
	government	firms		
× path dependency * social context * competition between modes * niche management	* insufficient stimulation of radical transformations * consensus in policy-making * international aspects	× profit seeking criteria * limited innovative strategies * narrow chain management	* teleshopping, teleworking, etc. * globalisation * decreasing importance of 'compact city' and 'urban networks'	* criteria for modal choice * 'slow motion' of transport systems

The first category of barriers are technological barriers. On the basis of findings in the innovation and diffusion literature (see Dosi et al., 1988), and a historical analysis of innovations in the transport sector, Bilderbeek et al. (1993) identified four technological barriers for the implementation of new transport technologies. Technological development is characterised by incremental, cumulative innovations in a specified direction, instead of radical innovations, because of high 'switching costs'. The existence of **path dependancy** means, for example, that the High Speed Train (HST) will be implemented because this technology is compatible with current rail infrastructure. On the contrary, the Maglev train uses a different technology which makes the construction of new infrastructure necessary (Rienstra et al., 1996). As a consequence, a Maglev infrastructure implies higher 'switching costs'; it is therefore less likely that the Maglev-train will be implemented. In addition, new technologies often imply **changes in the social context**: the so-called 'selection environment' (Kemp, 1993). In the case of the introduction of the electric car, changes in the social context are also necessary. This means that the construction of new infrastructure for the distribu-

tion of fuels (electricity) is needed. laws have to be adapted, etc. Demand for the new technology is also required for successful implementation, The introduction of a new transport mode has to *compete with existing transport modes*. Car drivers are especially disinclined to exchange their car for a new transport mode. This implies that new transport modes may attract new mobility instead of large-scale substitution. In addition, the introduction of new transportation systems often takes place in niches. This means that radical innovations are tested in an experimental situation. In these kind of experiments, much attention is given to technical aspects and barriers. However, for successful implementation of new transport systems, attention must be given to social feasibility and barriers.

The second category of barriers are institutional barriers. In the past, government policy has mainly been directed at stimulating incremental changes in transport technologies instead of focusing on a encouragement of radical innovations. This insufficient stimulation or radical innovation is largely connected with the tendency *towards consensus-building* in government policy (Van der Straaten, 1994). This means that (in the Netherlands) major public support in government decisions is important. This essentially mean that stakeholders, such as the car industry and the oil companies, have considerable influence in decision-making processes in transport policy (Rienstra and Nijkamp, 1996). As a consequence, radical innovations are rejected because their impact is likely to confront different stakeholders with huge losses. The same holds for transport policy in an international context. The *increasing importance of international aspects* (European Union) in transport and environmental problems is accompanied by co-ordination problems and 'free-rider' behaviour (Van der Straaten, 1994).

Furthermore. firms fulfil an important role in achieving *factor four* efficiency improvement in the transport sector. Considerable improvements can be made through logistic management. However, several barriers may restrict these improvements. Generally, firms evaluate new technological opportunities with *profit seeking criteria*. 'Factor four' goals, however. are not always compatible with these profit seeking goals, as in the case of the JIT-principle explained in the previous section. Another barrier

may be the *limited innovativeness of environmental strategies* of firms. Industries primarily seem however, to pursue a defensive environmental strategy (KPMG, 1996). For creating a *factor four* improvement in material and energy productivity, an innovative and creative environmental and transport policy at a firm level is of key interest. Such a progressive and innovative strategy is 'chain management', in which emissions and waste of the total production, consumption and waste chain is taken into account. However, '*chain management*' for transport problems in practice takes place on a very *limited* scale (Vellinga et al., 1997).

A third category of barriers is formed by spatial impediments. As argued earlier, the overall result of the impact of telematics and globalisation of the economy on the nature and size of transport *flows* is not clear. The *globalisation of economies* would possibly lead to more transport flows as a result of a geographical dispersion of firms and markets, but it could also possibly mean that markets would be more regional or local. The same holds for telecommunication opportunities, such as teleshopping, teleworking and teleconferencing, which make it possible to grant services without physical transport. However, the question arises what this would mean for the demand for mobility. With the introduction of the computer, many scientists forecasted a 'paperless' future, but the opposite has taken place; the use of paper has risen rapidly. As discussed in the previous section, the impact of telecommunication opportunities could also mean that in location choices the proximity of services would be of less importance, which implies that the *importance of planning concepts such as 'compact city' and 'urban networks' is decreasing*. As a result, transport flows would *deconcentrate*, and give fewer opportunities for public transport (Van Geenhuizen et al., 1995).

Finally, some structural barriers for realising *factor four* in the transport sector are worthy of mention. These barriers refer to consumption patterns and production structure. The first barrier refers to the criteria for modal choice. For consumers, 'speed' is an important criterion in the selection of a transport option (Baaijens et al., 1997). As a result, consumers prefer fast transport modes such as the car and the

aeroplane. instead of the slower transport modes like the train and bus. This tendency toward a ‘quickenning’ of transport systems results in more transport and the use of fast transport modes. In order to accomplish a *factor four* improvement, ‘slow motion’ types of transport systems would be preferable.

8. Policy implications

Up to now we have constructed a framework for dealing with sustainability in the transport sector (see Figure 1). We have also identified several potential barriers to achieving a ***factor four*** improvement in the transport sector. In this section we explain the implications of the constructed framework for a ***factor four*** transport policy. The main question is how government policy can diminish the barriers for implementation of new technologies in the transport sector.

By referring to the presented framework, we have suggested that the main objective of a transport policy must be sustainability. We have argued that a transport system is sustainable when the material and energy productivity is improved with a ***factor four***. The strategy for attaining a sustainable transport system is a transformation of the transport system. The implications of this framework would be that policy must be directed toward the four strategic directions of change.

In their book, Von Weizsäcker et al. (1997) suggest two underlying problems for the given examples of improving material and energy productivity which are not yet being implemented: information and, in many cases, profitability. They argue that most of their examples are profitable, in the sense that the investments will pay off after a certain amount of time. However, they must compete for attracting scarce capital with other investments which are more profitable. Furthermore, they argue that the incentive structures in our societies do not seem conducive to the ‘efficiency revolution’. The incentive structures were developed to encourage fuller use of natural resources in the

service of technological progress instead of more efficient use of resources. Von Weizsäcker et al. introduce the following eight principles for improving material and energy productivity: (1) Best buys first. Find the cheapest ways to do the job, then buy them, (2) Invest in saving resources wherever that is cheaper than extracting them, (3) Make markets in saved resources. (4) Use prices that tell the truth, (5) Foster and monetise competition among all options on a level playing field, (6) Reward the behaviour you want. not its opposite. (7) Tax the undesirable, not the desirable, (8) Scrap inefficient devices prematurely and replace them with efficient ones. According to these principles. Von Weizsäcker et al. (1997) suggest that the answer to unsustainable market activity is market activity in a more sustainable direction.

According to Von Weizsäcker et al. (1997), and by consulting our framework, we suggest that measures for a factor *four* policy in the transport sector must be directed toward four strategic areas. We suggest the following measures:

i *technological measures*

promote research and development of innovative alternative technologies that improve material and energy productivity;
support implementation of new transportation technologies by pilot-project in niches;
more attention on the effect that implementing new transport modes will possibly lead to new mobility instead of substitution of transport modes.

ii *institutional measures*

reflect the full social, economic and environmental costs of each mode of transport as accurately as possible in market prices (e.g. road pricing);
more attention upon improving material and energy productivity in policy making in government policy as well as in policies of firms.

iii *spatial measures (urban planning and transportation planning)*

concentrate urban growth and limit sprawl. This would reduce demand (especially for automobile trips) by moving origins and destinations closer together;

give priority to less polluting, lower impact modes of transportation in the design of transportation systems and urban areas. Pedestrian and bicycle paths should be provided as attractive and safe alternatives to cars:

stimulate research on the implications of the increasing importance of telematics and the trend of globalisation for mobility.

iv structural measures

influence modal choice by maintaining and enhancing the health and viability of public transport.

In order to reach a *factor four* efficiency improvement in the transport sector government policy must be directed to these four areas of change. Implementation of new technologies with the aim of attaining sustainability will only be successful if complementary attention is given to technological, institutional, spatial and structural directions of change. However, we realise that these measures for government policy are not treated exhaustively. But they can serve to instigate further research on government policy and instruments for realising a *factor four* future for the transport sector by means of implementing new transportation technologies.

9. Concluding remarks and suggestions for further research

The idea of *factor four* refers to a doubling of wealth accompanied by a halving of energy and material use. In this paper we have discussed whether the concept of *factor four* can be useful in government policy in attaining a more sustainable transport sector.

We conclude that *factor four* can be useful in government policy but that several important extensions of the concept have to be made. Therefore, we have constructed a framework in which *factor four* is related to sustainability. In this framework the concept of *factor four* can be seen as a goal for a sustainable transport sector. The concept of *factor four* introduced by Von Weizsacker et al. largely emphasises technological solutions, with little attention to volume or indirect effects. We have argued that complementary

attention to technological, institutional, spatial and structural factors is required in order to reach an efficiency improvement for materials and energy in the transport sector with a *factor four*. However, realising this efficiency improvement can possibly mean encountering barriers. Therefore, government policy directed in these four strategic areas is necessary in order to diminish these barriers.

Several implications for further research can be made:

the goal or standard of a *factor four* efficiency improvement of materials and energy is rather arbitrary. Further research can be directed toward the question of whether a *factor four* is sufficient in order to reach sustainability, or if improvements with a factor 10 or 20 have to be made.

we have mentioned several possible barriers which can obstruct a *factor four* future in the transport sector. Further research can clarify which barriers are dominant and which are less important.

attention to the role of several stakeholders in the process of reaching a *factor four* improvement in the transport sector. Several stakeholders such as the government, firms, oil-companies, consumers, etc. can contribute, but also obstruct a factor four future.

research to the specific instruments governments can use in order to attain a factor four future in the transport sector.

development of strategic policy scenario's in which the four strategic directions to attain a factor four efficiency improvement are elaborated.

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