Accelerating a shift from road to rail freight transport in Germany – Three scenarios

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Abstract

As a core pillar of its GHG reduction policy the EC envisages shifting 50% of long distance freight transport to rail and inland navigation by 2050. While technical solutions to mitigate GHG emissions are well researched, non-technical policy paths still need further attention. It is in particular unclear, how assumptions on framework conditions impact the result of policy options in such long term forecasts. In this paper we therefore look at the performance of a set of measures to achieve a given modal shift target in front of alternative baseline developments of the German economy. We chose a 10 percentage point increase of national freight movements on rail to be achieved by 2030. The results found by applying the ASTRA-D system dynamics model indicate that the stronger the economic growth is assumed, the more easy the achievement of targets will be. In this case we run into much more serious capacity problems at the railways, but we can suspect that under more dynamic economic conditions capacity enlargement measures can be implemented more easily.

Keywords: shift from road to rail ; freight transport ; GDP forecasts ; future transport demand ; environmental benefits

Résumé

En tant que pilier fondamental de sa politique de réduction des GES la Commission Européenne souhaite déplacer 50% du transport de marchandises à longue distance vers le rail et la navigation intérieure en 2050. Alors que les solutions techniques pour atténuer les émissions de GES sont bien documentées, les chemins non techniques de la politique à adopter ont encore besoin d'attention complémentaire. Il existe une grande incertitude sur la façon dont les hypothèses d'encadrement du secteur influencent le résultat des options politiques dans les prévisions de long terme. Dans cet article, nous nous intéressons à la performance d'un ensemble de mesures visant à atteindre un objectif de transfert modal dans différentes hypothèses de référence du développement économique en Allemagne. Nous avons choisi une croissance de 10 pour cent d'ici à 2030 des mouvements de marchandises sur rail dans le pays. Les résultats obtenus par l'application du modèle de dynamique de système ASTRA-D indiquent que plus la croissance économique supposée est forte, plus la réalisation des objectifs est facilitée. Dans cette hypothèse, nous rencontreront des problèmes de capacité beaucoup plus graves sur les chemins de fer, mais nous pouvons conjecturer que dans des conditions économiques plus dynamiques des mesures d'accroissement de capacité seront plus faciles à mettre en œuvre.

Mots-clé: transfert de la route vers le rail, le transport de fret, les prévisions de PIB, la demande future des transports; avantages environnementaux

1. Background and structure

The European Commission's Transport White Paper 2011 (EC, 2011) envisages the cut of transport greenhouse gas (GHG) emissions by 60% in 2050 related to 1990 levels, while curbing mobility is not considered an option. The White Paper describes a modal share of rail and inland navigation of 50 % at tonne-kilometres (tkm) in European freight transport in distances above 300 km. In the EC scenarios modal shift to environmentally friendly modes of transport play a key role for meeting the 2050 GHG reduction scenarios. This should then be complemented by technical energy efficiency and GHG mitigation measures, such as renewable energy use, efficient drive trains or aerodynamic truck. A massive shift of goods to rail can make use of both reduction potentials as already today rail emits only 25 % of CO_2 emissions per tkm compared to road haulage, and the sector can profit even more from more renewables in generating traction energy.

Today, modal share in freight transport in Germany is dominated by road haulage, serving roughly 63 % of tonne-kilometres of domestic transport in 2010. The remaining performance is carried by rail (22 %), inland waterways (12 %) and pipelines (3 %). A massive shift to rail thus affects not only the railway sector, its supply industry and its customers, but also the automotive and fuel industries. The impacts of such non-technical measures to impact freight transport mode choice, and especially their overall impact on macroeconomic indicators are not well assessed. The paper will contribute here by applying the ASTRA-D system dynamics model to a series of measures for enhancing rail mode share. The model consists of a full scale macro-economic core based on national input-output tables and feedback loops, allowing the evaluating of wider economic impacts of measures in transport and economic sectors.

Another interesting problem is the impact of varying framework conditions on the benefits and costs of sustainable transport measures. Looking at a current divergent and unstable economic situation in European and worldwide regions this issue is of fundamentally higher interest than during the rather stable planning phases in 1970s, 1980s and partly the 1990s. Thus, this paper investigates the sensitivity of measures to shift from road to rail haulage in different baseline scenarios. Three different scenarios from different GDP forecasts for Germany were selected and freight transport demand was derived from those. Two of these are modelled by the ASTRA-D model, while a third scenario is discussed qualitatively. For each baseline scenario the assessment of three instruments - namely transport pricing, train acceleration, train capacity improvement) and their combination - are tested.

The paper is organised as follows: section 2 goes a bit deeper into the German freight market, before section 3 selects the scenarios and bundles of measures and section 4 describes the methodology of the assessment. Section 5 then presents the results and section 6 briefly discusses their implications for future freight policy in Germany.

2. Shortcomings of freight transport planning in Germany

2.1. Forecasts on economic development and freight performance in Germany

Before and during the financial and economic crises a number of economic forecasts to 2020 and sometimes 2030 have been issued by public institutions in Germany. These mainly differ in the way the impacts of the crises have been considered. The sudden downturn of global and national economic performance indicators is an unprecedented case for standard economic models, which usually cannot be calibrated without intervening into the core model structure. Especially its impact on freight transport with the sudden drop of around 20% in road transport volume has implications on two variables: the value-to-volume-ratio, measuring how many tons are generated by a given gross value added produced in a sector and the average distance per tonne. It is often the latter that caused overall transport volume to rose significantly and with an elasticity of greater than one.

The trends of future transport development are depending on a wide range of possibilities, as each influencing factor may develop in its own manner. Some of the interrelation effects together with a guideline to build consistent scenarios are presented in (Savy and Burnham, 2013). However, it is not exactly clear how a business-as-usual-scenario would look like, as even for GDP forecasts there is no broad consensus on the future paths for Germany. Due to unresolved problems in the financial sector and limited room for manoeuvre for public budget it is likely that the growth expectations before the crisis cannot be met and that the unexpected recovery of the German economy in 2010 was only of temporal nature.

2.2. Development in freight transport in Germany

Between 1960 and 2030 freight transport performance in Germany has grown (and will most probably grow in the future) fourfold since 1960. The term transport performance – measured in tonne-kilometres – describes the product of transported freight in tonnes and the distance covered in kilometres. Growth accelerated markedly in the 1990s and continued in the new millennium (see figure 1).

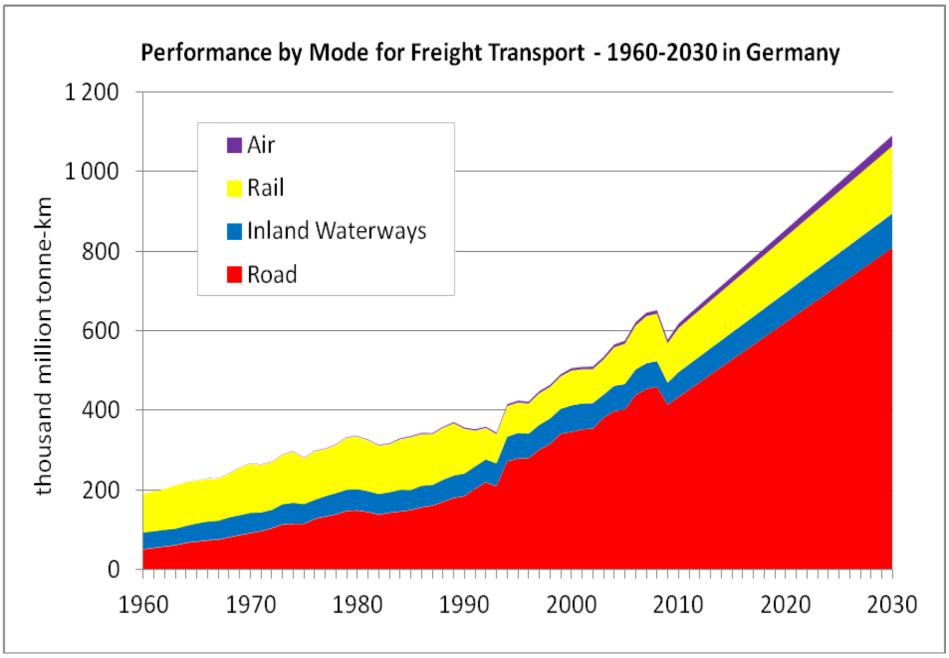

Figure 1: Past and projected freight performance in Germany 1980 to 2030 (Source: UBA (2013): TREMOD 5.25 (Data from 2012 - 2030 is scenario)

The reason for the growth in freight transport performance lies in the increase in transport distance. By contrast, freight transport volume – that is the volume of transported freight in tonnes – remained static (BMVBS, 2012).

The German Federal Environment Agency (Umweltbundesamt, hereafter UBA) expects further high rates of growth in freight transport in the period to 2030 and will be dominated strongly by road transport. Such a development would further increase CO_2-emissions, air pollution, noise nuisance, land-take and water pollution, and would compromise environmental protection requirements.

Further forecasts of freight demand have been issued by official bodies. As for the environmental forecasts, the impacts of the crises have only been considered in some of the projections. The main sources used here are:

- The cross-sector forecast of the Federal Ministry for Transport, Building and Urban Development BMVBS issued in 2010 without consideration of the crises (ITP and BVU, 2007) feeding into the federal investment plan 2015. Being issued before the crises the respective effects have naturally not been considered. The report thus concludes with a freight demand growth rate of 78 % between 2008 and 2025 marking the upper end of available forecasts.
- An alternative forecast was issued by the Federal Government in 2011 when the turn-around in the national energy policy after the tragic incident in Fukushima happened. The objective was to replace all German nuclear power plants by renewable sources by 2022 (Schlesinger et al., 2010 and Schlesinger et al., 2011). The report included the potential long-term impacts of the crises, arriving at a tkm growth rate of 34 %.

- The assessment report of the integrated energy and climate package of the federal government issued in 2008 developed some rough assumptions on freight markets. The forecasts carried out with the ASTRA model results in a growth of tkm from 2010 to 2030 of "only" 35 % (Schade et al., 2009).
- Other forecasts mainly based on the ASTRA system dynamics model of Fraunhofer ISI for Europe and Germany widely framed the above findings with tkm growth figures between 15 % (iTREN 2030, Fiorello et al., 2009) and 47 % (Renewbility II, Zimmer et al., 2012)

The results of the forecasts are presented in table 1.

Table 1: Comparison of freight demand forecasts for Germany 2010 - 2030

Source	Bn. tkm 2008	Bn. tkm 2030	Growth 2008-2030	Considering the crisis?
TREMOD Version 5.3	640	1.065	66 %	No
BM VBS (2007)	604	1.074	78 %	No
Schlesinger et al. (2010)	654	876	34 %	Yes
Zimmer et al. (2012): ASTRA-D	590	988	60 %	Yes
Schade et al. (2008): ASTRA	604	817	35 %*	Yes
Fiorello et al. (2009): ASTRA	609	702	15 %	Yes

* Growth rate interpolated for 2008 – 2030 (Source: Doll et al., 2012)

2.3. Changes in freight transport required to protect the environment

Mobility in Germany has to meet the demands of sustainable development: the need for social contacts and communication should be fulfilled, and access to goods and services ensured. At the same time, this should neither endanger human health nor impair the efficiency and viability of the environment and nature. A pre-condition is that Germany achieves its objectives for climate protection, air pollution control, noise control, nature conservation and landscape preservation as well as for the quality of the living environment and the protection of resources.

The Federal Government is aiming to reduce greenhouse gas emissions by 40 % by 2020 compared to 1990. According to findings by the Federal Environment Agency (UBA), the transport sector must contribute to this reduction by cutting 40 million tonnes of CO_2 compared to 2005 (direct emissions) (UBA, 2009).
In addition, the Federal Government has set the following objectives in its sustainability strategy:

- A 5 % reduction in freight transport intensity by 2020 compared to the base year 1990 (status in 2011: +12,6 %, BMVBS (2012) and DeStatis (2013)
- A rise in rail's share of freight transport to 25 % by 2015 (status in average 1998 to 2012: ca. 17 %, Doll et al., 2012)
- A reduction of land-take to 30 hectares per day by 2020 (2008 to 2011 average: 81 hectares per day (DeStatis, 2013)

Also, in many German inner cities, the EU-wide limit values for fine particulate matter and nitrogen dioxide are being clearly exceeded. Moreover, around 13 million people are exposed to noise levels that give rise to noise-related health risks and sleep disorders (UBA, 2009). A freight train produces less CO_2 and air pollutants per tonne-kilometre than a heavy goods vehicle. Shifting freight transport from road to rail is therefore sensible, provided noise emissions from rail freight transport are reduced (UBA, 2009).

3. Scenario selection for the current evaluation

3.1. Three base scenarios

The following base scenarios were used to evaluate the policy impacts of measures aiming at increasing the railway share by 10 percentage points in 2030:
The first base run was based on a project funded by the German Federal Environment Agency named "Renewbility II" (Zimmer et al., 2012). Here, a rather low annual GDP growth rate for Germany was assumed: 1.1% per year, beginning with 2012, based on the above-mentioned study of the Federal Government (Schlesinger et al., 2010). Freight transport demand in this scenario was rather high, as it was based on traffic projection of the German Federal Ministry of Transport, Building and Urban Development (ITP and BVU, 2007), but adjusted for new socio-economic parameters. Thus, truck transport demand in 2020 is 422 bn. tkm, in 2030 713 bn. tkm and overall freight transport demand rises 67% from 2005 to 2030. Rail transport demand in 2020 is 112 bn. tkm and 199 bn. tkm in 2030.

The second base run was based on a paper prepared for the WCTR 2013 (Hartwig et al., 2013). For this, a higher GDP growth rate was assumed, based upon the forecast of the OECD economic outlook (OECD, 2012). In this, an average annual growth rate of 1.6% for the years 2012-2017 was predicted and 1.1% for the years 2018-2030. Freight transport demand was projected lower in this run and was based upon a projection and national programmes 2013 of the Federal Government (Bundesregierung, 2013) with the same economic development assumed. In this scenario, truck transport demand is projected 457 bn. tkm in 2020 and 590 bn. tkm in 2030 and rail transport demand is 122 bn. tkm in 2020 and 159 bn. tkm in 2030. Overall freight transport demand rises 51% from 2005 to 2030.

Both freight transport demand scenarios were modelled with ASTRA-D, a combined socio-economic-transport model (see next section). These runs are somewhere in between a globalisation scenario or a business-as-usual scenario (Savy and Burnham, 2013).

The third scenario is a zero growth scenario. This will be treated qualitatively for the following reasons: firstly, there is currently no consistent modelling approach available for any zero growth scenario; standard approaches, including the ASTRA-D model setting, usually do not work. Secondly, the uncertainties for economic indicators like sectoral gross value added or employment are far higher than for scenarios where the growth rate offsets at least some of the productivity gains. Thirdly, the overall economic effects are probably higher comparing the base scenarios than evaluating the effects of transport policies in such a scenario. This scenario is characterised not only by a stagnant economy, but also a shrinking in overall transport volume, as productivity will improve further. Here, a substantial shift is made also to non-motorized vehicles or a combination of freight and passenger transport, such that there are assignment difficulties.

3.2. The policy case: increasing railway share by 10 percentage points

Freight trains in average produce four times less greenhouse gas (GHG) emissions per ton-kilometre (tkm) than HDVs and emit – depending on traction – considerably less air pollutants (compare Table 2). Shifting freight transport from road to rail is therefore sensible, provided noise emissions from rail freight transport are reduced.

Table 2: Specific emissions in g/tkm for road and train freight transport in 2010

	GHG*	NOx	PM
HDV**	97.5	0.49	0.0079
Train	23.4	0.07	0.0012

* Greenhouse gases (GHG): carbon dioxide (CO_2), methane (CH_4) and di-nitrous oxide (N_20), in CO_2-equ.
** HDV from 3.5 tonnes (inclusive trailer truck)
Data source: TREMOD Version 5.25 (2011)

In 2009, UBA published its "strategy for sustainable freight transport". A modal share of rail transport of 17.8% in 2008 to 25.9% in 2025 was envisaged. A rise of 80% in rail freight transport would be a pre-condition. This volume in rail freight transport is ambitious but possible (UBA, 2010). While the 2008 target of Federal Government - rise in rail's share of freight transport to 25 % by 2015 – is no longer realistic to achieve, UBA has published a new realistic target in 2013: increasing the railway share in national freight transport by 10 percentage points (17% to 27%) (Doll et al., 2012) between 2010 and 2030. From the railway's perspective, this would correspond to an increase of almost 80% compared to a reference scenario until 2030. This policy case is assessed in this paper against the three baseline assumptions described above.

3.3. Instruments for the achievements of the policy case

For the achievement of the ambitious modal shift targets a set of policy instruments have to be applied. Out of the various options which can enhance rail share we picked out (1) pricing instruments, (2) investments in railway infrastructures and (3) market regulation. For the two baseline scenarios which are modelled quantitatively with the ASTRA-D model we assume the instrument sets and their parameters to remain unchanged. Table 3 gives an overview of the instruments, while their implementation in the model is described in the next section.

Table 3: Measures and instruments in freight transport

Instrument	Instrument design	Costs
Instrument 1: Pricing	HDV* (LDV)* road tolls 15 (0) €-Ct./km 2015 to 30 (9) €-Ct./km in 2025	€600 mill. p.a. for toll system expansion to HDVs <12t and federal trunk roads (=10 % of current costs)
Instrument 2: Investments	Closure of major railway bottlenecks, in particular in port hinterland and trans-Alpine traffic	€300 mill. p.a. for rail tracks and €600 mill. p.a. for station and terminal infrastructure
Instrument 3: Regulation	Increase train length from 740 m to 1.5 km on main rain freight corridors	€450 mill. p.a. for overtaking tracks and station / terminal adaptation.

* HDV (heavy-duty vehicles): > 12t; LDV (light-duty vehicles): ≤ 12t

Source: Doll et al. (2012)

The implementation and operation cost values were selected based on stakeholder consultations. It is assumed that the instruments are financed by federal government spending. On the other hand, the public sector receives the net HDV toll revenues and saves money through lower road wear and tear. Finally, the mix of the three instruments was set by the project team based on the instruments' effectiveness to achieve the 10 percent modal shift target by 2030.

4. Methodology

4.1. The model ASTRA-D

The ASTRA-D model is used to assess the macro-economic effects of the selected measures. This model is a further development for Germany of the European ASTRA model ("Assessment of Transport Strategies"), which was constructed within the framework of several research projects assessing transport strategies (Schade, 2005). The degree of analysis has been substantially refined for the German version; the individual sectors have been separated based on the German Federal Statistics Office's 2003 classification of economic activities. The period of calibration covers the years 1995 to 2012.

The use of input-output tables enables the integration of "bottom-up" impulses to assess policy measures by sector including any possible second-round effects. ASTRA-D does not limit itself to one branch of macro-economic theory, but connects elements such as the neo-classical production function for modelling economic growth with Keynesian demand impulses. An important characteristic is the possibility to allow imbalances to occur between demand and supply. Therefore ASTRA-D is not an optimization model.

On a very simplified level, figure 2 illustrates how the main macro-economic contexts have been modelled. It is not possible to list all equations of this model here; however, all relationships in figure 2 are modelled quantitatively and can be found together with a more detailed discussion in Schade (2005) or Krail (2009). ASTRA-D enables a gradual scaling of policy measures over time by calculating steps each year. This makes it possible to design policy instruments flexibly with regard to their intensity and to pinpoint any differences attributable to different investment paths for example.

The instruments implemented in the model were a rise of truck tolls for HDV from currently 15.5€/100vkm to 30€/100vkm and an introduction of truck tolls for LDV of 9€/100vkm. Furthermore, an improvement of the average rail speed of 10% was assumed as well as an improvement of load factors of 8-20%, dependent on the goods category.

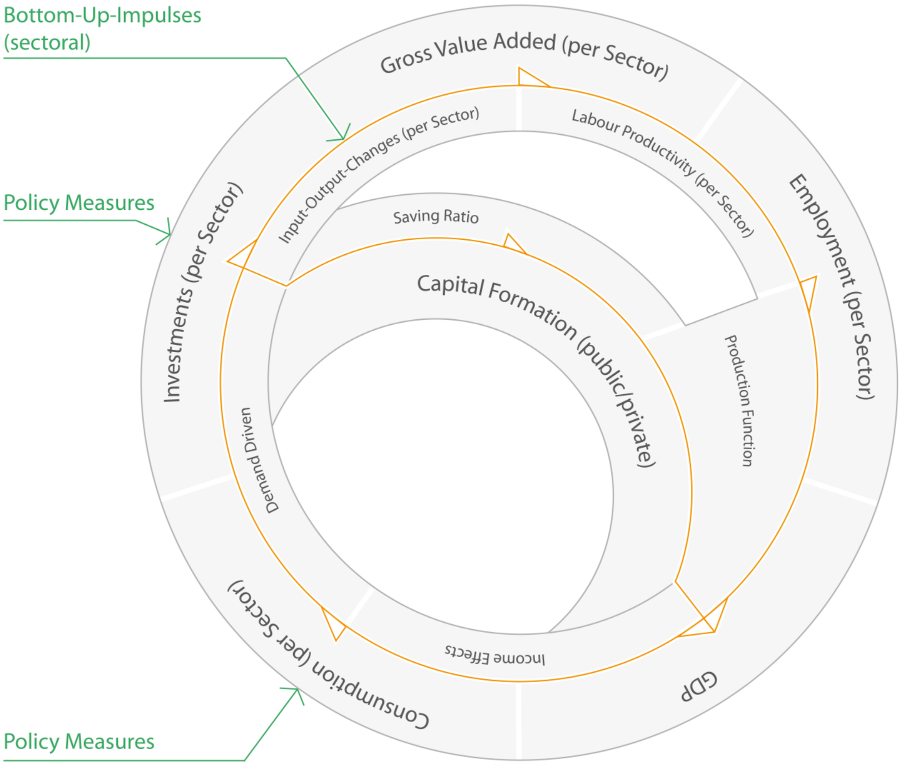

Figure 2: Macro-economic modelling logic in ASTRA-D (Source: Hartwig et al., 2012)

4.2. Data inputs for the policy runs

All instruments were introduced in 2015 and gradually faded in until 2025 in order to allow enfolding their full impacts by the time horizon 2030. The first instruments considered are charges for heavy duty vehicles (HDVs) on all roads. They influences the absolute amount of general costs in road haulage, and the investments in the transport sector for establishing and running the charging system and, as a second round effect, cost and revenue changes in the vehicle manufacturing sector reacting on changes in mode share. The generalised costs influence the logit-function, used to calculate modal share, as shown in equation 1:

$$v_i = \frac{e^{-\beta c_i + \mu_i}}{\sum_{j=1}^{N} e^{-\beta c_j + \mu_j}} \qquad (1)$$

where N is the number of freight modes (five). Generalised costs are formed on a vehicle-kilometre basis differentiated by goods category, origin-destination-relation and freight mode.

5. Results

Both modelled scenarios predict no decoupling tendency between the total volume of freight transport measured in tkm and economic development represented by GDP. The elasticity is 2.82 for the NTM-study and 2.33 for the WCTR-study. They both differ also in their trade share (imports plus exports plus transit traffic): for NTM this share is 53.8% and for WCTR it is 67.6%. Overall transport demand is much stronger in the NTM-study, which has some consequences for the target achievement. The transport indicators of the two base runs are summarised in table 4.

Table 4: Effect of transport policies on transport indicators

Transport indicator			2020	2030
Transport demand	Road	Renewbility II/NTM	422	713
In tkm		WCTR	457	590
	Rail	Renewbility II/NTM	112	199
		WCTR	122	159
Modal share base run				
% of tkm	NTM	Road	70.4 %	72.2 %
		Rail	18.6 %	20.1 %
	WCTR	Road	71.2 %	72.3 %
		Rail	18.3 %	18.8 %
Modal share changes				
% of tkm	NTM	Road	-3.6 %	-12.1 %
		Rail	3.4 %	11.9 %
	WCTR	Road	-4.6 %	-9.5 %
		Rail	4.9 %	10.1 %

Table 4 gives also an overview of the modal share changes, achieved by the implementation of the policy measures. One can see that it is easier to obtain the envisaged modal shift if the transport volume rises significantly.

Table 5: Effect of transport policies on economic indicators

Economic indicator		2020	2030
Infrastructure cost savings road	Renewbility II/NTM	230	1,102
in Mio. $€_{2010}$	WCTR	228	573
Additional capacity costs rail	Renewbility II/NTM	596	3,097
in Mio. $€_{2010}$	WCTR	670	1,914
Overall toll charge income	Renewbility II/NTM	1,436	5,045
in Mio. $€_{2010}$	WCTR	1,087	3,198
GDP	Renewbility II/NTM	0.023 %	0.019 %
change compared to base run	WCTR	0.068 %	0.235 %
Employment	Renewbility II/NTM	0.041 %	-0.077 %
change compared to base run	WCTR	0.112 %	0.225 %
Investments	Renewbility II/NTM	0.162 %	- 0.129 %
change compared to base run	WCTR	0.538 %	1.188 %
Consumption	Renewbility II/NTM	0.053 %	0.039 %
change compared to base run	WCTR	0.043 %	0.294 %

In table 5 the economic effects are summarised: they show that policies in a scenario with lower overall transport volume has higher effects on the rest of the economy. That is, infrastructural measures are generally higher if transport volume rises stronger, so additional effects from policy measures do not impinge as strong as if infrastructural investments are generally lower. On the other hand, additional rail capacity becomes much more urgent, not only in the base run with higher transport volume but also in the policy scenario. One reason for this is that rail transport cannot serve origin-destination relationships as direct as road transport and with rail transport there is a need of distributing the freight to its final destination.

For a zero growth scenario the reduction of overall transport volume would render the need for additional capacity obsolete. It is more probable for such a scenario that the shift from road to other modes happens without policy engagement. However, this scenario would mean a new model of civilization (Savy and Burnham, 2013), and even the implications for the economy as a whole would be enormous and are still awaiting to be analysed, not to mention the effects on transportation.

6. Discussion

In this paper we have analysed the impact of different baseline assumptions on the feasibility and the economic consequences of a given set of policy instruments to achieve a 10 percentage point shift in rail freight transport in Germany by 2030. Without interventions the ASTRA-D model predicts rail market share to be at 20 % in the Renewbility-II, and 19 % in the WCTR scenario related to tkm. Given that in the past two decades rail freight market share has just about stabilised in Germany after a steep decline in the early 1990s, achieving the policy goal constitutes a huge task.

The comparison of the two different base scenarios shows that the more transport volumes grow, the more influence policy seems to have on the market share of transport modes. We can interpret this in a way that the better financial conditions and market dynamics under growth scenarios provide a greater variety of leverage points for policy and the transport sector to take proactive measures to design market structures. On the contrary, under a low- or even zero growth market scenario companies rather are reluctant to test out any new logistics patterns with an uncertain outcome. In this case, lower tax income limits the spending opportunities of the public sector. This finding is far from being surprising.

On the other hand policy measures have a higher impact on the rest of the economy if transport volumes are lower, even if overall economic growth is more optimistic. This means that sensitivity analyses of transport studies should pay more attention on the growth path of freight transport volume and less on the overall economic growth path and take into account that 1.) higher transport volumes may leave more room for policy measures and 2.) lower transport volumes may overstate the effects on the remainder of the economy.

In German federal transport investments planning, as probably in most other national infrastructure planning processes, sensitivity assumptions on the baseline scenarios are not foreseen. The outcomes of this paper, however, strongly suggest that there are included. This is in particular relevant as looking 20 to 30 years ahead in time now is way more unsecure than it was in the 1970s and 1980s. Good investment planning then would select those “low regret measures”, which lead to about the desired policy objectives under several conceivable future economic and transport market developments.

References

BMVBS (2012): Verkehr in Zahlen 2012/2013 (Transport in Figures 2012/2013). Federal Ministry of Transport, Building and Urlan Development (BMVBS), Berlin. Edited by: German Institute for Econonic Research (DIW), Berlin.

Bundesregierung (Federal Government) [ed.] (2008): Fortschrittsbericht zur nationalen Nachhaltigkeitsstrategie 2008 (progress reporet to the national sustainability strategy 2008). p. 81/82. Berlin.

Bundesregierung (Federal Government) [ed.] (2013): Projektionsbericht der Bundesregierung 2013. Berlin

DeStatis (2013): Siedlungs- und Verkehrsfläche wächst täglich um 81 Hektar (Settlement and transport area grows by 81 ha.per day). Federal Office for Statistics (DeStatis), Wiesbaden. URL: https://www.destatis.de/DE/PresseService/Presse/Pressemitteilungen/2013/01/PD13_023_331.html.

Doll, C., Maibach, M., Lambrecht, U., Hartwig, J, Senger, F., et al. (2012): Economic aspects of non-technical measures to reduce traffic emissions. Study on behalf of the Federal Environment Agency (UBA). Fraunhofer-ISI, INFRAS, IFEU. Karlsruhe.

EC (2011): White Paper Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. European Commission COM (2011) 144 final. Brussels.

Fiorello D., De Stasio C., Köhler J., Kraft M., Newton S., Purwanto J., Schade B., Schade W.,Szimba E. (2009): The iTREN-2030 reference scenario until 2030. Deliverable 4 von iTREN-2030 (Integrated transport and energy baseline until 2030). Mailand, Italien, Oktober 2009.

Hartwig, J., Schade, W., Sievers, L. (2012): Kurzübersicht des Modells ASTRA-D. Working Papers Sustainability and Innovation S 10/2012. Fraunhofer ISI, Karlsruhe.

Hartwig, J., Senger, F., Doll, C. (2013): Non-technical measures for influencing a shift in freight modal share in Germany in 2030. Proceedings of World Conference on Transport Research, Rio de Janeiro, forthcoming.

ITP and BVU (2007): Prognose der deutschlandweiten Verkehrsverflechtungen 2025 (Forecast of Germany-wide transport flows 2025). Intraplan (ITP, Munich) and Beratergruppe Verkehr und Umwelt (BVU, Freiburg) on behalf of the Federal Ministry for Transport, Building and Urban Develpment (BMVBS, Berlin). Summary report.

Krail, M. (2009): System-based analysis of income distribution impacts on mobility behaviour; Baden-Baden: Nomos-Verlag.

OECD (2012). Medium and long-term scenarios for global growth and imbalances. OECD Economic Outlook (Vol. 2012, pp. 191-224).

Savy, M. and Burnham, J. (2013): Freight transport and the modern economy. Routledge studies in the modern world economy No. 112, London.

Schade W. (2005): Strategic Sustainability Analysis: Concept and application for the assessment of European Transport Policy. Dissertation, NOMOS-Verlag, Baden-Baden.

Schade, W., Lüllman, A., Beckmann, R. and Köhler, J. (2009): IEKP Makro - Gesamtwirtschaftliche Wirkungen von Energieeffizienzmaßnahmen in den Bereichen Gebäude, Unternehmen und Verkehr Modul (Economic Impacts of Energy Efficiency Measures in the Areas Real Estate, Companies and Transport). Fraunhofer ISI on hehalf of the Federal Environment Agency (UBA). Karlsruhe.

Schlesinger, M., P. Hofer, A. Kemmler A. Kirchner, S. Strassburg, D. Lindenberger, M. Fürsch, S. Nagl, M. Paulus, J. Richter, J. Trüby, Ch. Lutz, O. Khoroshun, U. Lehr, I. Thobe (2010): Energieszenarien für ein Energiekonzept der Bundesregierung (Energy Scenarios for an Energy Concept of the Federal Government). Study on behalf of the Federal Ministry for Economic Affairs and Technology (BMWi), Berlin.

Schlesinger, M., D. Lindenberger, Ch. Lutz (2011): Energieszenarien 2011 (Energy Scenarios 2011). Study on behalf of the Federal Ministry for Economic Affairs and Technology (BMWi), Berlin.

UBA (2009): Strategy for Sustainable Freight Transport. Federal Environment Agency (UBA). Dessau.

UBA (2010): Schienennetzstudie 2025/2030 (rail network study 2025/2030). Federal Environment Agency (UBA), Dessau.

Zimmer, W., Hacker, F., Rausch, L., Fritsche, U., Cyganski, R., Justen, A., Knitschky, G., Lischke, A., Mehlin, M., Müller, S., Schade, W., Hartwig, J., Sievers, L. (2012): Renewbility II. Szenario für einen anspruchsvollen Klimaschutzbeitrag des Verkehrs. Endbericht an das Umweltbundesamt, Fkz. 37 10 96 175, Berlin.