ANALYSIS OF EMITTED POLLUTANTS OF ROAD VEHICLE PRODUCTION VERSUS EMISSIONS CAUSED BY VEHICLE OPERATION

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Abstract

In recent years the role of transport as a major contributor to environmental problems has been discussed vividly. However, most studies in this field focus on the transport activities rather than on the production of vehicles and other intermediate inputs. This paper specifically deals with the emissions generated by the motor vehicle production and compares the results with the emissions caused by the vehicles' operation.

In order to identify the CO_2- and NOx-emissions that can be attributed to the final demand of road vehicles an input-output analysis is performed. Based on the emission coefficients and the Leontief inverse direct and indirect emission production that comes along with the satisfaction of the final demand can be calculated.

The input-output analysis is followed by a consideration of the emissions assigned to the operation over the vehicles' whole lifespan. Results derive from an integrated transport assessment model, which has been applied for several EU-projects.

Both parts deliver results for three types of road vehicles and for 1991 and 1998. Thus the development of the production-related versus operation-related emissions can be analyzed over time.

Keywords: Emissions; Input-output; Vehicle production
Topic area: B7 Input-Output System and Transportation

1. Introduction and theoretical background

Though the relevance of transport as driving force has been scrutinized closely in the last decade, research work clearly focused on the transport activities rather than on the direct and indirect emissions related to the road vehicle production. The paper at hand gives a first overview of the emissions emitted within the vehicle production and establishes a relationship with the pollution initiated by the vehicles' operation. The study, which accounts for carbon dioxide and nitrogen oxides, focuses on the German situation of 1991 and 1998. It is subdivided into two parts:

- analysis of emissions resulting from the annual vehicle production
- analysis of emissions resulting over vehicles' lifespan

Main goal of the first section is to identify the production structure of the motor vehicle production. In doing so, it is of particular interest to point to different input structures of road and rail vehicles, which in turn allows a separate (and thus more meaningful) analysis of associated emission production. The application of the input-output technique allows for the consideration of direct and indirect effects. Input-structure and absolute flows are based on the official input-output tables and the relevant emission data derive from the official environmental accounting.

Within a second step the approach allows to identify the level of emissions annually caused by the sectors 'Road transport' and 'Rail transport'.

It must be emphasized that sector 'Road transport' does only cover transport services, which are part of the economic process. Clearly the majority of freight transport is included here. However, passenger transport is restricted to busses and taxis. Motorized individual traffic is not included, since private trips do not add to the production value. This also holds for commuting in private cars. Consequently the above mentioned shift from individual to public (rail) transport will affect vehicle production and 'Rail transport', but will not change output of sector 'Road transport'.

The focus of the second part is on the road vehicles' emissions over their lifespan, with no regard to ownership or purpose of the vehicle. Clearly regulatory policy and complementary market incentives speeded up fleet renewal, which in turn resulted in decreasing emissions over the vehicles' lifetime. Since relevant data are hardly available in official statistics, calculations of a dynamic transport model, developed at the institute for economic policy research, are taken into account.

Finally this section compares emissions resulting from production versus handling of vehicles. Since the regulatory policy has been stricter at the operation side, i.e. incentives to reduce emissions have been stronger; it can be assumed that the ratio of 'emissions by operation / emissions by production' declines over time.

Since the following study relies heavily on the findings of the input-output analysis it is probably important to define the most frequently used expressions in this study first. When monetary input-output tables are used exclusively for economic purposes or when input-output tables - formed by a single physical indicator - are applied for ecological purposes, there arise no major methodological problems. Total input (Xj) of each sector is defined as the sum of all intermediate (Xij) and primary inputs (Xprimary inputs,j) of sector j, and equals (if i=j) total sectoral output (Xi), which is given by the intermediate outputs of sector i (Xij) and the sectoral final demand (Xi, final demand). Taking into account the A-matrix that is formed by the direct intermediate input-coefficients (aij= Xij/Xj), and unity matrix I eventually the Leontief inverse matrix $(I-A)^{-1}$ can be calculated. Finally the classical input-output equation is given by:

(1) $X=(I-A)^{-1}\ Y$

Y represents the final demand of the sectors. The multiplication with the Leontief inverse results in vector X, which shows the sectors' production values. Additional final demand in one particular sector, given by Y*, will, due to the intermediate linkages lead to additional production X* for almost all sectors. Equation (1) can also be written as:

(2) X=LY

where L $(=(I-A)^{-1})$ is used in recognition of Wassily Leontief.

For an n-sector economy, equation (2) can be transferred into:

$$X_1 = l_{11}Y_1 + ... + l_{1n}Y_n$$

(3) $$...$$

$$X_n = l_{n1}Y_1 + ... + l_{n,n}Y_n$$

where l_{ij} are elements of the Leontief inverse.

The environmental extension, which is described in further detail e.g. by Perman et al. (1999) or Schaffer (2002) and which has been applied by McNicoll and Blackmore (1993), now implements CO_2- and NOx- emissions into the model. With E_i for the absolute (direct) emissions given for sector i equation (4) can be set up:

(4) $E_i = \varepsilon_i X_i$

where ε_i define the sectoral emission-coefficients. These show the quantity of emissions associated with one unit of sectors' i output.

Taking into account equation (3) sectoral emissions can as well be given in dependency on final demand:

$$
(5) \quad
\begin{aligned}
E_1 &= \varepsilon_1 X_1 = \varepsilon_1 l_{11} Y_1 + ... + \varepsilon_1 l_{1n} Y_n \\
&\quad ... \\
E_n &= \varepsilon_n X_n = \varepsilon_n l_{n1} Y_1 + ... + \varepsilon_n l_{n,n} Y_n
\end{aligned}
$$

Assuming final demand increases for sector k (ΔYk) and remains unchanged for the other sectors, equation (1) calculates a new output vector X* which may lead to an additional production for sector k and the other sectors.

2. Emissions related to vehicle production

Based on 14x14 sector input-output tables for 1998 (table 1) and 1991 (table 2), the environmental accounting and the equations outlined above, this section assigns direct and indirect CO_2- and NOx-emissions to vehicle production and transport activities.

With regard to the particular interest of the transport sphere, transport categories are further subdivided into road and rail vehicle production as well as road and rail transport. Furthermore sector 'Complementary transport services and other transport' completes the detailed description of the transport field. In order to perform the environmental analysis tables 1 and 2 include the sectoral indirect CO_2- and NOx-emissions.

Apart from sector 'Rail vehicles', which has been separated from the sector 'Vehicles besides road vehicles', Table 1 derives directly from official 70x70 sector input-output table of 1998. The same holds for the emissions, which are given by sectors by the official environmental accounting. Due to the poor data availability a separation of car and truck production has not been done. However, the plan to identify different input structure is still followed and will be performed on the base of case studies in the future.

In order to perform an environmental analysis Holub and Schnabl (1994) suggest to use real instead of nominal input-output tables. In doing so the variations of emission coefficients over time can be assigned to process or product changes rather and eliminate price effects. Consequently, the IOT of 1991 (table 2) is given in prices of 1998. The year 1991 has been chosen, since former tables are only available for Western Germany.

The absolute flows for 1998 and 1990 show that the economic activities of 1998 result in a total output of roundabout 3835 billion Euro (including imports but excluding paid net taxes on goods). The monetary output is accompanied by a production of emissions amounting to 674.1 million tons of CO_2 and 1.2 million tons of NOx.

Table 1: Aggregated German input-output-table for 1998 - domestic production and imports in million Euro (basic producer prices)

	from / to	Sectors No.														Total intermediate outputs	Private and public consumption	Investments (incl. storing)	Exports	Total outputs	Emissions in 1000 t	
No.	Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	CO_2	NO_x
1	Crude oil, coal products, petroleum, fossile materials	11826	5604	384	319	20	840	116	1905	1646	853	1076	102	472	3317	28480	10566	2658	2368	44072	23835	40
2	Chemicals, rubber, plastic, glas, ceramics, minerals, metals	618	98420	35762	30535	1308	469	213	372	1178	44996	5273	61	2198	30093	251496	28376	18093	126363	424328	122515	185
3	Mechanical engineering, ADP, electronics, instrumental engin.	307	8113	72197	12390	416	297	213	445	3141	12907	3326	194	3545	16949	134440	17679	91164	147835	391118	8296	21
4	Road vehicles	1	345	301	48746	11	377	0	0	0	0	4012	0	1	210	54004	45427	23009	89610	212050	5357	9
5	Rail vehicles	0	3	0	0	2001	156	284	20	1	0	188	0	0	105	2758	1004	3563	7743	15068	304	1
6	Road transport	140	3392	1194	968	24	1290	15	227	216	1791	337	47	287	7127	17055	16897	3754	8554	46260	14537	107
7	Rail transport	112	1016	194	188	4	10	1137	20	278	133	188	35	136	1525	4976	7380	125	1806	14287	1751	15
8	Complementary transport services, other transport services	199	2999	3073	2946	42	3966	849	34110	140	256	2310	460	1185	4698	57233	17751	1400	14887	91271	20669	134
9	Energy, gas and water supply	319	10211	2819	1561	60	436	1121	236	2880	265	3198	617	1425	14418	39566	27323	-80	634	67443	324755	291
10	Construction	124	2412	931	486	13	414	190	502	1465	4370	1140	417	3449	31279	47192	4231	178001	104	229528	10479	57
11	Wholeservice, retail trade, repair services	346	12684	12378	5668	182	2974	203	2458	1248	10412	21386	887	2379	32288	105493	187368	13603	28346	334810	25452	131
12	Financial services	168	1697	1098	436	23	1561	153	799	771	1870	3551	107354	1657	7744	128882	40127	0	1790	170799	2035	3
13	Telecommunication, business related services	1514	26446	24842	8379	642	2761	565	3447	4405	8380	28218	23178	48835	86118	267730	40098	29141	17426	354395	6406	18
14	Other products and services	1606	24342	12197	7288	1055	2375	547	7727	10497	36635	49418	8738	30708	237022	430155	892259	25918	91049	1439381	107671	190
15	Total intermediate inputs	17280	197684	167370	119910	5801	17926	5606	52268	27866	122868	123621	142090	96277	472893	1569460	1336486	390349	538515	3834810	674062	1202
16	*Taxes on goods*	*21*	*1162*	*1107*	*416*	*38*	*2581*	*317*	1074	*1246*	*1644*	*2361*	*4462*	2091	*19570*	*38030*	*119594*	*30561*	*-615*	*187570*	211940*	522**
17	Total intermediate inputs (incl. Taxes on goods)	17301	198846	168477	120326	5839	20507	5923	53342	29112	124512	125982	146492	98368	492463	1607490	1456080	420910	537900	4022380	886002	1724
18	Wages and salaries	1721	85418	90158	35985	2207	19565	7803	15338	15141	69334	138816	48894	99608	401432	1031420						
19	Taxes on production less subsidies	171	2405	1242	196	-67	-1115	-831	627	1032	809	6678	2774	428	-6919	7430						
20	Company profits a. depreciation	2391	31215	18732	10344	366	1982	646	13368	21381	32008	59014	-34517	139176	406874	702980						
21	Production value	21584	317884	278609	166851	8345	40939	13541	82675	66666	226663	330490	163643	337580	1293850	3349320						
22	Imports	22488	106444	112509	45199	6723	5321	746	8596	777	2865	4320	7156	16815	145531	485490						
23	Total inputs	44072	424328	391118	212050	15068	46260	14287	91271	67443	229528	334810	170799	354395	1439381	3834810						

* CO_2 assigned to household activities

** NO_x assigned to household activities

Table 2: Aggregated German input-output-table for 1990 - domestic production and imports in million Euro (in prices of 1998)

	from / to	Sectors No.														Total intermediate outputs	Private and public consumption	Investments (incl. storing)	Exports	Total outputs	Emissions in 1000 t	
No.	Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	CO_2	NO_x
1	Crude oil, coal products, petroleum, fossile materials	19121	6768	689	264	16	1536	282	2387	3595	1180	2198	140	713	5439	44328	14759	2100	3131	64318	32359	49
2	Chemicals, rubber, plastic, glas, ceramics, minerals, metals	1466	103487	43050	29839	1333	721	412	481	1021	43685	6793	73	2278	40636	275275	31766	17264	105539	429845	129982	255
3	Mechanical engineering, ADP, electronics, instrumental engin.	448	9311	78727	12286	406	401	367	511	3390	11432	4015	184	3359	19597	144433	22062	111283	125317	403096	9827	29
4	Road vehicles	0	151	271	28104	10	330	0	0	0	0	2788	0	0	254	31908	51620	29945	61542	179015	5042	10
5	Rail vehicles	0	1	0	0	1824	122	449	7	0	0	0	0	0	94	2497	936	3576	7824	14833	373	2
6	Road transport	158	3140	1316	833	23	1354	16	235	161	1828	360	37	277	6629	16367	18680	3872	7330	46249	16340	168
7	Rail transport	296	2414	582	486	14	34	2528	44	725	361	960	50	373	3781	12650	7502	140	1056	21349	2455	25
8	Complementary transport services, other transport services	191	2350	2284	1704	19	3276	877	29506	138	227	2134	222	672	3646	47244	15922	0	14239	77405	15760	200
9	Energy, gas and water supply	793	11072	3149	1357	78	545	810	281	2059	306	4316	826	1502	16676	43771	26633	0	899	71303	350905	370
10	Construction	115	1757	754	324	14	372	215	630	871	3539	2496	506	2034	22512	36139	3466	172072	385	212062	9240	85
11	Wholeservice, retail trade, repair services	372	12206	13597	4122	182	2984	306	2474	929	9560	25951	289	2939	34831	110744	183130	16583	24673	335130	25037	212
12	Financial services	173	1369	920	116	19	1538	115	922	480	628	3451	95498	1430	7127	113788	31760	0	287	145835	2004	4
13	Telecommunication, business related services	1834	21122	18617	4811	386	2287	594	3082	2882	5465	26786	15592	34536	71478	209472	32744	24272	9821	276310	6803	27
14	Other products and services	3006	29267	11880	5960	378	2334	788	7105	16056	28261	47701	6551	26020	253303	438611	806215	30360	86902	1362088	121738	250
15	Total intermediate inputs	27973	204416	175836	90206	4703	17834	7759	47665	32308	106471	129950	119969	76133	486003	1527228	1247196	411468	448944	3634836	727865	1687
16	*Taxes on goods*	37	1520	1690	466	59	2165	395	800	1570	1081	2672	3356	2130	23879	*41820*	107220	25440	-3204	*171276*	243367*	839**
17	Total intermediate inputs (incl. Taxes on goods)	28010	205937	177526	90672	4762	19999	8154	48466	33877	107552	132623	123325	78263	509882	1569048	1354416	436908	445740	3806112	971232	2526
18	Wages and salaries	2405	96881	107417	34128	2274	18911	12196	14154	17400	71026	135068	45511	74579	380851	1012800						
19	Taxes on production less subsidies	298	2402	1183	491	-226	-686	-269	366	-2642	1409	4667	2694	248	-9491	444						
20	Company profits and depreciation	913	36272	27076	11768	598	4724	980	6029	21812	29860	58166	-31435	113340	338016	618120						
21	Production value	31626	341492	313201	137059	7408	42948	21061	69014	70447	209846	330524	140095	266430	1219258	3200412						
22	Imports	32692	88352	89894	37956	7426	3301	288	8390	856	2215	4606	5740	9880	142829	434424						
23	Total inputs	64318	429845	403096	175015	14834	46249	21349	77405	71303	212062	335130	145835	276310	1362087	3634836						

* CO_2 assigned to household activities

** NO_x assigned to household activities

Table 1 and 2 form the baseline for the following analytical analysis, which focuses on the environmental side effects of industrial production. First step of the analytical part is the calculation of the direct input-coefficient matrix A, which is given in the annex. Considering transport services, the trend of the strong decrease of the railway shares can be confirmed. In parallel road transport services generally gain in importance. However, some sectors seem to decrease overall transport inputs, which in turn even diminishes the demand for road transport services slightly. This is particularly true for the rapidly developing sector 'Telecommunication and other business related services', where transport shares have been small in 1991 already and further declined in 1998.

Besides the direct input-coefficients, emission coefficients can be calculated and compared according to equation (4). Table 3 gives an insight into the development, which is due to the application of 1998 prices for the 1991 table, solely based on product modifications and process changes.

Table 3: Emission coefficients in kg / 1000 Euro

		Emission coefficients in kg / 1000 Euro (based on sectoral output)			
		1991		1998	
No.	Sector	CO_2	NO_x	CO_2	NO_x
1	Crude oil, coal products, petroleum, fossile materials	503.1	0.8	540.8	0.9
2	Chemicals, rubber, plastic, glas, ceramics, minerals, metals	302.4	0.6	288.7	0.4
3	Mechanical engineering, ADP, electronics, instrumental engin.	24.4	0.1	21.2	0.1
4	Road vehicles	28.8	0.1	25.3	0.0
5	Rail vehicles	25.2	0.1	20.2	0.1
6	Road transport	353.3	3.6	314.2	2.3
7	Rail transport	115.0	1.2	122.6	1.0
8	Complementary transport services, other transport services	203.6	2.6	226.5	1.5
9	Energy, gas and water supply	4921.3	5.2	4815.3	4.3
10	Construction	43.6	0.4	45.7	0.2
11	Wholesale, retail trade, repair services	74.7	0.6	76.0	0.4
12	Financial services	13.7	0.0	11.9	0.0
13	Telecommunication, business related services	24.6	0.1	18.1	0.1
14	Other products and services	89.4	0.2	74.8	0.1
15	Total economic activities	200.2	0.5	175.8	0.3

Source: Own calculation, based on official environmental accounting

In general both, CO_2- and NOx-coefficients decrease or remain at least constant. Only the first sector, which includes fossil energy sources, shows increasing NOx-coefficients. Rising CO_2-coefficients can be observed, in addition to the first sector again, for 'Complementary transport services and other transports', which can be explained by the higher share of air transport. To a small extend also 'Rail transport' shows increasing CO_2-coefficients. Other sectors remain more or less at the same (e.g. 'Construction') or decreasing intensities (e.g. 'Road transport', 'Energy, gas and water supply'). Despite decreasing emission coefficients for 'Road transport' and slightly increasing intensities for 'Rail transport', road coefficients still more than double their rail counterparts in both categories.

The analytical part continues with the generation of the Leontief inverse matrix $(I-A)^{-1}$ for the IOTs of 1991 and 1998 – both listed in the annex. The application of equation (5) presents the sectoral emissions in dependence on the respective final demand. Table 4 shows the relevant emission matrix for 1998.

Table 4: Sectoral production of CO_2-emissions (1998)

No.	Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
1	Crude oil, coal products, petroleum, fossile materials	11549	2516	903	889	41	504	100	879	570	1263	943	122	169	3386	23835
2	Chemicals, rubber, plastic, glas, ceramics, minerals, metals	146	65759	11452	12076	508	253	109	227	394	14890	2543	224	498	13435	122515
3	Mechanical engineering, ADP, electronics, instrumental engin.	5	142	6725	352	12	11	6	12	41	327	107	14	34	507	8296
4	Road vehicles	0	10	15	5191	1	9	0	1	1	8	98	1	1	23	5357
5	Rail vehicles	0	1	1	0	286	2	5	0	0	1	4	0	0	4	304
6	Road transport	26	662	476	477	16	9455	9	62	51	710	216	37	57	2283	14537
7	Rail transport	8	83	44	45	2	3	1244	4	18	43	34	6	9	211	1751
8	Complementary transport services, other transport services	45	775	1168	1313	27	958	225	12335	56	450	810	157	159	2193	20669
9	Energy, gas and water supply	983	30446	19149	15290	652	2080	4163	1425	140966	11672	16887	3147	3087	74806	324755
10	Construction	5	104	91	67	3	20	9	24	39	8565	113	33	60	1346	10479
11	Wholeservice, retail trade, repair services	20	665	1005	664	24	183	20	142	72	974	18802	85	94	2700	25452
12	Financial services	3	47	52	34	2	36	5	18	14	76	103	1350	19	275	2035
13	Telecommunication, business related services	20	381	553	305	19	62	15	63	59	340	558	341	1846	1844	6406
14	Other products and services	93	1661	1659	1276	117	266	74	496	483	3403	3743	712	865	92824	107671
	Total	12905	103252	43291	37980	1711	13843	5984	15688	142763	42721	44961	6228	6897	195838	674062
	Final Demand (in Mio. Euro)	15592	172832	256678	158046	12310	29205	9311	34038	27877	182336	229317	41917	86665	1009226	2265350

Source: Own calculation

The last column shows the emissions that accompany the sectors' output production and totals match the absolute emissions given by table 1. But the application of the Leontief inverse allows for further conclusions. Particularly, the question of indirect emissions, which result from the final demand, can be answered. Considering for example road vehicles, the emissions relating to the sectors' production equal 5357 thousand tons of carbon dioxide. However, in order to satisfy the consumers' final demand for cars, the considered branch absorbs inputs from all other sectors, which produce emissions too. Consequently, emissions that accrue for the intermediate inputs must be taken into account as well. On the other hand, emissions that accompany the production for other intermediate sectors and not for final demand must not taken into account. Finally the row 'Total' shows the direct and indirect emissions, which come along with the satisfaction of the final demand. In the case of the road vehicle production, the final demand of 158 billion Euro (last row) results in direct and indirect emissions of 37980 thousand tons of CO_2. Generally sectors, which deliver a high percentage of their production to categories of final demand, show relatively high emissions that result in a direct or indirect way from any of the final demand category (row 'Total'). On the other hand classical intermediate sectors, where the output share of deliveries to final demand is relatively small, and that instead deliver a majority of their goods and services to other industries, may, referring to the level of their own final demand, prove to be much less emission intensive. Energy supply and road transport services, which as mentioned already does not include trips in private cars, can hold as good examples. While the energy sector produces in total 324755 thousand of carbon dioxide (column 'Total'), whereof only 140966 thousand tons can be assigned to the final demand of energy. Though some indirect emissions have to be added, the total emissions related to the final demand is no more than 142763 thousand tons of CO_2. Table 5 shows the emissions, produced by the sectors versus direct and indirect emissions that are necessary to satisfy the sectors' final demand.

Table 5: Emissions produced by sectors versus emissions attributed to the satisfaction of the sectors' final demand for 1991 and 1998.

Emissions in 1000 tons		1991				1998			
		Emissions produced by sector i		Emissions produced by all sectors, to satisfy the final demand of sector i.		Emissions produced by sector i		Emissions produced by all sectors, to satisfy the final demand of sector i.	
No.	Sector	CO_2	NO_x	CO_2	NO_x	CO_2	NO_x	CO_2	NO_x
1	Crude oil, coal products, petroleum, fossile materials	32359	49	17218	27	23835	40	12905	21
2	Chemicals, rubber, plastic, glas, ceramics, minerals, metals	129982	255	100602	186	122515	185	103252	150
3	Mechanical engineering, ADP, electronics, instrumental engin.	9827	29	52244	113	8296	21	43291	75
4	Road vehicles	5042	10	37803	78	5357	9	37980	62
5	Rail vehicles	373	2	1861	5	304	1	1711	3
6	Road transport	16340	168	16417	130	14537	107	13843	81
7	Rail transport	2455	25	3773	17	1751	15	5984	16
8	Complementary transport services, other transport services	15760	200	14399	135	20669	134	15688	86
9	Energy, gas and water supply	350905	370	143371	155	324755	291	142763	130
10	Construction	9240	85	45359	152	10479	57	42721	103
11	Wholesale, retail trade, repair services	25037	212	52991	216	25452	131	44961	134
12	Financial services	2004	4	6458	12	2035	3	6228	10
13	Telecommunication, business related services	6803	27	7176	18	6406	18	6897	13
14	Other products and services	121738	250	228193	446	107671	190	195838	318
15	Total economic activities	727865	1687	727865	1687	674062	1202	674062	1202

Source: Own calculation

In a final step the emissions assigned to the purchase of one vehicle can be estimated. Since vehicles of different size clearly show diverse emissions related to their production and their usage, calculations take five different vehicle categories into account:

- a medium size car with a cubic capacity of 2000-2500 cm3
- an upper class car with a cubic capacity of more than 2500 cm3
- a truck with a permissible maximum weight of more than 12 tons.

Basically, the emissions derive from the vehicles' production value. Subsequently the input structure of sector 'Road vehicles' counts for cars and trucks. Clearly this approach to estimate the emissions is quite simple and should be interpreted as a first step to open the field for further research. Though the assumption of assigning more emissions to more expansive vehicles may serve as a good first approximation for the road vehicle production, it is planned to disaggregate the road vehicle production into passenger cars and heavy good vehicles in the future. Average vehicle prices in 1998 derive from the official statistics of production.

Since vehicle prices did not only rise because of inflation (which has already been equalized), but also because of quality improvements (e.g. safety, air conditioning, navigation), the calculation account for price reductions of 15 percent for 1991. Taking into account the reduced prices, emissions are calculated via the IOT of 1991, which in turn most probably leads to emission changes smaller or larger 15 percent. Table 6 provides an overview of assumed prices and the emissions that accompany the satisfaction of the additional demand of one vehicle. While the consumption of private cars is clearly part of the final demand, the situation for HGVs is not as clear at first glance. However, trucks can be seen as investment rather than intermediate goods, which allocates the consumption to final demand as well.

Table 6: Prices and emissions per vehicle

Vehicle prices in Euro (basic prices); Emissions in kg		1991			1998		
		Average price per vehicle	Emissions produced by all sectors, to satisfy the final demand of one additional vehicle		Average price per vehicle	Emissions produced by all sectors, to satisfy the final demand of one additional vehicle	
No.	Sector	Euro	CO_2	NO_x	Euro	CO_2	NO_x
1	Passenger car with cubic capacity of 2000-2500 cm^3	22100	5838	12	26000	6249	9
2	Passenger car with cubic capacity of more than 2500 cm^3	29750	7859	17	35000	8411	14
3	Truck with a permissible max. weight of more than 12 tons	63750	16840	35	75000	18025	30

Source: Own calculations

According to these first calculations higher CO_2- but lower NO_x-emissions occur in order to satisfy the demand for one additional vehicle, no matter which vehicle category. For NO_x, the reduction goes hand in hand with the generally decreasing emission coefficients. Though CO_2-intensities decline for the most important inputs of the road vehicle production as well, this trend can not equalize the trend to ever better equipped and often bigger (thus more expansive) cars, which in turn request a higher material throughput and additional indirect CO_2-emissions per vehicle.

3. Hot emissions over vehicle lifespan

In the following the hot emissions of the three vehicle types applied in the input-output analysis are calculated. Hot emissions in this paper include all emissions occurring during the driving activity without considering cold start emissions or upstream emissions of fuel production. For the calculation of hot emissions over the whole lifespan of a vehicle an aggregated approach is used. It is based on the average annual mileage driven with a specific vehicle that is distinguished into a set of main driving situations like urban traffic or motorway traffic and a set of vehicle technologies that provides the technological development over time. This leads to the following basic equation for calculating hot emissions of cars and trucks:

$$(6) \quad EM_{VC,EMStd} = \frac{1}{1000} \sum_{Age,TS} AM_{VC,EMStd,Age,TS} * EFAC_{VC,EMStd,TS} * shTS_{VC,TS}$$

where: EM = emission quantity [kg/car]
AM = average annual mileage [km/year]
EFAC = emission factor [g/km]
shTS = share driven in traffic situation as fraction [dmnl]
VC = index vehicle categories [medium size car, luxury car, truck]
EMStd= index emission standards[PreEURO, EURO1, EURO2, EURO3, EURO4]
Age = index age category [1,average life time]
TS = index traffic situation [urban, rural, highway]

Different traffic situations are linked with variations in driving mode e.g. acceleration, speed, stop-and-go traffic. Each driving mode is connected with a specific engine load and different emission factors. Three different traffic situations are considered in our calculation: urban, rural and highway traffic. Urban traffic is usually most diverse concerning changes of speed due to congestion or traffic signalling. Engines are driven far below their optimal load such that emissions and fuel consumption are high. Rural traffic is less diverse though, depending on the landscape, it could be affected by significant ascending slopes or inclines. Usually speeds are lower than in the final considered traffic situation, which are motorways such that emission factors for rural traffic should be lowest. The applied distribution of different traffic situations is shown in table 7. Though trucks may spend quite some time on urban and rural roads, the driven kilometres are dominated by the transport on highways.

Table 7: Distribution of three major traffic situations in Germany, shares of driven kilometres

	Shares for cars	Shares for trucks
Urban	37.24%	2%
Rural	38.37%	15%
Highway	24.39%	83%

Source: ANDRE et al. (1999) p.168

In order to calculate the hot emissions over the lifespan of a vehicle the next important input is the mileage driven over the whole lifespan. For this purpose average annual mileage and the vehicles' average life-time is considered next.

Average life-time is required to calculate hot emissions over the lifespan. This is based on the average age of cars when they are taken out of service and signed off from the Central German Car Registration. In some cases, used cars are exported to other countries such that the average lifespan in our calculations should be slightly underestimated. The average age of cars that is equivalent to the lifespan of a car is increasing in Germany since 1970. During the 1990ies the highest level is reached with close to 12 years and an average of **11.41** years that is used for the calculation of total driven vehicle-km over the whole lifespan of a car. This means for 11 years the full yearly annual mileage is used while for the 12th year only 41% of average annual mileage is taken. An equal approach has been chosen for trucks, where the average lifespan of trucks matches **10.82** years.

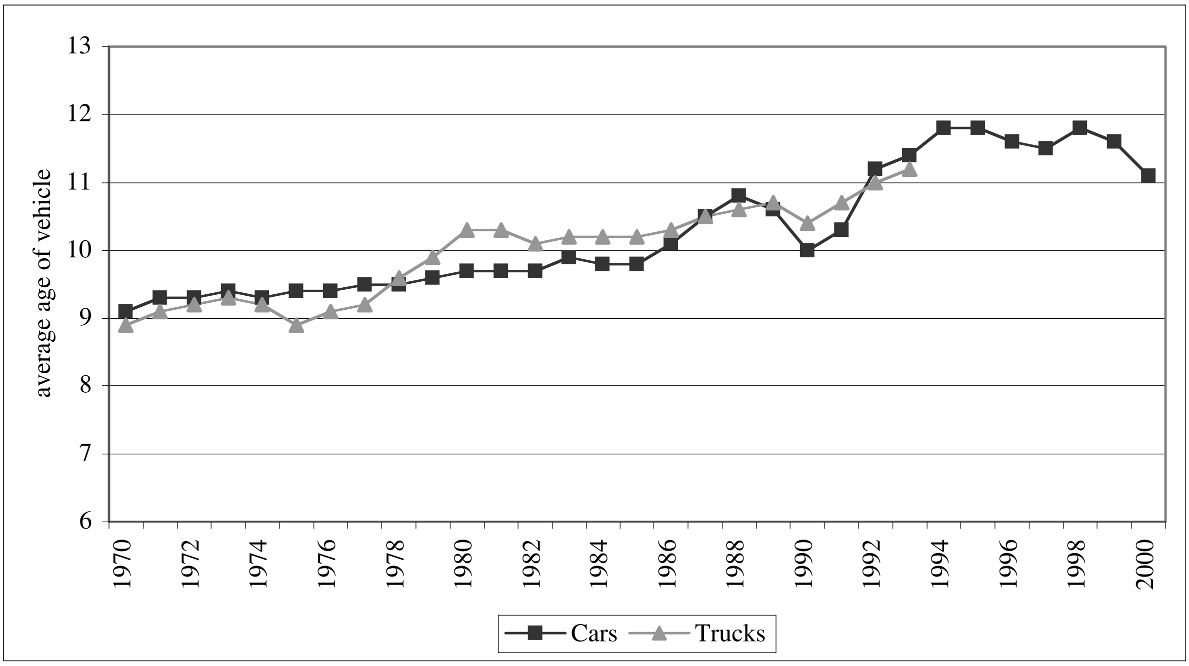

Figure 1: Development of average car and truck age at scrapping in Germany
(Own figure after KBA 1994, BMV 2001)

For the selected car categories average yearly mileage is available as absolute values and (for cars only) as usage factor related to the overall average annual mileages. Using the latter allows for sensitivity tests assuming variations in annual mileage. It can be identified from table 8 that annual mileage increases with vehicle size. For diesel cars, which are not considered in this paper, annual mileage would even be higher.

Table 8: Annual mileages of different road vehicles

[km/(year*vehicle)]	Annual mileage	Usage factor to average annual mileage
Passenger car with cubic capacity of 2000 – 2500 cm3	13550	1.03
Passenger car with cubic capacity of more than 2500 cm3	13950	1.06

Source: ANDRE et al. (1999) p.170

It can be observed that the annual mileage varies not only for different types of cars but also for different age categories. In general, new cars are used more intensive than older cars. Especially in the first two years mileage is significantly higher than in later years. Around the 7th year the average annual mileage is reached and usage for later years remains below the average annual mileage. The values in table 9 refer to Switzerland for cars and to Sweden for trucks. The calculations at hand assume a similar usage structure in Germany.

Table 9: Annual mileage of different vehicle age categories

[km/ year*vehicle]	Passenger cars			Trucks
	Annual Mileage	Usage Factor to Average Annual Mileage	Annual Mileage Based on Usage Factor	Annual Mileage
year 1*)	15722	1.21	15677	74040
year 2	15722	1.21	15677	70620
year 3	13249	1.1	14252	66410
year 4	14007	1.08	13992	61480
year 5	13538	1.04	13474	56060
year 6	13363	1.03	13345	50500
year 7	13148	1.01	13086	45180
year 8	12489	0.96	12438	40430
year 9	12007	0.93	12049	36430
year 10	10849	0.84	10883	33230
year 11	10849	0.84	10883	30780
year 12	10849	0.84	10883	
Total Mileage over Lifespan	149391		150217	559773

Source: ANDRE et al. (1999) p.169-172; *) value missing, assumed to be the same as in year 2

The emission factors used in the emission calculations stem originally from the Swiss-German Handbook on Emission Factors (HB-EFAC) (BUWAL et al. 1995, 1999) and are extracted from an integrated transport assessment model (named ASTRA). In fact ASTRA implements a set of different driving characteristics, each reflecting a mix of traffic situations from HB-EFAC (ASTRA 2000). E.g. the emission factor for urban traffic in this paper is composed out of 20% traffic on side roads, 50% traffic on main roads with traffic signals and 30% traffic on urban main roads without significant crossings etc. (e.g. urban highways). Emission factors are differentiated into three different traffic situations (see distribution of traffic situations in table 7) and into different categories of gasoline cars since these reveal distinct variations of the development of emission factors as well as of emissions that occur during production. In order to represent the development of lifespan emissions over time hot emission factors for cars belonging to three different emission standards are applied. The ECE1504 accompanies the production year 1991 and EURO II holds for 1998. Additionally EURO IV, which is current standard, and one category, which describes a situation that would approach the target of 120 g CO_2/km for the average emission factor of all new vehicles sold within one year are added. This target is defined by a voluntary agreement between car manufacturers and the European Commission and should be reached until 2012, with an intermediate target of 140 g/km until 2008 (CEC 1999). However, the factors used for the different traffic situations and vehicle categories are our own assumptions as the idea of including this "emission standard" into our calculations is to have an expected longer term trajectory of the development of hot emissions from cars.

For trucks the voluntary target is currently not under consideration. Thus no calculations have been performed in this case. Furthermore the ECE1504, which has originally been assigned to passenger cars, should be interpreted as Pre-EURO standard for heavy good vehicles.

Table 10: CO_2-emission factors of vehicles for different traffic situation, engine types and emission standards

[g/km]		ECE1504	EURO II	EURO IV	Target 120 g/km
Urban	Passenger car with cubic capacity of 2000 – 2500 cm^3	205.28	198.99	189.04	130.00
	Passenger car with cubic capacity of more than 2500 cm^3	258.32	242.52	230.39	150.00
	Trucks with a permissible max. weight of more than 12 tons	855.40	892.77	931.52	-
Rural	Passenger car with cubic capacity of 2000 – 2500 cm^3	156.00	153.63	145.94	110.00
	Passenger car with cubic capacity of more than 2500 cm^3	182.93	193.93	184.24	135.00
	Trucks with a permissible max. weight of more than 12 tons	704.36	719.15	747.09	-
Highway	Passenger car with cubic capacity of 2000 – 2500 cm^3	185.72	179.54	170.57	120.00
	Passenger car with cubic capacity of more than 2500 cm^3	208.09	228.08	216.68	150.00
	Trucks with a permissible max. weight of more than 12 tons	801.44	808.66	831.10	-

Source: ASTRA (2000) derived from BUWAL et al. (1995, 1999)

The application of equation (6) and of parameters presented in the previous tables yields CO_2-emissions for the different car categories. Cars with smaller engine size reduce emissions slightly while for large cars with more than 2.5 litre cubic capacity the lifespan emissions remain stable. Relating the emissions of EURO IV vehicles, the emission standard that is required from the year 2005 onwards, to the emissions of Pre-EURO vehicles (ECE-1504 standard) the medium size car category shows a decrease of about 7 percent and the large category of about 3%. The voluntary agreement in the last column of table 11 would require a 33% reduction for all categories. If the voluntary agreement is taken seriously in the 7 years after 2005, further reductions of about 20-25% of CO_2-emission factors, compared to the roughly 8-10% reduction during the 15 years between 1990 (ECE-1504) and 2005 (EURO IV), could be observed.

Table 11: CO_2-emissions per vehicle lifespan and emission standard

[kg/vehicle lifespan]	ECE-1504	EURO II	EURO IV	120 g/km
Passenger car with cubic capacity of 2000 – 2500 cm3	28098	27362	25993	18549
Passenger car with cubic capacity of more than 2500 cm3	34576	35087	33333	22968
Trucks with a permissible max. weight of more than 12 tons	441079	446092	459299	-

Source: own calculations

Emission factors of cars and trucks for NOx-emissions are presented in table 12. As for carbon dioxide these exclude cold start emissions as well as upstream emissions of fuel production. NOx-emission factors are significantly reduced with the introduction of EURO I compared to

Pre-EURO emissions standards (ECE-1504) due to the introduction of the catalytic cleaning technology. Improvement of this technology leads to further reductions of subsequent standards.

Table 12: NOx-emission factors of vehicles for different traffic situation, engine types and emission standards

[g/km]		ECE1504	EURO II	EURO IV
Urban	Passenger car with cubic capacity of 2000 – 2500 cm^3	1.855	0.193	0.049
	Passenger car with cubic capacity of more than 2500 cm^3	2.255	0.154	0.037
	Trucks with a permissible max. weight of more than 12 tons	10.18	7.09	3.82
Rural	Passenger car with cubic capacity of 2000 – 2500 cm^3	2.822	0.294	0.075
	Passenger car with cubic capacity of more than 2500 cm^3	2.945	0.207	0.049
	Trucks with a permissible max. weight of more than 12 tons	7.75	5.25	2.79
Highway	Passenger car with cubic capacity of 2000 – 2500 cm^3	3.879	0.493	0.125
	Passenger car with cubic capacity of more than 2500 cm^3	4.090	0.351	0.084
	Trucks with a permissible max. weight of more than 12 tons	8.76	5.82	3.04

Source: ASTRA (2000) derived from BUWAL et al. (1995, 1999)

The significant technological improvement of cleaning technology can also be revealed from the NOx-emissions over the lifespan of cars, which are reduced by about 96 percent for all size categories comparing EURO-IV with Pre-Euro standard (ECE-1504).

Table 13: NOx-emissions per vehicle lifespan and emission standard

[kg/vehicle lifespan]	ECE-1504	EURO II	EURO IV
Passenger car with cubic capacity of 2000 – 2500 cm3	420.8	47.2	12.0
Passenger car with cubic capacity of more than 2500 cm3	472.5	35.4	8.4
Trucks with a permissible max. weight of more than 12 tons	4833.0	3225.1	1689.1

Source: own calculations

4. Conclusions

Taking into account the results of the previous section, the emissions allocated to the vehicles' operation can be compared to the emissions caused by the usage. Table 14 summarizes the results of tables 6, 11 and 13 and gives an overview of the development for both activities. Results base on the assumption that the vehicles produced in 1991 meet the ECE-1504 standard, while the production of 1998 fulfills the EURO II norm.

Table 14: Emissions allocated to production and operation of vehicles

		CO_2			NO_x		
Type of vehicle	Year	Vehicle production	Vehicle operation	Total	Vehicle production	Vehicle operation	Total
Passenger car with cubic capacity of 2000-2500 cm^3	1991	5838	28098	33936	12	421	433
	1998	6249	27362	33611	9	47	56
Passenger car with cubic capacity of more than 2500 cm^3	1991	7859	34576	42435	17	472	489
	1998	8411	35087	43498	14	35	49
Truck with a permissible max. weight of more than 12 tons	1991	16840	441079	457919	35	4833	4868
	1998	18025	446092	464117	30	3225	3255

Source: Tables 6, 11, 13

While total CO_2-emissions decline slightly for medium size cars, they increase marginally for the higher cubic capacity cars. Both types show growing emissions related to the production, but only medium size cars present decreasing emissions attributed to the operation. Consequently a slightly higher share, from 17 to 19 percent, for production related emissions can be identified by figure 2.

As mentioned already the implementation of the catalytic technology results in a significant decrease of NOx-emissions. At the production side, the decrease of nitrogen oxides has not been that significant, which in turn results in a higher share of production related emissions in 1998. Still the operation related emissions dominate the production related ones, but compared to the situation in 1991, production shares have grown significantly (figure 3).

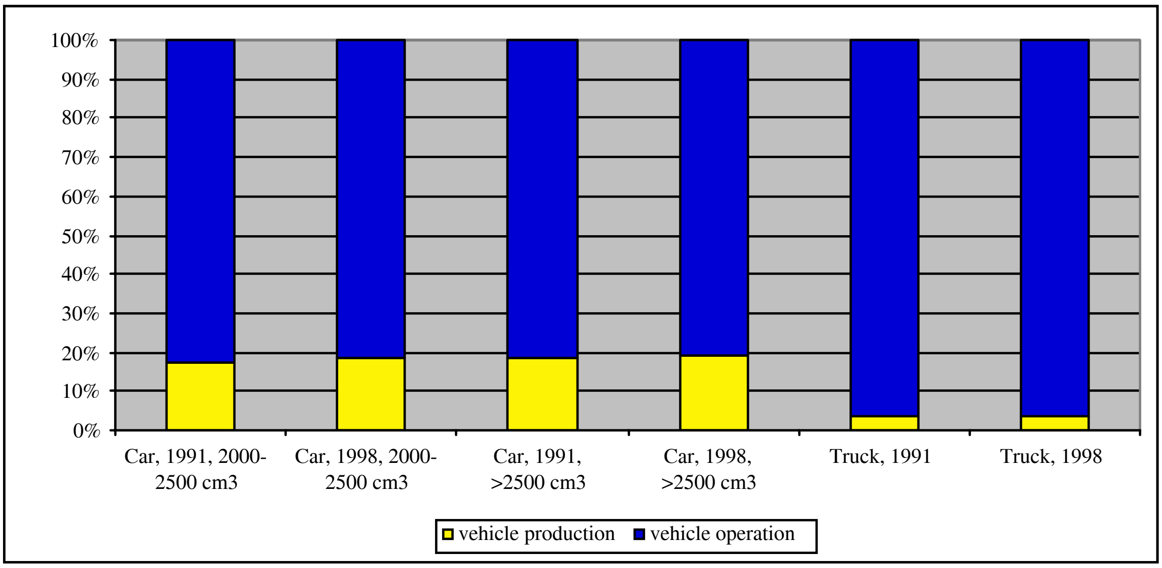

Figure 2: CO_2-emission shares of vehicle production and operation

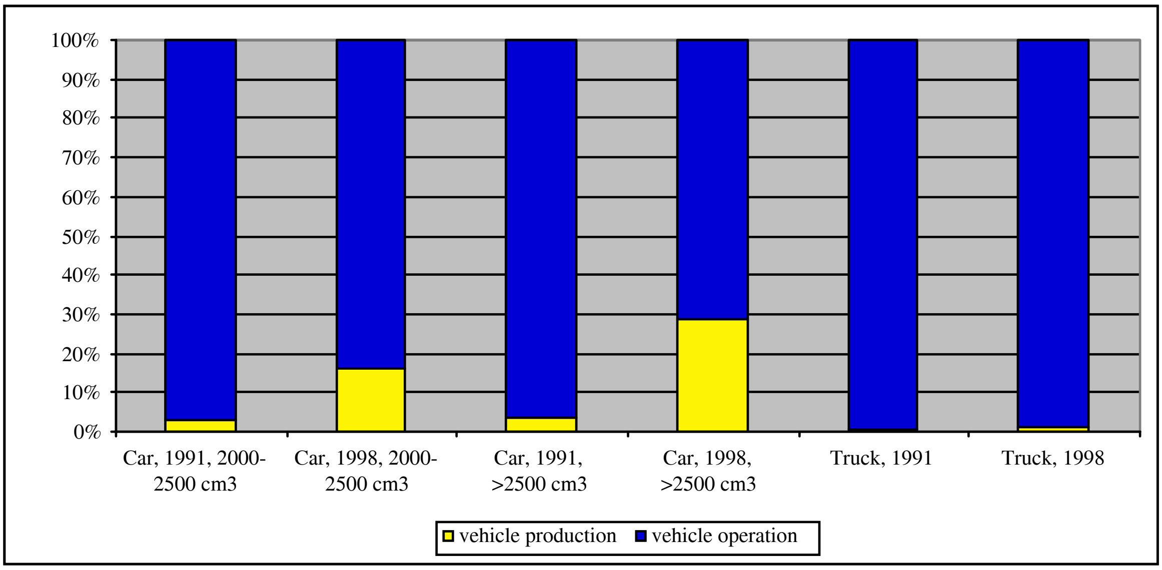

Figure 3: NOx-emission shares of vehicle production and operation

Both figures point to the dominating role of the emissions, caused by the vehicles' operation. This is due to the high mileage, particularly true for heavy good vehicles. Consequently efforts to reduce operation-related emissions must continue strongly. However, saving potentials can be identified for the production process as well. This is true for nitrogen oxide, where the share of production related emissions increased significantly, but due to the absolute flows, this also holds for carbon dioxide. In addition the production related CO_2 share might further increase, if the above-described voluntary agreement is taken seriously.

Due to the dominating indirect emissions, no matter, whether CO2- or NOx-emissions are considered, the task to abate production-related emissions is a challenge faced by all industries not only (or even to a minor part) by the 'Road vehicle' sector. Clearly this does not make things easier, but on the other hand a successful identification of saving potentials will not only reduce emissions related to vehicle production, but to any other production as well.

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Annex

Table A1: A-matrix for 1998 - domestic production and imports (intermediate input coefficients)

No	to / from Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Sectors No.													
1	Crude oil, coal products, petroleum, fossile materials	0.268	0.013	0.001	0.002	0.001	0.018	0.008	0.021	0.024	0.004	0.003	0.001	0.001	0.002
2	Chemicals, rubber, plastic, glas, ceramics, minerals, metals	0.014	0.232	0.091	0.144	0.087	0.010	0.015	0.004	0.017	0.196	0.016	0.000	0.006	0.021
3	Mechanical engineering, ADP, electronics, instrumental engineering	0.007	0.019	0.185	0.058	0.028	0.006	0.015	0.005	0.047	0.056	0.010	0.001	0.010	0.012
4	Road vehicles	0.000	0.001	0.001	0.230	0.001	0.008	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.000
5	Rail vehicles	0.000	0.000	0.000	0.000	0.133	0.003	0.020	0.000	0.000	0.000	0.001	0.000	0.000	0.000
6	Road transport	0.003	0.008	0.003	0.005	0.002	0.028	0.001	0.002	0.003	0.008	0.001	0.000	0.001	0.005
7	Rail transport	0.003	0.002	0.000	0.001	0.000	0.000	0.080	0.000	0.004	0.001	0.001	0.000	0.000	0.001
8	Complementary transport services, other transport services	0.005	0.007	0.008	0.014	0.003	0.086	0.059	0.374	0.002	0.001	0.007	0.003	0.003	0.003
9	Energy, gas, water supply	0.007	0.024	0.007	0.007	0.004	0.009	0.078	0.003	0.043	0.001	0.010	0.004	0.004	0.010
10	Construction	0.003	0.006	0.002	0.002	0.001	0.009	0.013	0.006	0.022	0.019	0.003	0.002	0.010	0.022
11	Wholeservice, retail trade, repair services	0.008	0.030	0.032	0.027	0.012	0.064	0.014	0.027	0.019	0.045	0.064	0.005	0.007	0.022
12	Financial services	0.004	0.004	0.003	0.002	0.002	0.034	0.011	0.009	0.011	0.008	0.011	0.629	0.005	0.005
13	Telecommunication, business related services	0.034	0.062	0.064	0.040	0.043	0.060	0.040	0.038	0.065	0.037	0.084	0.136	0.138	0.060
14	Other products and services	0.036	0.057	0.031	0.034	0.070	0.051	0.038	0.085	0.156	0.160	0.148	0.051	0.087	0.165
15	Total intermediate inputs	0.392	0.466	0.428	0.565	0.385	0.388	0.392	0.573	0.413	0.535	0.369	0.832	0.272	0.329

Table A2: Inverse matrix for 1998 - domestic production and imports

No	to / from Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Sectors No.													
1	Crude oil, coal products, petroleum, fossile materials	1.369	0.027	0.007	0.010	0.006	0.032	0.020	0.048	0.038	0.013	0.008	0.005	0.004	0.006
2	Chemicals, rubber, plastic, glas, ceramics, minerals, metals	0.033	1.318	0.155	0.265	0.143	0.030	0.041	0.023	0.049	0.283	0.038	0.019	0.020	0.046
3	Mechanical engineering, ADP, electronics, instrumental engineering	0.016	0.039	1.235	0.105	0.047	0.017	0.032	0.017	0.069	0.085	0.022	0.016	0.019	0.024
4	Road vehicles	0.000	0.002	0.002	1.300	0.002	0.012	0.001	0.001	0.001	0.002	0.017	0.001	0.000	0.001
5	Rail vehicles	0.000	0.000	0.000	0.000	1.153	0.004	0.025	0.001	0.000	0.000	0.001	0.000	0.000	0.000
6	Road transport	0.005	0.012	0.006	0.010	0.004	1.031	0.003	0.006	0.006	0.012	0.003	0.003	0.002	0.007
7	Rail transport	0.004	0.004	0.001	0.002	0.001	0.001	1.087	0.001	0.005	0.002	0.001	0.001	0.001	0.002
8	Complementary transport services, other transport services	0.013	0.020	0.020	0.037	0.010	0.145	0.107	1.601	0.009	0.011	0.016	0.017	0.008	0.010
9	Energy, gas and water supply	0.013	0.037	0.016	0.020	0.011	0.015	0.093	0.009	1.051	0.013	0.015	0.016	0.007	0.015
10	Construction	0.007	0.013	0.008	0.009	0.006	0.015	0.021	0.015	0.031	1.029	0.011	0.017	0.015	0.029
11	Wholeservice, retail trade, repair services	0.017	0.051	0.052	0.055	0.026	0.083	0.029	0.055	0.034	0.070	1.079	0.027	0.014	0.035
12	Financial services	0.019	0.023	0.017	0.018	0.012	0.104	0.042	0.045	0.041	0.035	0.038	2.704	0.019	0.023
13	Telecommunication, business related services	0.071	0.122	0.119	0.107	0.086	0.118	0.087	0.103	0.118	0.103	0.135	0.450	1.178	0.101
14	Other products and services	0.080	0.129	0.086	0.108	0.127	0.122	0.106	0.195	0.232	0.250	0.218	0.227	0.133	1.230
15	Total	1.646	1.795	1.723	2.046	1.634	1.729	1.693	2.119	1.682	1.907	1.601	3.500	1.420	1.529

Table A3: Inverse matrix for 1990 - domestic production and imports

No	from \ to	Sectors No.													
No	Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Crude oil, coal products, petroleum, fossile materials	1.428	0.036	0.011	0.014	0.007	0.059	0.031	0.076	0.079	0.020	0.016	0.010	0.007	0.012
2	Chemicals, rubber, plastic, glas, ceramics, minerals, metals	0.053	1.338	0.186	0.294	0.147	0.042	0.049	0.037	0.053	0.303	0.051	0.024	0.026	0.064
3	Mechanical engineering, ADP, electronics, instrumental engineering	0.019	0.045	1.254	0.118	0.046	0.022	0.035	0.024	0.073	0.085	0.027	0.018	0.023	0.030
4	Road vehicles	0.000	0.001	0.002	1.192	0.001	0.010	0.000	0.001	0.001	0.001	0.011	0.000	0.000	0.001
5	Rail vehicles	0.000	0.000	0.000	0.000	1.140	0.003	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	Road transport	0.005	0.012	0.006	0.009	0.004	1.032	0.003	0.007	0.005	0.013	0.003	0.003	0.002	0.007
7	Rail transport	0.009	0.010	0.004	0.007	0.003	0.003	1.136	0.003	0.014	0.005	0.005	0.003	0.003	0.005
8	Complementary transport services, other transport services	0.010	0.016	0.016	0.025	0.006	0.122	0.078	1.620	0.009	0.009	0.015	0.011	0.006	0.009
9	Energy, gas, water supply	0.022	0.040	0.018	0.022	0.012	0.019	0.049	0.013	1.039	0.015	0.021	0.023	0.010	0.020
10	Construction	0.006	0.010	0.006	0.007	0.004	0.014	0.016	0.019	0.020	1.024	0.014	0.018	0.012	0.023
11	Wholeservice, retail trade, repair services	0.016	0.051	0.057	0.050	0.025	0.085	0.029	0.068	0.031	0.071	1.096	0.020	0.020	0.042
12	Financial services	0.016	0.021	0.016	0.013	0.009	0.111	0.026	0.065	0.030	0.021	0.040	2.909	0.022	0.024
13	Telecommunication, business related services	0.063	0.099	0.092	0.076	0.054	0.100	0.061	0.109	0.085	0.077	0.126	0.375	1.160	0.091
14	Other products and services	0.107	0.153	0.092	0.109	0.066	0.126	0.098	0.227	0.321	0.226	0.225	0.221	0.148	1.266
15	Total	1.754	1.833	1.759	1.937	1.525	1.748	1.637	2.270	1.760	1.871	1.650	3.635	1.440	1.592