Material Flows Mobilized by Motor Vehicles and Transport Equipment Manufacturing and Use in the Czech Republic: an Application of Economy-Wide Material System Analysis

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Abstract

Manufacturing of motor vehicles and transport equipment is a key industry in the Czech Republic – it contributes to the national GDP by about 4.6%. The article applies economy-wide material system analysis (EW-MSA) in order to quantify physical material flows mobilized by manufacturing and use of motor vehicles and transport equipment in the Czech Republic. The results show that the Czech Republic is not endowed with the resources needed for the manufacture of motor vehicles such as metals or crude oil for manufacturing of plastics and thus these resources have to be imported. The physical stock of motor vehicles is growing in the Czech Republic, which poses a need for expansion of transport infrastructures. Moreover, almost 70% of waste from motor vehicles manufacturing and use is exported or landfilled, which represent a loss of resources that could be recycled domestically and sent back to manufacturing.

Keywords

Economy-wide material system analysis (EW-MSA), motor vehicles and transport equipment, dependency on foreign natural resources, physical stock of the economy, waste recycling, Czech Republic

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INTRODUCTION

The manufacture of motor vehicles and transport equipment is one of the most significant global industries: it contributes to global GDP by 1.6% and to global manufacturing value added (MVA) by about 10% (UNIDO, 2021). At the same time the automotive industry mobilizes large volumes of resources and products. About half of the global consumption of oil and rubber, about $^1/_4$ of the glass output, and $^1/_6$ of the steel output is accounted for by the automotive industry. The industry is the second after aircraft construction in terms of the volume of consumed products of other industries (Saberi, 2018).

The Czech Republic is a medium-sized country in central Europe with 10.7 million inhabitants and has been a member of the European Union since 2004. The Czech economy depends to a large degree on the manufacturing industry: its share in GDP was almost 23% in 2018, which was the second highest value in the EU after Ireland. The most important part of the manufacturing industry is the manufacture of motor vehicles and transport equipment in the Czech Republic. Its share in MVA was 20% in 2018, which was the second highest value globally after Slovakia. In terms of the share of automotive industry in global GDP, the Czech Republic accounted for 4.6% in 2018, which was in fact the largest share in the world followed by Slovakia (4%), Republic of Korea (3.8), Hungary (3.5%), Germany (3.5%) and Japan (3.4%) (UNIDO, 2021). Motor vehicles and transport equipment manufacture was further an important employer in the Czech Republic, providing about 5% of total jobs and representing 16% of manufacturing industry jobs in 2018 (Czech Statistical Office, 2019c).

In spite of the crucial role manufacturing motor vehicles and transport equipment plays in the Czech economy, only fragmented and internally inconsistent information is available on the amount of resources and products from other industries needed for the Czech automotive industry and on the waste flows from car manufacturing and use. This can be considered a shortcoming because the viability of a particular industry for an economy is not determined by its economic performance only. Other factors such as whether resources and products needed for the industry are available domestically or have to be imported, or the ways in which waste from the industry is treated are also important and contribute to the long-term viability of the industry.

The aim of this article is to provide a comprehensive picture of all material flows mobilized by manufacturing and use of motor vehicles and transport equipment in the Czech Republic. These flows will be expressed in physical units, namely tonnes, and we will discuss whether they contribute to a long-term viability of the automotive industry in the country. The literature search showed that there are various approaches for monitoring material flows related to motor vehicles in physical terms. For instance, Ortego et al. (2020) developed a method to identify strategic elements for the automobile sector. This approach defined a variable called Strategic Metal Index (SMI), which was calculated for each metal. Andersson et al. (2017) analyzed to which extent strategic metals in end-of-life vehicles were recycled in Sweden. Carmona et al. (2021) identified how steel accumulation in vehicles contributed to passenger mobility between 1960 and 2015. Liu et al. (2020) carried out a dynamic material flow analysis in order to quantify the amount of end-of-life passenger cars in China in the future while Sharma and Pandey (2020) examined the recovery of resources from end-of-life passenger cars in the informal sector in India.

The above studies are focused on a selection of material flows related to motor vehicles and transport equipment such as strategic metals and/or end-of-life vehicles and their recycling. The approaches from these studies are therefore not designed to quantify all material flows mobilized by motor vehicles and transport equipment manufacturing and use. The above studies further claim that they apply a material flow analysis (MFA). This term comprises a family of methods which have some common features including the focus on physical flows or clear definition of the studied system and its boundaries, but otherwise they can significantly differ, which hampers the compatibility and comparability of resulting studies (OECD, 2008). So far there have been only a few methods quantifying material flows, which achieved a high level of standardization, one of them being economy-wide material flow analysis (EW-MFA) (Eurostat, 2001; Eurostat, 2018). EW-MFA has been widely applied both in developed and developing countries by various research studies (e.g. Adriaanse et al., 1997; Krausmann et al., 2009; West et al., 2014; Schandl and West, 2012; Giljum, 2004; Matthews, 2000), but also by international institutions like Eurostat (Eurostat, 2021), or the UN Environment Programme International Resource Panel (UN Environment Programme International Resource Panel, 2020).

EW-MFA regards the economy as a black box and is devoted exclusively to the monitoring of overall input and output material flows while physical flows within the economy are neglected. This is the reason why EW-MFA cannot be used to quantify how various product groups like motor vehicles and transport equipment are produced in the economy, what their demand on raw materials is, or how they contribute to waste production and waste recycling. There are, however, a few methods which can build on the standardized EW-MFA framework and open the black box of the economy. In that respect, material system analysis (MSA) is a promising candidate.

MSA is defined by the OECD (2008) as follows: "Material system analysis is based on material specific flow accounts. It focuses on selected raw materials or semi-finished and finished goods at various levels of detail and application (e.g. cement, paper, iron and steel, copper, plastics, timber, water) and considers life-cycle-wide inputs and outputs. It applies to materials that raise particular concerns as to the sustainability of their use, the security of their supply to the economy, and/or the environmental consequences of their production and consumption". The OECD definition of MSA is quite general which leaves space for further development of this method and it's tailoring to specific purposes. Recently, MSA has been extended by Kovanda (2021), who developed an economy-wide material system analysis (EW-MSA). EW-MSA covers all manufactured product groups as well as all extracted raw materials, imported and exported raw materials and products, and emission and waste flows and shows their physical flows through various phases of material processing and use. The method thus opens the black box of the economy and, on top of that, utilizes the system boundaries and major accounting principles typical for EW-MFA, thus ensuring the compatibility of these two approaches.

EW-MSA covers all raw materials and product groups which flow through the economy, and can be monitored and analyzed as a whole as shown by Kovanda (2021), or with the focus on selected raw materials and products. The approach can thus be used for monitoring of material flows mobilized by manufacturing and use of motor vehicles and transport equipment, which is the goal of this study. The rest of the article is structured as follows: Section 1 describes the conceptual framework of EW-MSA and its main components: EW-MSA indicators, EW-MSA database and EW-MSA flow charts. It further illustrates how data for the EW-MSA of motor vehicles and transport equipment can be collected and modelled for the Czech Republic. Section 2 provides results of the EW-MSA of motor vehicles and transport equipment for the Czech Republic while Section 3 shows how these results can be interpreted in order to assess long-term viability of motor vehicles and transport equipment manufacturing and use. Last section concludes on the EW-MSA applicability and results.

1 METHODS AND DATA

1.1 EW-MSA methodology

The EW-MSA methodology has been described in detail by Kovanda (2021). This section thus only repeats its key features needed to understand EW-MSA results for motor vehicles and transport equipment.

Unlike EW-MFA, EW-MSA further splits the system into sub-components by phases of material processing and use. These include extraction, manufacturing, use, waste treatment and waste treatment – recycling. The last sub-component was set aside from waste treatment, since recycling and reuse of resources are crucial for establishing circular economies. On the other hand, like EW-MFA, EW-MSA focuses on the physical flows at the current stage of its development. This means, for instance, that net additions to physical stock of the economy are quantified, but in-use physical stock as such is not.

The focus on physical flows is suitable for evaluation of environmental pressures, foreign resource dependency or the rate of recycling. The authors of the study are aware that even small physical flows can present significant monetary flows (e.g. in the case of electronics), but analysis of monetary flows would require a different methodological approach.

The major types of material flows include primary materials that can be identified as belonging to the category domestic extraction (DE) in EW-MFA. That said, the pilot EW-MSA for the Czech Republic does not include unused domestic extraction (UDE). Products include any manufactured commodities at various levels of processing either used for further manufacturing or for final consumption. Waste and water emissions are a result of product manufacturing and primary material and product use and are tackled by waste treatment. After that they are either transformed into secondary materials and input back into manufacturing or added to the physical stock of landfilled materials of the economy in the form of waste deposited in controlled landfills or released to the environment. Some residual waste is also produced in the process of recycling. Air emissions are emitted during product manufacturing, primary material and product use and waste treatment. Some products and collected waste such as fertilizers, manure or pesticides are applied intentionally to the environment (dissipative use of materials). Other products and infrastructures are added to the in-use physical stock of the economy. Finally, even though EW-MSA, like EW-MFA, does not account for bulk water and air flows in general, it includes some of them in input and output balancing items, which are needed for the transformation of material inputs into material outputs, but are usually not a part of resource extraction or emission statistics. Gases from ambient air (oxygen and nitrogen) that take part in oxidizing processes when burning fuels are examples of such balancing items on the input side, while water vapor generated from the water and hydrogen content of fuels in combustion constitute a balancing item on the output side. The introduction of input and output balancing items is necessary in order to establish a material balance. This balance must hold for the EW-MSA system as a whole as well as for manufacturing, use, waste treatment and waste treatment – recycling sub-components. This means, for instance, that the input of materials into the use phase (primary materials from extraction and imports, products from manufacturing and imports, input balancing items) is equal to the output of materials from the use phase (waste and water emissions from use, air emissions from use, dissipative use of products, output balancing items) plus net additions to stock.

The EW-MSA was designed to be compiled in an aggregated form and also broken down by major groups of primary materials and products. The above mentioned material balances also hold true for these major groups of primary materials and products. In order to be able to use official statistical figures as much as possible when populating the system with data, we decided to stick to official classification of products by activities (CPA). Table 1 shows the classification of EW-MSA primary material and product groups by CPA. The article is focused on motor vehicles and transport equipment, which are shown in bold in Table 1.

Table 1 Classification of EW-MSA primary material and product groups by CPA

Primary materials/ product	Group name	CPA
Primary materials	Plant biomass	CPA 01.1, CPA 01.2, CPA 01.3
	Forestry products	CPA 02
	Hard coal	CPA 05.1
	Brown coal and lignite	CPA 05.2
	Crude oil	CPA 06.1
	Natural gas	CPA 06.2
	Ores	CPA 07
	Industrial non-metallic minerals	CPA 08.9
	Construction non-metallic minerals	CPA 08.1

Table 1 (continuation)

Primary materials/ product	Group name	CPA
Products	Animal biomass	CPA 01.4, CPA 03
	Food and tobacco products	CPA 10, CPA 12
	Beverages	CPA 11
	Textiles	CPA 13
	Wearing apparel and leather products	CPA 14, CPA 15
	Wood and wood products	CPA 16
	Paper and paper products	CPA 17
	Coke and refined petroleum products	CPA 19
	Chemicals, chemical and pharmaceutical products	CPA 20, CPA 21
	Rubber and plastic products	CPA 22
	Other non-metallic mineral products	CPA 23
	Basic metals	CPA 24
	Fabricated metal products	CPA 25
	Computer, electronic and optical products	CPA 26
	Electrical equipment	CPA 27
	Machinery	CPA 28
	Motor vehicles and transport equipment	**CPA 29, CPA 30**
	Furniture	CPA 31
	Other manufacturing products	CPA 32
	Manufactured gaseous fuels	CPA 35.21
	Buildings and infrastructures	CPA 41, CPA 42
	Books and magazines	CPA 58

Source: Own construction

The quantification of material flows in EW-MSA is carried out by unambiguously defined EW-MSA indicators. A list of these indicators broken down by phases of material processing and use is shown in Table 2.

Table 2 EW-MSA indicators

Material processing and use phase	Indicator identifier and title
A. Extraction	A.1 Production of primary materials sent to further manufacturing
	A.2 Production of primary materials sent to use
	A.3 Exports of primary materials
B. Manufacturing	B.1 Domestic production of materials intended for manufacturing
	B.2 Imports of materials intended for manufacturing
	B.3 Production of products sent to further manufacturing
	B.4 Production of products sent to use
	B.5 Exports of products
	B.6 Manufacturing waste sent to treatment
	B.7 Manufacturing water emissions sent to treatment
	B.8 Manufacturing air emissions
	B.9 Manufacturing input balancing items
	B.10 Manufacturing output balancing items

Table 2 (continuation)

Material processing and use phase	Indicator identifier and title
C. Use	C.1 Domestic production of materials intended for use
	C.2 Imports of materials intended for use
	C.3 Net additions of primary materials and products to stock
	C.4 Dissipative use of primary materials and products
	C.5 Use waste sent to treatment
	C.6 Use water emissions sent to treatment
	C.7 Use air emissions
	C.8 Use input balancing items
	C.9 Use output balancing items
D. Waste treatment	D.1 Domestic waste intended for treatment
	D.2 Imports of waste
	D.3 Exports of waste
	D.4 Water emissions intended for treatment
	D.5 Net additions of waste to stock (waste controlled landfilling)
	D.6 Waste sent to uncontrolled landfilling
	D.7 Waste sent to recycling
	D.8 Incineration/waste water treatment air emissions
	D.9 Water emissions released to the environment
	D.10 Incineration/waste water treatment input balancing items
	D.11 Incineration/waste water treatment output balancing items
E. Waste treatment – recycling	E.1 Waste intended for recycling
	E.2 Production of secondary material for manufacturing
	E.3 Dissipative use of waste
	E.4 Net additions of recycling waste to stock (recycling waste controlled landfilling)
	E.5 Recycling waste sent to uncontrolled landfilling
	E.6 Recycling air emissions
	E.7 Recycling input balancing items

Source: Own construction

Net additions to stock (NAS) represent the amount of materials added yearly to the physical stock of the economy. According to the EW-MFA methodology (Eurostat, 2018), NAS includes not only primary materials and products like motor vehicles, but also waste deposited into controlled landfills, which are considered parts of the economy. NAS is therefore reported under three indicators in EW-MSA: C.3 Net additions of primary materials and products to stock, D.5 Net additions of waste to stock (waste controlled landfilling) and E.4 Net additions of recycling waste to stock (recycling waste controlled landfilling).

As mentioned above, material balances are held for the material processing and use phases (for the indicator identifiers see Table 2).

Manufacturing:

1) B.1 + B.2 + B.9 = B.3 + B.4 + B.5 + B.6 + B.7 + B.8 + B10.

Use:

2) C.1 + C.2 + C.8 = C.3 + C.4 + C.5 + C.6 + C.7 + C.9.

Waste treatment:

3) D.1 + D.2 + D.4 + D.9 = D.3 +D.5 + D.6 + D.7 + D.8 + D.10.

Waste treatment – recycling:

4) E.1 + E.6 = E.2 + E.3 + E.4 + E.5.

The data on EW-MSA indicators are organized in an EW-MSA database held in MS Excel. The database is split into worksheets by the material processing and use phases which are further broken down by particular primary material and product groups. The results of EW-MSA are presented by Sankey flow charts drawn with the use of e!sankey software: <*https://www.ifu.com/e-sankey*>.

1.2 Data collection and modelling for EW-MSA of motor vehicles and transport equipment

An EW-MSA of motor vehicles and transport equipment was carried out for the Czech Republic using 2017 data.

Domestic input-output tables (Czech Statistical Office, 2019a) were used for the attribution of domestically-produced products to manufacturing of motor vehicles and transport equipment and for the quantification of motor vehicles and transport equipment sent to the use phase while the data on total domestic production of these products came from the Czech Statistical Office (2018b). Use of monetary input-output tables for attribution of various physical flows to manufacturing and use of products is a common approach applied by practitioners from the field of environmentally extended input-output analysis (Tukker et al., 2013). It was also used in the Raw Material Equivalent Model published by Eurostat (Eurostat, 2019) and in our previous work (Kovanda, 2018). We assumed a direct proportion between monetary and mass flows for this attribution.

Imports of products for manufacturing and use of motor vehicles and transport equipment as well as exports of motor vehicles and transport equipment was taken from the database on foreign trade (Czech Statistical Office, 2019b). This data was corrected by the direct transit of goods which were not used for production and consumption purposes in the Czech Republic and therefore did not enter manufacturing and use phases of EW-MSA. The correction as well as the attribution of imported products to manufacturing and use of motor vehicles and transport equipment was made with the help of monetary input-output tables for imported commodities (Czech Statistical Office, 2019a).

The generation of waste by industries is reported by the Czech Statistical Office (2018a). Waste was attributed to motor vehicles and transport equipment with the help of monetary supply tables (Czech Statistical Office, 2019a), which provide information on product group supply by particular industries. Afterwards the generated waste was split between the manufacturing and use phases according to the amount of materials entering the respective phases.

The generation of emissions to water by industries is reported by the T. G. Masaryk Water Research Institute (Dlabal, 2019). This was attributed to motor vehicles and transport equipment in the same way as generation of waste. Data on air emissions from manufacturing and use phases were taken from reporting for the International Panel for Climate Change (Czech Hydrometeorological Institute, 2019). This reporting allows for distinguishing whether air emissions stem from the transformation of material inputs into products during manufacturing or from the use of products, as well as for identification which product groups are responsible for which air emissions.

Net additions to stock of motor vehicles and transport equipment was calculated as the difference between inputs and outputs into and from the use phase.

Imports and exports of waste and waste sent to recycling were taken from the Eurostat waste statistics (Eurostat, 2021). These are reported by waste categories, which can be attributed to motor vehicles and transport equipment in EW-MSA. Waste sent to landfill was calculated as the difference between inputs and outputs into and from the waste treatment phase. Incineration/waste water treatment air emissions were taken over from reporting for the International Panel for Climate Change (Czech Hydrometeorological Institute, 2019) and attributed to motor vehicles and transport equipment according to the amount of incinerated waste (Eurostat, 2021). Data concerning water emissions released to the environment were provided by T. G. Masaryk Water Research Institute (Dlabal, 2019) and attributed to motor vehicles and transport equipment in the same way as generation of emissions to water.

Recycling waste sent to landfill came from Eurostat (Eurostat, 2021), which reports recycling wastes by waste categories. Recycling air emissions were taken over from reporting for International Panel for Climate Change (Czech Hydrometeorological Institute, 2019). Production of secondary materials for manufacturing were calculated as a difference between inputs and outputs into and from the waste treatment – recycling phase.

After populating the EW-MSA database with the described data, the material balance was held for those phases, where one of the indicators was calculated as a balance of material inputs and outputs. In order to arrive at full material balance for all the phases, we applied a RAS-type approach, which reconciled inconsistencies in data that should match or sum up to the same amount. For details on the RAS approach see e.g. Lahr and de Mesnard (2004).

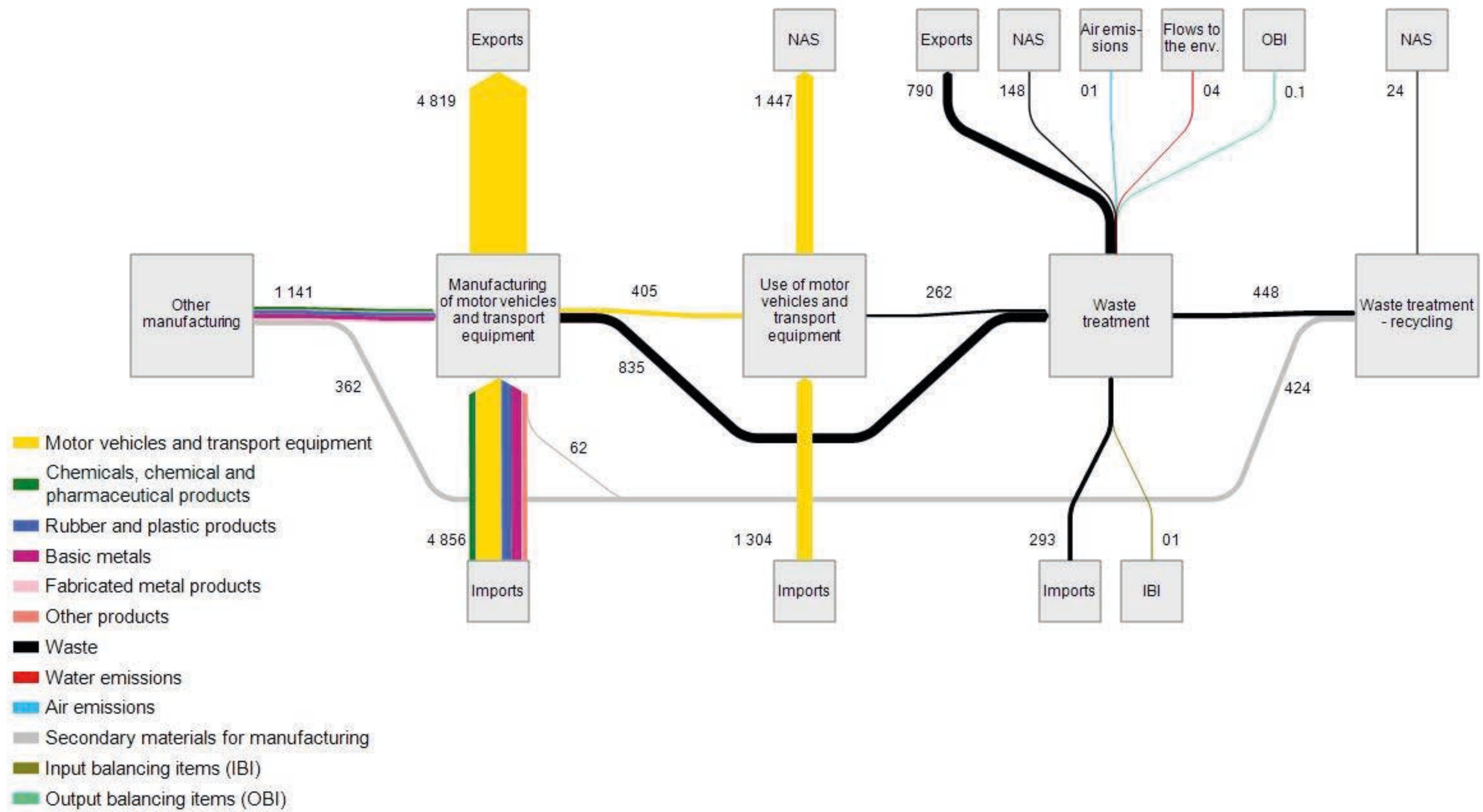
2 RESULTS

Figure 1 shows the overall EW-MSA of motor vehicles and transport equipment for the Czech Republic. Figure 2 depicts a more detailed flowchart for the manufacturing phase.

Manufacturing of motor vehicles and transport equipment did not receive any primary materials from the extraction phase. It only consumed manufactured products – 6 059 thousand tonnes in total in 2017. The largest part of them came from abroad (80%, 4 856 thousand tonnes). Imports consisted especially of various motor vehicles and transport equipment parts (45%, 2 170 thousand tonnes), followed by basic metals (18%, 853 thousand tonnes), rubber and plastic products (17%, 832 thousand tonnes) and chemicals, chemical and pharmaceutical products (11%, 528 thousand tonnes). Other domestic manufacturing supplied manufacturing of motor vehicles and transport equipment with 1 141 thousand tonnes of materials (19% of total material inputs). They were mostly composed of basic metals (30%, 366 thousand tonnes), rubber and plastic products (26%, 310 thousand tonnes), chemicals, chemical and pharmaceutical products (18%, 212 thousand tonnes) and fabricated metal products (13%, 157 thousand tonnes). Secondary materials contributed to material inputs into manufacturing of motor vehicles and transport equipment by only 1%. Regarding material outflows, the largest part was exported (79%, 4 819 thousand tonnes), 7% was sent to use (405 thousand tonnes) and 14% (835 thousand tonnes) was manufacturing waste and water emissions sent to waste treatment.

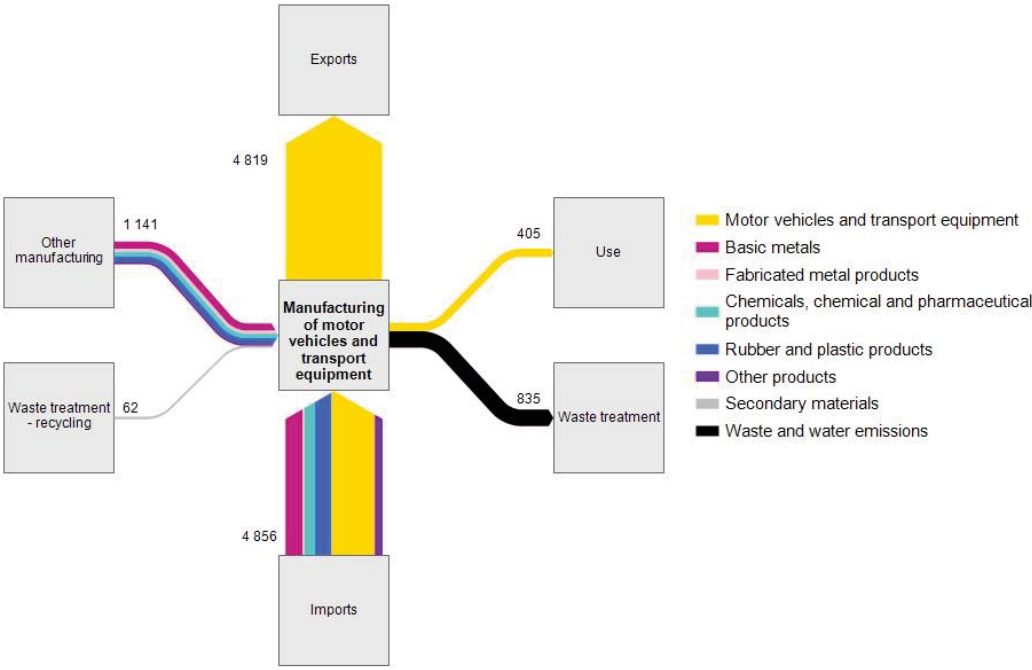
A total of 405 thousand tonnes of motor vehicles and transport equipment entered the use phase from domestic manufacturing (24% of material inputs) and 1 304 thousand tonnes from imports (76% of material inputs). Motor vehicles and transport equipment totaling 1 447 thousand tonnes was then added to physical stock while 262 thousand tonnes of vehicles currently in-use was discarded and sent to waste treatment. The total mass of waste and water emissions entering waste treatment amounted to 1 390 thousand tonnes, of which 60% came from manufacturing phase (835 thousand tonnes), 19% from use phase (262 thousand tonnes) and 21% was imported (293 thousand tonnes). The largest amount of this waste was exported (57%, 790 thousand tonnes), 448 thousand tonnes was sent to waste treatment

Figure 1 EW-MSA of motor vehicles and transport equipment (thousand tonnes), Czech Republic (2017)



Source: Own calculation

Figure 2 EW-MSA of motor vehicles and transport equipment – manufacturing phase (thousand tonnes), Czech Republic (2017)



Source: Own calculation

– recycling (32%) and 151 thousand tonnes of waste and water emissions was landfilled or released to the environment (11%). A minor amount of waste was further incinerated, which resulted in some negligible air emissions and input and output balancing items. In the waste treatment – recycling phase, 424 thousand tonnes was sent back to manufacturing in the form of secondary materials (95%) and 24 thousand tonnes was landfilled (5%). In the case of secondary materials, 62 thousand tonnes headed directly to manufacturing of motor vehicles and transport equipment while 362 thousand tonnes headed to manufacturing of other products.

3 DISCUSSION

As stressed in the Introduction, manufacturing of motor vehicles and transport equipment plays a crucial role in the Czech economy. This has been determined by historical development as well as more recent policies. Tatra produced the first ever passenger car in Central Europe on the area of the current Czech Republic in 1897 followed by the first lorry in 1898. Laurin & Klement was producing motorcycles from 1899 and passenger cars from 1905, but merged with Skoda in 1925, which was originally founded as an engineering company in 1866. Walter produced motorcycles, passenger cars, lorries and buses from 1901, while Praga produced them from 1907 and Sodomka produced coachwork from 1925. Liaz was founded after WWII and focused on the production of utility motor vehicles while Skoda became the largest producer of passenger cars in communist Czechoslovakia (Karaban, 2012). When the communist regime was overthrown in 1989, the previously state-owned companies mentioned above were privatized and Skoda became a part of the Volkswagen Group in 1991 (Volkswagen Group, 2021). In the 1990s several other motor vehicle-producing companies established themselves in the Czech Republic, because the country offered a stable political and economic environment, qualified workforce and good access to the European market. Moreover, there was a number of investment incentives available for these companies, such as tax rebates, subsidies for affected municipalities or workforce education and requalification (Junga, 2009). Two notable companies included Toyota Motor Manufacturing Czech Republic Ltd., which started producing cars in 2005, and Hyundai Motor Manufacturing Czech Ltd., which opened in 2006. Thanks to these investments and also because Skoda has flourished under the Volkswagen Group, almost 1.5 million motor vehicles were produced in the Czech Republic in 2019, which was the fourth highest number in Europe after Germany, Spain and France (The European Automobile Manufacturers' Association, 2021).

In spite of a strong focus on manufacturing motor vehicles and transport equipment, the EW-MSA showed that the Czech Republic is not endowed with the appropriate resources for their manufacture. It does not mine any ores apart from a small amount of uranium ore and it extracts only a negligible amount of crude oil (Czech Geological Survey, 2018). This is the reason why the vast majority of semi-manufactured products needed for motor vehicles and transport equipment manufacturing had to be imported (Figure 2) and even those supplied by the Czech economy such as some basic metals, fabricated metal products or rubber and plastic products were produced from imported raw materials. This means that the environmental pressure associated with the production of imported raw materials and products is overwhelmingly shifted abroad, which poses a question about fairness of such manufacturing in terms of and environmental justice. For further details on the shifts of environmental pressure due to foreign trade see Kovanda and Weinzettel (2013). High dependency on natural resources from abroad, however, is also an economic threats, because the required resources and semi-manufactured products might not necessarily always be available on international markets and/or their price can fluctuate. Moreover, the Raw Material Policy of the Czech Republic (Ministry of Industry and Trade, 2017) pleads for decreasing foreign resource dependency. Any potential further increase in the share of motor vehicle manufacture in the Czech economy is thus in contradiction with this policy.

Over 92% of manufactured motor vehicles and transport equipment were exported in 2017 and contributed by 7% to total exports in terms of mass, but by 25% in monetary terms. No other product group had such a high share in monetary exports (Czech Statistical Office, 2019a). Four hundred and five thousand tonnes of motor vehicles and transport equipment was sent to use and another 1 304 thousand tonnes was imported for use. Despite 262 thousand tonnes of motor vehicles and transport equipment were discarded in 2017, its physical stock increased by 1 447 thousand tonnes (Figure 1). The number of road motor vehicles per 1 000 inhabitants was thus growing in the Czech Republic – it was 625 in 2016, but 645 in 2017, which was a yearly increase of more than 3% (Ministry of Transport, 2018). According to some researchers (Bringezu and Bleischwitz, 2009) growing physical stock (i.e. a positive NAS indicator) is a sign of unsustainability, as it implies growing material inputs for stock maintenance as well as growing waste flows from these stock in the future. Even though the NAS of motor vehicles and transport equipment constituted less than 2% of total NAS in 2017, about 86% of total NAS was related to buildings and transport infrastructures that year. This means that an increase in NAS and of the numbers of motor vehicles also drove an expansion of transport infrastructures, which accumulated a significant amount of materials. Moreover, increase in road traffic is related to many well-known negative impacts on ecosystems and human health (e.g. World Health Organization, 2000).

Waste-related policies in the Czech Republic required an increase in waste recycling in order to support a transition to an economy based on circular use of resources (Ministry of Industry and Trade, 2018). From the 1 390 thousand tonnes of motor vehicles and transport equipment waste which was either imported or came from manufacturing and use phases, the largest share was exported – 57% (790 thousand tonnes), 31% (424 thousand tonnes) was recycled and sent back to manufacturing and the rest was mostly landfilled (NAS) or released to the environment from waste treatment and waste treatment – recycling phases (Figure 1). Exported waste was sent abroad either for final treatment/disposal or recycling, representing a significant loss of resources which could have been recycled domestically and sent back to manufacturing. This touches upon the tricky question of the scale at which material loop closing should be attempted. Not all countries have domestic metal processing industries which would be required for the proper recycling of metals. Material cycles can, therefore, not easily be established at national scale – and it is not even clear if this would even make sense from a sustainable resource use perspective. In the case of the Czech Republic, however, manufacturing of basic metals and fabricated metal products is a key industry – the share of MVA from this manufacturing in total MVA was 15% in 2017 (Czech Statistical Office, 2019a). Therefore, capacity for metal recycling should be increased.

CONCLUSIONS

Manufacture of motor vehicles and transport equipment is a key industry in the Czech Republic – it contributes to national GDP by about 4.6%, which is in fact the highest share globally. The prominent position of motor vehicle manufacturing in the Czech Republic has been partly determined by historical development, since the first company producing motor vehicles was founded on the area of what is now the Czech Republic at the end of 19th century, and partly because of qualified workforce, good access to the European market and various investment incentives, which attracted large international car producers like Toyota and Hyundai to open their factories in the country after the communist regime had been overthrown in 1989. The aim of this article was to study physical material flows mobilized by motor vehicles and transport equipment manufacturing in order to assess long-term viability of these flows from the perspective of resource self-sufficiency and waste management. We applied an economy-wide material system analysis (EW-MSA) for this purpose – a new method recently developed by Kovanda (2021) – which monitors material flows along production chains, connects manufacturing and use of various products with related waste flows and shows how waste is recycled.

EW-MSA revealed that the Czech Republic is not endowed with resources needed for manufacturing of motor vehicles such as metals or crude oil. These resources have to be imported, which is related to controversial shifts of environmental pressure abroad, but also some economic threats, because the needed resources do not have to be always available on international markets for reasonable prices. The stock of motor vehicles is growing in the Czech Republic, which is reflected by an increase in motorization rate, i.e. the number of vehicles per 1 000 inhabitants. More motor vehicles pose a need for an expansion of transport infrastructures, which constitute a major part of total physical stock of the economy. This is a sign of unsustainability according to some researchers, because larger physical stock implies growing material inputs for stock maintenance as well as growing waste flows from these stock in the future. Regarding waste from motor vehicles manufacturing and use, 57% was exported, 31% was recycled and sent back to manufacturing and the rest was mostly landfilled. Both exported and landfilled waste represent a loss of resources which could be recycled domestically. While exported waste can still be recycled abroad, it would be much more beneficial for the Czech Republic to recycle it at home, send it back to manufacturing and decreasing the need to import further primary resources.

Focus on the manufacturing of motor vehicles and transport equipment brings about economic benefits for the Czech Republic, but as highlighted above the perspective of related physical material flows points at various critical issues. A further increase in the share of motor vehicles manufacturing in the economy would even be in the contradiction with some other policies like Raw Material Policy of the Czech Republic (Ministry of Industry and Trade, 2017), which pleads for decreasing foreign resource dependency. Also treatment of waste from motor vehicles manufacturing and use is far from being in line with the principles of circular use of resources (Ministry of Industry and Trade, 2018). Last but not least, the strong focus of an economy on one manufacturing branch can be risky from economic point of view in a long-term perspective, since we live in a changing world and the dominance of motor vehicles manufacturing in the global economy could abruptly come to an end, e.g. due to potential technological breakthroughs in the field of goods and passenger transportation. All these factors should be taken into account when designing further economic, but also social and environmental policies, which calls for horizontal and vertical policy coordination, articulated e.g. in the Strategic Framework Czech Republic 2030 (Government of the Czech Republic, 2017).

EW-MSA is a new methodological approach. This is the reason why we could provide international comparison of some more general indicators like the share of automotive industry in GDP, but we were not able to show any international benchmarking of particular EW-MSA indicators. Still, EW-MSA is a promising tool, which can be applied for other product groups as well, including food, textiles or plastics. Major shortcoming of EW-MSA is the fact that it is a very data-demanding method. Only a fraction of needed data is directly accessible in the official statistics while the rest has to be estimated and modelled with the use of various proxies like monetary input-output tables. This would present a challenge for official statistics if the proposed method was applied more widely or was considered obligatory by institutions like Eurostat.

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