

Car manufacturing case study

Introduction

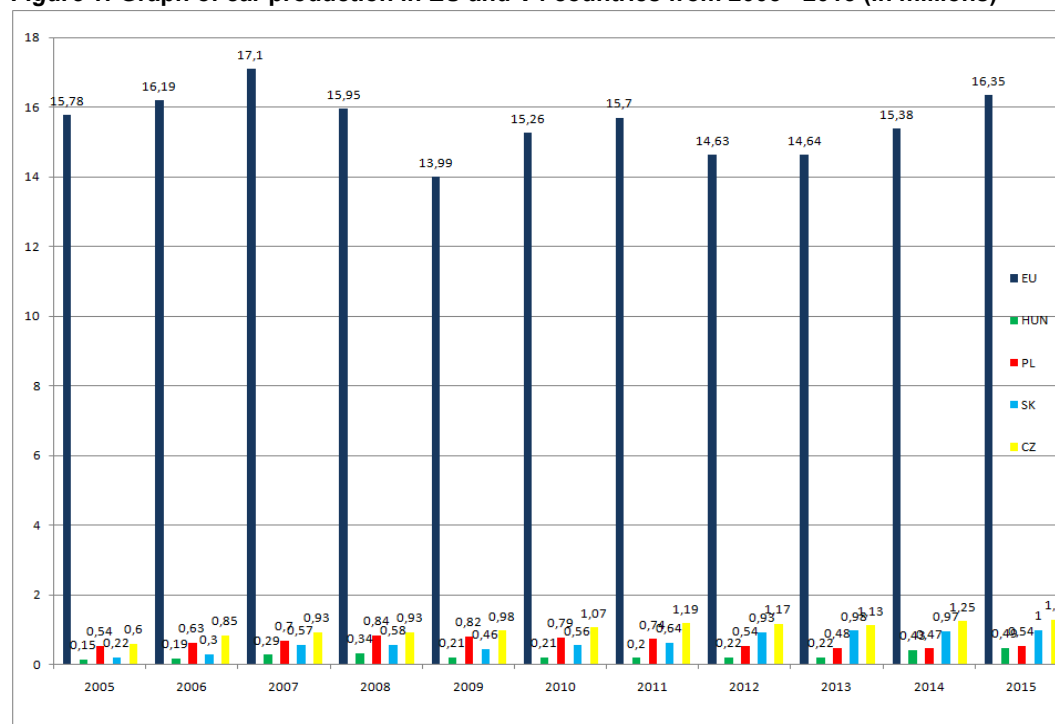
Thanks to crucial changes in new technology, innovations, and global markets, the automotive industry is undergoing a major transformation. Innovations regarding autonomous technologies, car sharing, lowering CO2 emissions and supporting electric motor vehicles will have a major impact on the automotive industry.

In the last decade the V4 region became the center of car manufacturing in Europe. Mainly thanks to the availability of a relatively cheap workforce, the stable political situation after entering European Union, being part of EU free market, having solid infrastructure and its proximity to the western European market. In all V4 countries industry has a traditionally strong role and position. The output of the automotive industry is crucial for the economic condition of the region and makes up an important share of exports for the region. Therefore trends in the automotive industry will have a significant socio-economic impact.

1. Importance of the automotive industry for V4 countries - basic data

1.1. Production statistics

Figure 1: Graph of car production in EU and V4 countries from 2005 - 2015 (in millions)

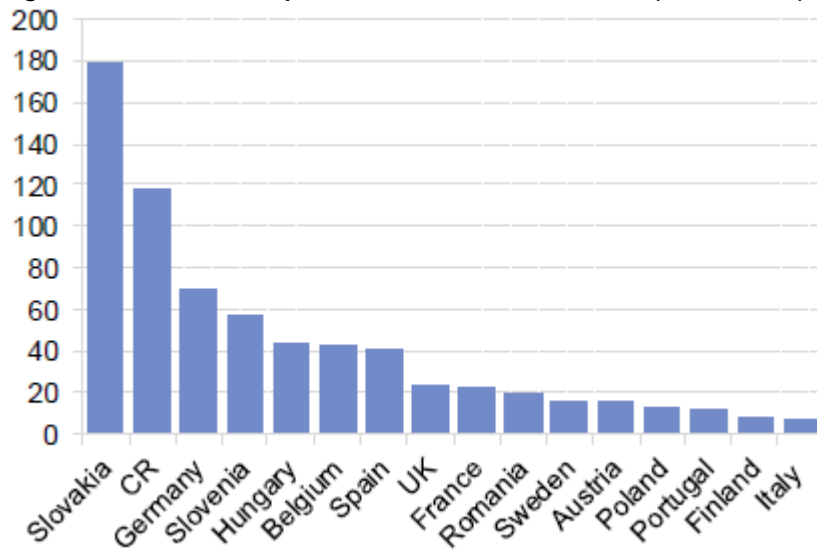


Source: OICA¹

¹<http://www.oica.net/category/production-statistics/>

Rounded on two decimal places

Figure 2: Produced cars per thousand inhabitants - 2014 (in 1000 cars)



Source: OICA; Eurostat² 2014

In year 2015 according to OICA - The International Organization of Motor Vehicle Manufacturers statistics, 68 539 516 cars were manufactured globally. In the European Union alone it was 18 515 293 cars, which is around a 27 % share of global markets. In the V4 countries together 3 324 657 cars were produced, which is a 4,9 % share of global production and 18 % of EU production.

According to ACEA – The European Automobile Manufacturers Association pocket guide³ for 2015 there were 221 plants in the European Union - out of which 30 plants were in V4 countries - Slovakia has only 3 plants, Hungary 4 plants, Poland 15 plants and the Czech Republic 8 plants. As we can see, a high number of plants does not necessarily mean bigger production numbers. In 2015 Slovakia had (with only 3 assembly plants) almost the same production statistics as the Czech Republic and twice as much in comparison to Poland.

1.2. Automotive industry and employment

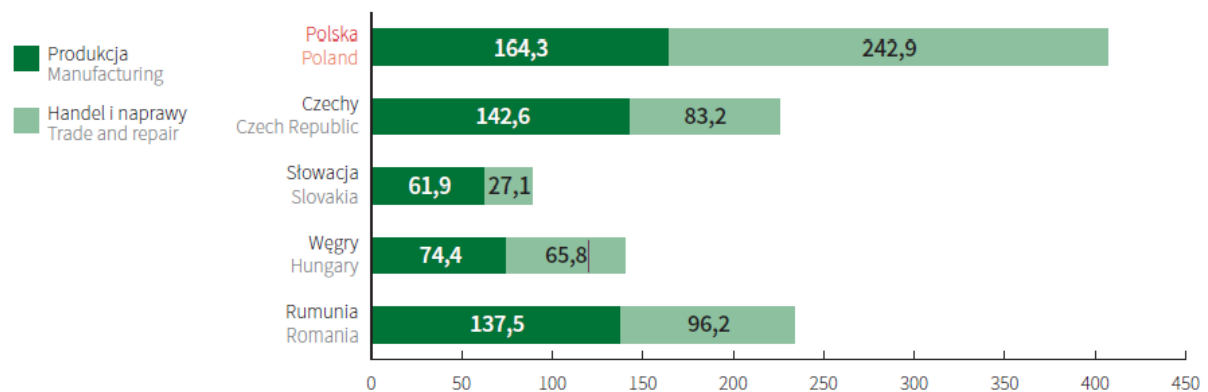
According to the ACEA pocket guide there were around 12 million jobs in 2012 connected to the automotive industry in the European Union. It is important to realize that this is not only car assembly - The automotive industry consists of direct manufacturing, indirect manufacturing (which means supplier companies which supply for example specific parts, tires etc.), automobile use connected jobs such as car sales, car repairs etc., transport connected jobs, and construction jobs. For the purpose of this report the most important are direct and indirect manufacturing jobs. In 2012 there were 2,3 million direct manufacturing jobs in the EU and 0,8 million in indirect manufacturing.

2IN: Kozelský Tomáš, and Novák Radek. "Automotive industry: future trends." CSAS. KNOWLEDGE CENTRE - Česká spořitelna, a.s., Sept. 2015. Web. 6 Feb. 2017.

3The Automobile Industry pocket guide. N.p.: ACEA, 2016. [Http://www.acea.be/](http://www.acea.be/). ACEA. Web.

According to the graph below in the V4 there are 443 200 jobs in car manufacturing. As we can see in comparison with data from production there is not an inevitable correlation between production numbers and the numbers of jobs. Slovakia, with less jobs in manufacturing than Poland and Hungary produced more cars than both countries combined (2013 Slovakia - 975 000 cars, Hungary - 321 000 cars, Poland - 590 120 cars). The main reason is that while Slovakia has only three plants, all of them are major plants with a high level of robotization, which enables them to produce more cars with less workers.

Figure 3: The employed in automotive companies in V4 and Romania in 2013 (1000 people)



Źródło: KPMG w Polsce na podstawie danych Eurostat i GUS. Dane obejmują pełną populację przedsiębiorstw
 Source: KPMG in Poland based on Eurostat and GUS data. Data cover complete statistical population

Source: Automotive industry report 2015 - Poland

Slovakia

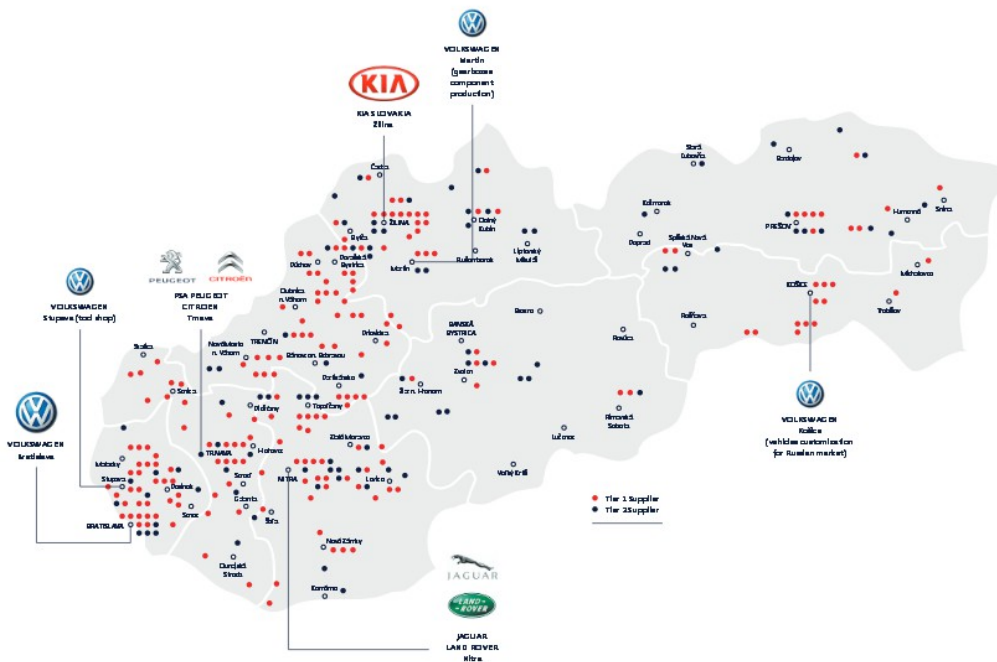
According to the Annual report on the progress of the automotive industry in 2015, 114 500 people were employed in the automotive industry⁴ in Slovakia. From that, roughly 17 000 people are employed in direct car manufacturing by three plants VW Bratislava, KIA Motors - Žilina and PSA Peugeot - Trnava. 82 000 people are employed by TIER 1,2,3 suppliers⁵. Average super-gross wage in 2015 was 1040 euros - in the last 5 years this raised by 19,1%. The average wage in VW Bratislava is 1750 euros. The lowest wages in general are in East Slovakia - the difference is around 30% compared to the average wage in the automotive industry.

These numbers show the complexity of the enterprise. The map below indicates that the whole manufacturing industry is based in Western Slovakia. (Blue dots represent Tier 1 suppliers and red Tier 2 in concrete area.) Slovakia has a long standing problem with regional inequalities- Eastern Slovakia especially falls behind in employment and economic performance indicators. Without any doubt the automotive industry has a major impact on Slovakia's economic growth, but the negative side is that it contributes to a deepening of regional disparities in Slovakia.

⁴Only in direct and indirect manufacturing

⁵Nowadays supply chains usually consists of 4 levels of suppliers: Tier 1, Tier 2, Tier 3, Tier 4 - detail explanation of supply chain in chapter 2.

Figure 4: Map of automotive TIER 1,2 suppliers in Slovakia



Source: SARIO

Czech Republic

In the Czech automotive industry the manufacturing of car parts has had a bigger share in market and employment than car manufacturing in the last decade.⁶ According to the statistics of the Czech association of the automotive industry, 66% of all automotive employees work in supplier companies. In the automotive industry in 2015, 155366 people were employed⁷, which is a 3,1% share of whole labor market. The average wage in 2015 was 1168 EUR, which is 47% higher than it was in 2005 and is 22,7% above the national average (source: Autosap). At present the major obstruction to further development of the automotive industry in the Czech Republic is the lack of a suitable labour force.

Figure 5: Map of automotive suppliers in Czech Republic



Source: Czechinvest

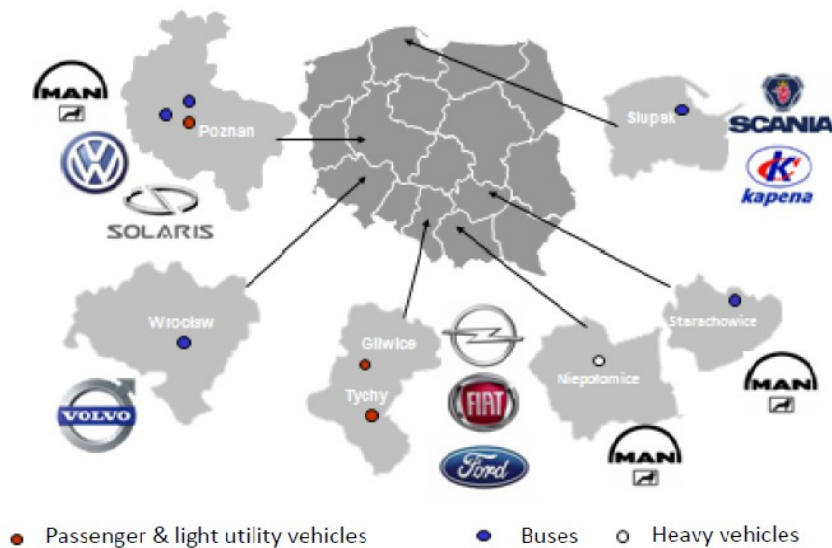
⁶Panorama zpracovatelského průmyslu ČR 2015. Praha: MPO, 2015. [http://www.mpo.cz/assets/cz/prumysl/zpracovatelsky-prumysl/panorama-zpracovatelskeho-prumyslu/2016/11/Panorama_CZ_internet_komplet.pdf](http://www.mpo.cz/Web/<http://www.mpo.cz/assets/cz/prumysl/zpracovatelsky-prumysl/panorama-zpracovatelskeho-prumyslu/2016/11/Panorama_CZ_internet_komplet.pdf>)

⁷Source: ČSÚ, MPO calculation

Poland

In 2013 the share of the automotive industry in employment was almost 9%. According to GUS data 407 200 people were employed in Poland's automotive industry in 2013, of which 40% were employed in manufacturing (direct and indirect). From 2006 - 2013 the automotive sector in Poland saw constant growth in employment - average employment increased by 40%⁸. This growth was not followed by growth of the share of the sector in the value of sold production of the processing industry, which ranges around 12%. According to Poland's investment agency this is not caused by a decrease in labor productivity, but by an increase of productivity in different industrial sectors in Poland. Labour productivity in the automotive sector is approximately 40% higher than in the entire processing industry.

Figure 6: Main manufacturers in Poland



Source: www.paiz.gov.pl.

Hungary

In 2014, out of all the V4 region, Hungary had the lowest hourly wages at around 8 euros per hour. In Poland wages were above 9 euros, and in the Czech Republic and Slovakia above 10 euros.⁹ In 2013 there were around seven hundred enterprises in the automotive industry which jointly employed 115 717 people. From that number, around 14 000 jobs were created by big manufacturing companies - (Audi, Suzuki, Mercedes and Opel). From TIER suppliers most the important employers are BOSCH, Denso, Knorr-Bremse, Hankook Tire, and Continental. From an investor's point of view Hungary has very competitive labor prices, but low mobility of workforce within the country.¹⁰

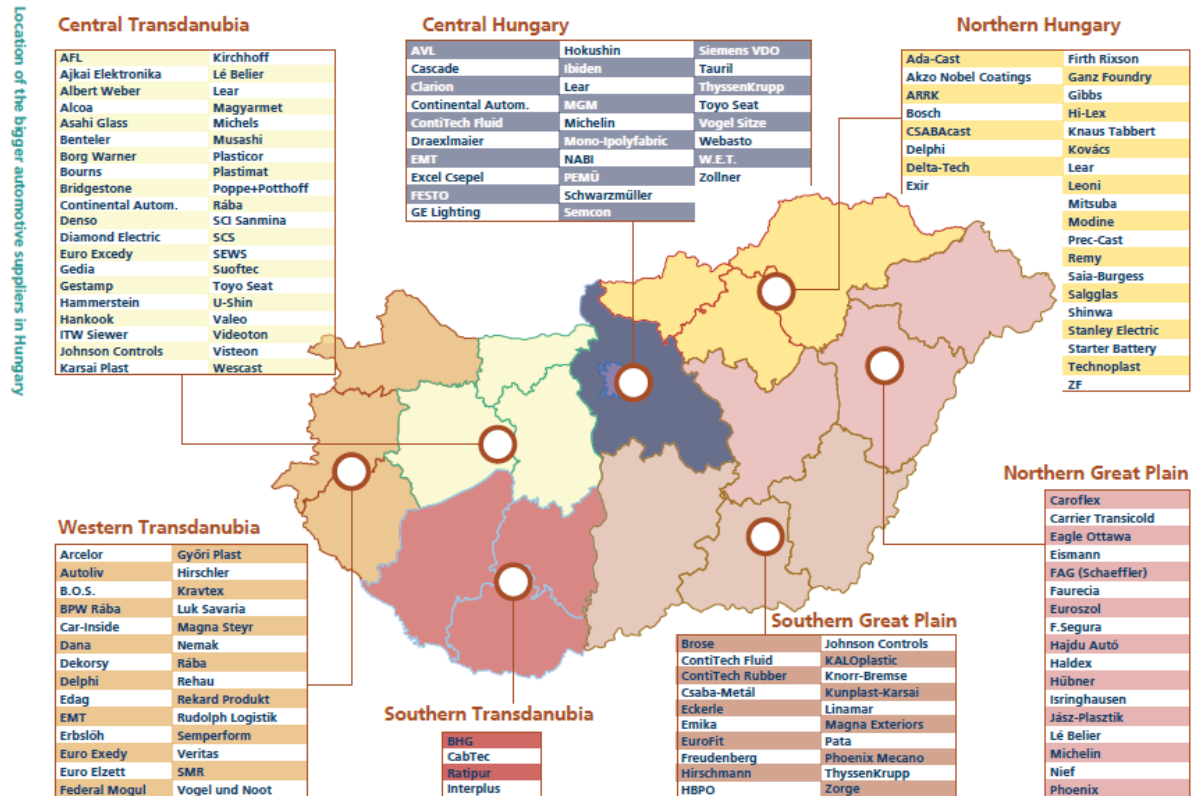
⁸The automotive sector in Poland - Sector profile. N.p.: Polish Information and Foreign Investment Agency, 2013. www.paiz.gov.pl. Web. 16 Feb. 2017.

⁹Automotive industry in Hungary. N.p.: HIPA - Hungarian investment promotion agency, 2014. www.hipa.hu. Web. 16 Feb. 2017.

¹⁰A Study on the Hungarian Automotive Industry - Market Opportunities for Canadian Automotive Suppliers. N.p.: Canadian Trade Commissioner Service, 2014.

<https://www.enterprisecanadanetwork.ca/>. Mar. 2014. Web. 16 Feb. 2017.

Figure 7: Map of automotive suppliers in Hungary



Source: www.hita.hu

1.3. The automotive industry and its impact on the economic growth of V4 countries

The automotive industry in all V4 countries is massively export oriented- more than 90% of production is meant for non domestic markets. In all V4 countries the automotive industry has played a key role since the 1990's in economic development and is essential for economic growth. The economic crisis in 2008 had a very different impact on the automotive sector in V4 countries. When we analyse it using the productivity statistics (figure 1) we can see the immediate impact the crisis had on Hungary, where it was represented by a massive drop in production in 2009 which recovered only in 2014. In Poland, even though the fall in production was not so sudden as in Hungary, between 2009 and 2014 the number of produced vehicles continually decreased and in 2014 statistics show production almost halved compared to 2008. 2015 was for Poland the first year of growth in the production of vehicles since 2008. Slovakia had a drop in production as well in 2009, but almost immediately in 2010 came back to steady growth and since 2005 Slovakia has had the fastest growing production statistics of all the V4 countries. The Czech Republic is the only V4 country whose growth in production was not influenced by the 2008 economic crisis. The data below about the share of the automotive industry in industrial production, total export and GDP illustrates that thanks to steady growth in production Slovakia and The Czech

<https://www.enterpriseacanadanetwork.ca/_uploads/resources/A-Study-on-the-Hungarian-Automotive-Industry.pdf>.

Republic were able to maximize the influence of the automotive industry on economic performance in comparison to Poland and Hungary.

In the Czech Republic in 2015 the automotive industry had a 24,7% share of industrial production, 7,4% share of GDP and 23,4 % share of total export¹¹. In Slovakia the share of the automotive industry in economic performance indicators is even higher. In 2015 the automotive industry had a 44% share of industrial production, 12% share of GDP and 40% of total export. The automotive industry in Slovakia generated 26 billion EUR worth of export.¹²

According to the automotive industry yearbook 2015¹³, the automotive industry in Poland had in 2015 9,7% share of industrial production and in 2014 it had 15,5 % share of total export which amounted for 25,3 billion EUR.

In 2013 the Hungarian automotive industry produced 17,8 billion in value, which is almost 20% of the entire industrial output. Its share of total export is 18 %, and the automotive industry has a 10 % share of the Hungarian GDP.¹⁴

Even considering this, Slovakia and the Czech Republic are (according to data) in the long term more attractive to automotive investors and were able thanks to growth in production to increase their economic performance indicators more than Hungary and Poland. This also illustrates their increasing dependency on the automotive sector especially in the case of Slovakia.

1.4. Investment incentives for the automotive industry

As we can see from the data above, the economic performance and growth of V4 countries is closely interconnected with the volume of investment. Each V4 country has its own investment agency. Their role is to encourage companies through so-called investment incentives to invest in the country.

Incentives can have different forms, for example:

- a subsidy for the acquisition of material assets and immaterial assets
- an income tax relief
- a contribution for created new jobs
- transfer of immovable property or exchange of immovable property at a price lower than a general asset value

In 2018 construction work will begin on the new Jaguar Land Rover plant in Nitra Slovakia. Jaguar will receive 130 million EUR worth of incentives which is around 9% of whole investment package prepared by Jaguar. Poland and Hungary also offered incentives

11 IN: Kozelský Tomáš, and Novák Radek. "Automotive industry: future trends." CSAS. KNOWLEDGE CENTRE - Česká spořitelna, a.s., Sept. 2015. Web. 6 Feb. 2017.

12Source: Slovak association of automotive industry, Statistics office of the Slovak republic

13*Automotive industry Year Book 2015*. N.p.: n.p., 2015. [Http://www.pzpm.org.pl/](http://www.pzpm.org.pl/). Polish Automotive Industry Association. Web. 17 Feb. 2017. <<http://www.pzpm.org.pl/en/Automotive-market/Reports/PZPM-Automotive-Industry-Report-2015>>.

14*A Study on the Hungarian Automotive Industry - Market Opportunities for Canadian Automotive Suppliers*. N.p.: Canadian Trade Commissioner Service, 2014.

[Https://www.enterprisecanadanetwork.ca/](https://www.enterprisecanadanetwork.ca/). Mar. 2014. Web. 16 Feb. 2017.

<https://www.enterprisecanadanetwork.ca/_uploads/resources/A-Study-on-the-Hungarian-Automotive-Industry.pdf>.

to Jaguar, but Slovakia offered more and therefore was able to get the investment. Even though it may appear as a competitive advantage to offer such a high incentives, the Slovak government decision to do so was widely questioned. One of the effects of incentives should be to lower regional disparities - therefore incentives should be mostly directed to eastern Slovakia and not to the west, as is the case here.

2. The supply chain of car manufacturing

Car manufacturing is a complex enterprise which includes a number of interconnected companies cooperating in a so called supply chain network. A supply chain includes every step in the production process from extracting raw materials to finishing the final product including its supply to the final users. In the last two or three decades thanks to changes in the global economy the importance and complexity of the global supply chain increased massively. Nowadays supply chains usually consist of 4 levels of suppliers: Tier 1, Tier 2, Tier 3, Tier 4¹⁵

TIER 1: first level suppliers - companies which export directly to manufacturing plants. Some of these suppliers are so called global mega-suppliers with their own innovations capacities. In the V4 group Hungary has a strong chain of TIER 1 suppliers (BOSCH, Denso, Knorr-Bremse).

TIER 2: second level suppliers are companies which manufacture parts exactly according to designs provided by car manufactures or global mega-suppliers. Experience and skill in processing engineering is necessary for these companies to function. They usually have a concrete market that they concentrate on, but bigger companies try to be part of the international market. An example of a Tier 2 supplier would be OSRAM a.s. in Slovakia, in Nové Zámky, where car lights are manufactured.

TIER 3: Suppliers of basic products. These companies often have basic engineering experience focused in one area. There is often a great level of price competition among these companies. Among the biggest Tier 3 suppliers we count organisations such as steelworks companies. In Slovakia for example it is U.S. Steel Košice

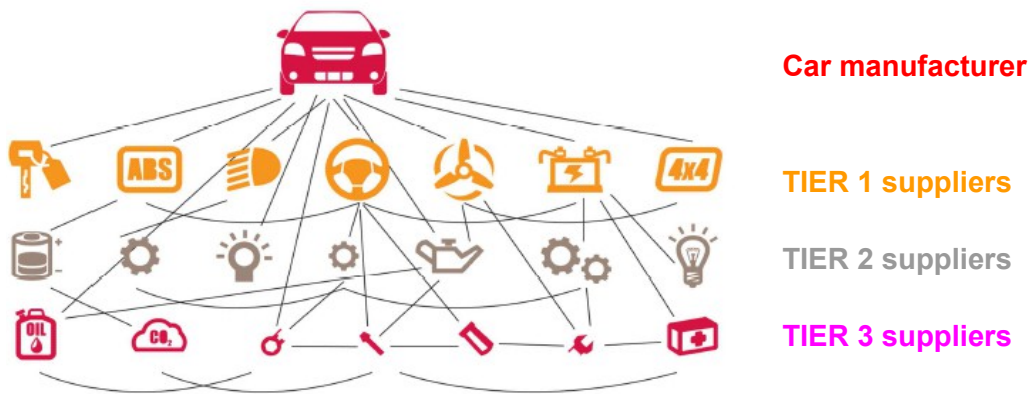
TIER 4: Raw material suppliers. They supply raw materials usually to TIER 3 suppliers. TIER 4 is often left out from characterizations of the supply chain, because there is not much information on interaction available to the public.

For car manufacturing various raw materials are used including steel, plastic, Aluminium, Rubber, Glass and variety of precious metals (for example platinum, rhodium, palladium, lithium).

¹⁵Slušná, Ľubica, and Miroslav Balog. *Automobilový priemysel na Slovensku a globálne hodnotvé reťazce*. Bratislava: Slovenská inovačná a energetická agentúra, 2015. <https://www.siea.sk>. Web. 17 Feb. 2017.

<https://www.siea.sk/materials/files/inovacie/publikacie/studia_Automobilovy_priemysel_na_Slovensku_a_globalne_hodnotove_retazce_SIEA_web.pdf>

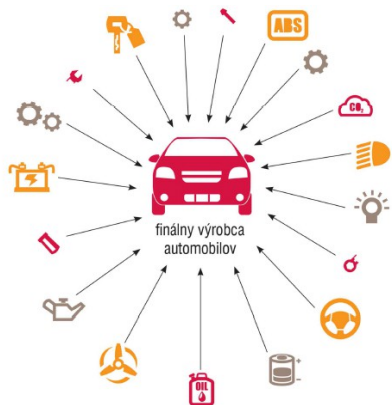
Figure 8: structure of supply chain and its interconnections



Source: in: *Automobilový priemysel na Slovensku a globálne hodnotvé reťazce*

In figure 9 below is example of supply scheme from 70s and 80s. Car manufacturers had a huge variety of suppliers, without any complex structure. Usually everything was assembled “under one roof”. This structure proved to be less effective especially in terms of management and logistics and it left manufacturers more vulnerable to market changes.

Figure 9: conventional supply scheme from 70s and 80s



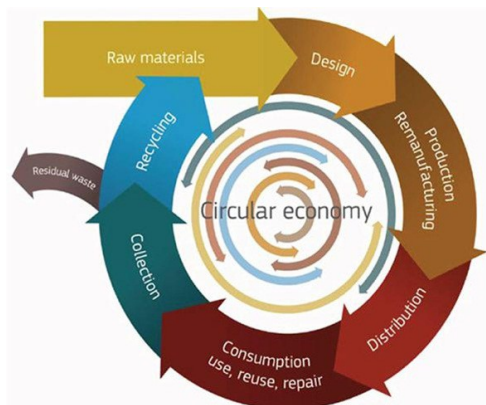
Source: in: *Automobilový priemysel na Slovensku a globálne hodnotvé reťazce*

Side note: The transition from figure 9 to figure 8 represents the transition from so called “fordism” to the global economy. Globalised markets, thanks to many interconnections and a constant flow of many different inputs (innovations, capital etc.) change much faster than markets back in 70s. The Detroit collapse was an example of the inability of car manufacturers to adapt to quickly changing markets. Complex supply chains allow car manufacturers more flexibility and higher efficiency. On the other hand, the lowest parts of the supply chain are more vulnerable to unfair price competition. Suppliers of raw materials, thanks to low prices of raw materials in some cases, are not able to meet environmental standards and also work environment standards. In developing countries unfair wages and dangerous work conditions are often the case and as a result human rights are violated.

3. Lifecycle of a car - from cradle to grave

According to EIPRO - the environmental impact of products study by the European Commission - passenger transport in 2000 had a 15% to 35% share in the environmental impact of private consumption. Defining all parts of products lifecycle is key to understanding the environmental and social impact of a concrete product. To ensure responsible production and consumption sustainability has to be considered throughout the product life - from cradle to grave. A circular economy is an ambitious concept which aims to create harmony between consumption, production and environmental limits. The ambition is to “close the loop” of a products lifecycle through more efficient recycling and reuse. Such an approach could foster energy savings and ease dependence on raw materials. Implicit in this concept is a condition that an economy can not grow exponentially.

Figure 10: Circular economy diagram



Source: <http://www.acceleratio.eu>

3.1. Basic car lifecycle¹⁶

A full lifecycle includes everything from the raw materials extraction process to the car disposal. The five stages below represent 5 clusters of the most significant processes throughout the car's lifecycle with significant environmental impact implications. A car as a product has huge number of environmental and social impacts including for example noise pollution, safety issues, a variety of health risks or its influence on urban life and public spaces. It is not possible to include them all in this report.

The major categories of environmental impacts:

Climate change (GWP) - causes the increase of Earth's average surface temperature through the greenhouse effect, which is caused mainly by carbon dioxide emissions from burning fossil fuels.

¹⁶NEMRY, Françoise , and Guillaume LEDUC. *Environmental Improvement of Passenger Cars (IMPRO-car)*. N.p.: n.p., 2008. <http://ipts.jrc.ec.europa.eu/>. European Communities. Web. 18 Feb. 2017. <<http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=1564>>.

Acidification (AP) - This process happens when compounds like ammonia, nitrogen oxides and sulphur dioxides are converted in a chemical reaction into acidic substances. Most of the compounds are a direct result of air pollution.

Eutrophication (EP) - Eutrophication is the enrichment of an ecosystem with chemical nutrients, typically compounds containing nitrogen, phosphorus, or both. Human activities can accelerate the rate at which nutrients enter ecosystems.

Ozone depletion (ODP) - Destruction of stratospheric ozone, by a group of manufactured chemicals, containing chlorine and/or bromine. These chemicals are called "ozone-depleting substances" (ODS). (used in vehicle air conditioners)

Photochemical oxidation (POCP) - Photochemical oxidation is secondary air pollution, also known as summer smog. It is formed in the troposphere and caused mainly by the reaction of sunlight with emissions from fossil fuel combustion creating other chemicals¹⁷.

Consumption of primary energy resources (PE)¹⁸ - Primary energy consumption refers to the direct use at the source, or supply to users without transformation, of crude energy, that is, energy that has not been subjected to any conversion or transformation process.

Abiotic depletion (excluding primary energy depletion) (AD) - Human depletion of abiotic / non-living resources, such as water, soil, and minerals is a source of concern for humans.

Solid waste / Bulk waste (BW) - refers to waste types that are too large to be accepted by regular waste collection.

Emissions of particulate matters with a diameter lower than 2.5 microns (PM2.5) - PM 2.5 particles are 2.5 micrometers in diameter or smaller, and can only be seen with an electron microscope. Such particles are produced from all types of combustion, including motor vehicles, power plants, residential wood burning, forest fires, agricultural burning, and some industrial processes. This type of pollution is connected to different kinds of health complications such as irritations, shortness of breath etc.

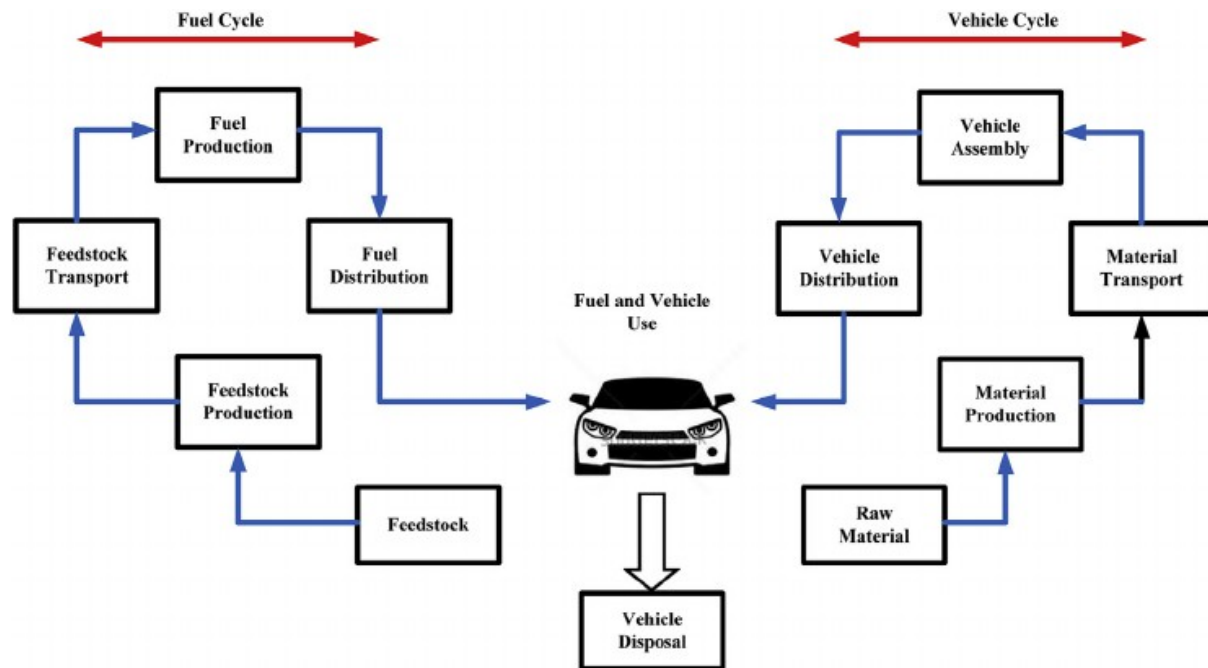
Car life cycle stages:

1. Car production (raw material extraction, material transformation and car assembly)
2. Replacement and spare parts production (tyres, battery, lubricants and refrigerants)
3. Fuel transformation process upstream to fuel consumption (well-to-tank - WTT)
4. Fuel consumption for car driving (tank-to-wheel - TTW)
5. Car disposal and waste treatment (end-of-life - EOL)

¹⁷Source: Life cycle association of New Zealand

¹⁸Definition by OECD

Figure 11: Vehicle life cycle diagram



Source: <https://www.researchgate.net>

3.2. The Impact of individual stages of car's life cycle on chosen major environmental impact categories mentioned above.

Consumption of primary energy resources (PE)

Most of primary energy resources is connected to the fourth stage TTW -Tank to wheels. Other important processes where primary energy is consumed:

- Energy used for refinery processes and fuel distribution (WTT phase)
- The production phase uses energy: A indirectly - energy needed to extract raw materials, transform and transport them B directly - for assembly purposes
- In spare parts production energy is used mostly on production materials used (rubber, steel etc.) and energy used in manufacturing tyres (Tyres as a most used spare part)
- Energy associated with recovery and recycling is not worth accounting for.

Climate change is a direct result of primary energy consumption, due to combustion processes which have a major share in emitting greenhouse gases.

Figure 12: Percentage contribution by substances emitted in the different phases on the total GWP impact (petrol car)

Substances	Production	Spare parts	WTT	TTW
Carbon dioxide	4.5	0.4	12.3	76.2
Methane	0.1	--	0.9	--
HFC-134a	--	--	--	2
Remaining substances	3	0.3	--	--
Total	8	1	13	78

Source: <http://ipts.jrc.ec.europa.eu>

Acidification

The acidifying substance emitted in largest quantities is SO₂ - also NO_x and ammonia are emitted. SO₂ emissions are mainly emitted throughout the extraction and transportation of crude oil as well as in the production of unleaded petrol. The Production of materials for cars and its components is also significant depending on the zinc coating processes during which SO₂ is emitted.

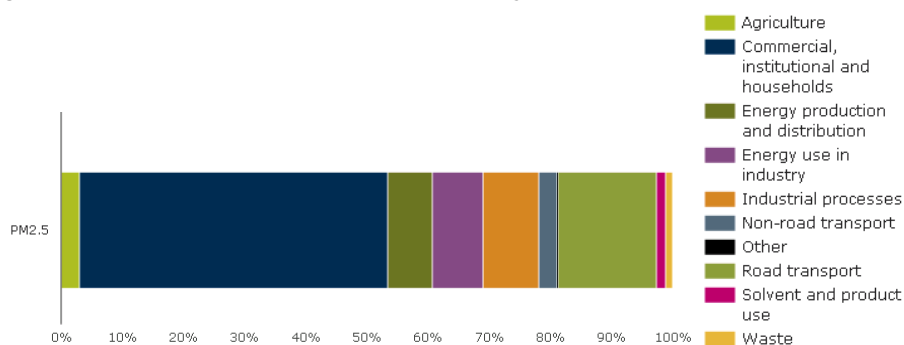
Figure 13: Percentage contribution of different life cycle phases to the acidification impact

Processes	%	Phases
Energy in crude extr.	23	WTT
Energy in refinery	12	WTT
Zinc	8	Production
Palladium	7	WTT
Transportation	7	WTT
Platinum	3	Production
TTW	2	TTW
Rhodium	2	Production
Polypropylene	1	Production
Palladium	1	Production
Remaining processes	32	

Source: <http://ipts.jrc.ec.europa.eu>

PM 2.5 particles

Figure 14: Sector share of emissions of primary PM 2.5. Particulate matter

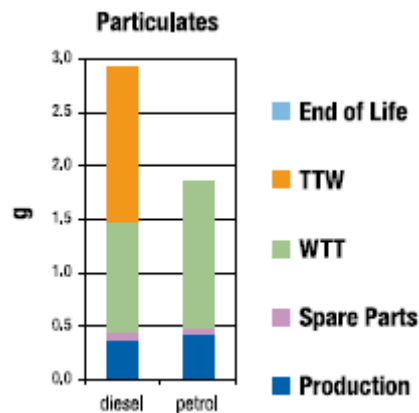


Source: European environment agency

Road transportation contributes over 16% and energy production and distribution over 7% to PM 2.5. Pollution. From the TTW phase all of the emissions are from diesel cars. That means that through its life cycle a diesel car emits almost twice as many particles in comparison to petrol car. Since 1990 there has been a 35% reduction in emissions of fine particulate matter (PM_{2.5}). Standards for the reduction of PM 2.5. particles were set by

revision of the Gothenburg Protocol in 2012 and are planned till 2020. Reductions by EEA-33 countries are in general greater than required.

Figure 15: Comparison of diesel and petrol car in particulate emissions throughout the life cycle



Source: <http://ipts.jrc.ec.europa.eu>

Bulk waste

The highest amounts of bulk waste are produced through production phases. Mostly from steel production and refinery processes.

Abiotic depletion

Lead used in batteries has the largest impact in this category. The copper used in electronics and precious metals used in catalytic convertors is also important.

Figure 16: Share of different phases of abiotic depletion impact

Processes	%	Phases
Lead	56	Spare parts
Zinc	28	Production
Copper	6	Production
Lead	6	Production
Rhodium	2	Production
Remaining processes	3	

Source: <http://ipts.jrc.ec.europa.eu>

3.3. Raw materials and car manufacturing

Car manufacturing requires a variety of raw materials including steel, aluminium, plastics, rubber, glass as well as a variety of precious metals for example platinum group metals for catalytic convertors. It is important not to forget the metals used in batteries especially lead and lithium. Lithium is used in electric vehicles - thanks to the transformation to low emission transportation the dependence of the automotive industry on lithium is expected to increase radically. In table 1 in the back we can see the material composition of a typical/baseline petrol and diesel car.

In the WWF report *Critical materials for the transition to a 100% sustainable energy future*¹⁹ a list is available of the most important material resources produced worldwide, their annual production rates and the most important sectors.

For automotive sector most crucial minerals:

Minerals	Sector usage	Production estimation and major producers
Barite (BaSO4)	petroleum industry, paints, plastics, rubber, transport, metal casting, radiation shielding	95 years China, India and Morocco
PGM - Platinum group metals	catalysts, chemicals production, electronics, glass manufacturing, displays, jewelry	N/A South Africa
Copper	electronics, machinery, transportation	186 years. Chile, China, Congo
Aluminium	transportation, packaging, buildings, electrical, machinery, consumer durables	1474 years Australia, China, Russia, Canada
Iron	steel production, transportation, construction	209 years China, Australia, Brazil
Lead	especially battery production	333 years China, Australia, USA
Lithium	ceramics and glass, batteries, lubricants, air treatment, polymers, aluminum production, pharmaceuticals	882 years Chile, Australia, China
Tantalum	capacitors, alloys, automotive electronics, phones, computers	Adequate Rwanda, Congo, Brazil

There are a lot of conditions that need to be met to characterize a mineral or metal as scarce. First of all the total amount of the material and the recoverable part from that. Secondly the expected demand in the future. Last also the geopolitical situation needs to be taken into account. WWF made a list of materials which were identified in recent reports as critical. From the above mentioned materials we identified: Copper, Lithium, PGM and tantalum.

Aluminium used in automotive

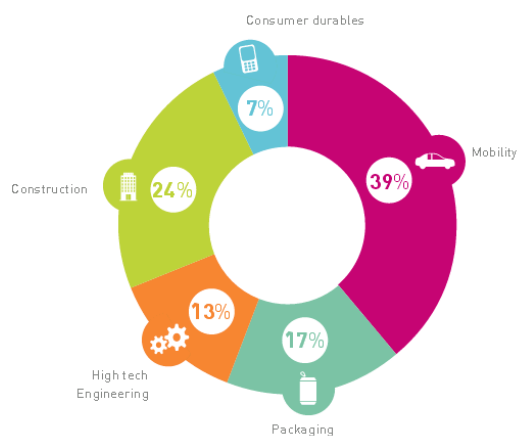
Aluminum is the second most used metal after steel. Thanks to its light weight and resilience to rust it is widely used in automotive industry. Roughly 130 kg of aluminium is

¹⁹*Critical materials for the transition to a 100% sustainable energy future*. N.p.: WWF, 2014.

used in one passenger car.²⁰ In the process of extracting aluminium, bauxite mining is the first step. Australia is the biggest producer of bauxite, and there are also big suppliers in Brazil, China, etc. In Europe there are smaller bauxite mines in Hungary, Greece, Italy and France.

Bauxite is extracted from ores by surface mining, which often leads to massive land use, even resettlements of local inhabitants. The Juriti Velho mine, which belongs to the biggest aluminium producer Alcoa plans to cut down 8 thousand hectares of rainforest and resettle 1800 families. In Jamaica bauxite mining is the main cause of deforestation (5000 hectares of forest).

Figure 17: Sector usage



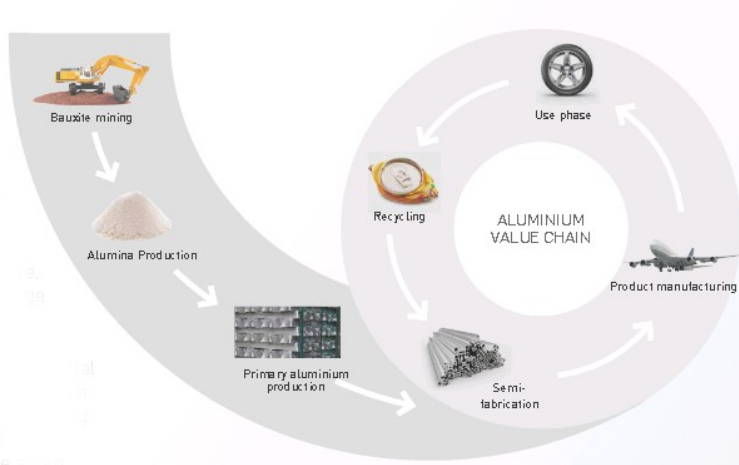
Source: <http://www.european-aluminium.eu/>

Huge volumes of tailings are produced through the bauxite mining process. For one tonne of aluminium five tonnes of waste is produced. Tailings from bauxite are toxic and so called red mud tailings are formed. Extremely high energy consumption is needed for the process of aluminium production. For one kilo of aluminium 47,5 kWh is needed. For glass it is only 2,1 kWh for kilo and for tinned sheets it is only 9,25 kWh. In the beginning of the 90s the energy consumption of Aluminium plants/smelters was higher than the total consumption of energy of all african countries. Hydroelectric power plants are often constructed near smelters to supply plants with power. The Russian dams Bratskaja and Krasnojarskaja supply the two biggest aluminium plants in world. 123 thousand people had to be resettled due to the construction of these dams.

In the year 2003 35-40 million tonnes of aluminium was consumed globally, and only 13 million was made from recycled scrap, even though recycling is 95% more energy effective than primary consumption. Aluminium is infinitely recyclable. It remains essentially unchanged no matter how many times it is processed and used. The EU consumed 10,7 million tonnes and produced only 2,9 million tonnes in 2003, and in 2015 it was only just above 2 million. Between 2002 - 2015 the number of smelters in Europe decreased significantly by 38% and it is expected to drop further. Europe is the world leader in recycling and is able to recycle 60% of packaging and 90% of construction and automotive products. In 2013 in Europe alone more than 10 million tonnes of aluminium were recycled.

²⁰Česká Stopa. Brno: Zelený Kruha a Hnutí Duha, 2005. Web.

Figure 18: Aluminium value chain



Source: <http://www.european-aluminium.eu/>

Figure 19: Aluminium recycling

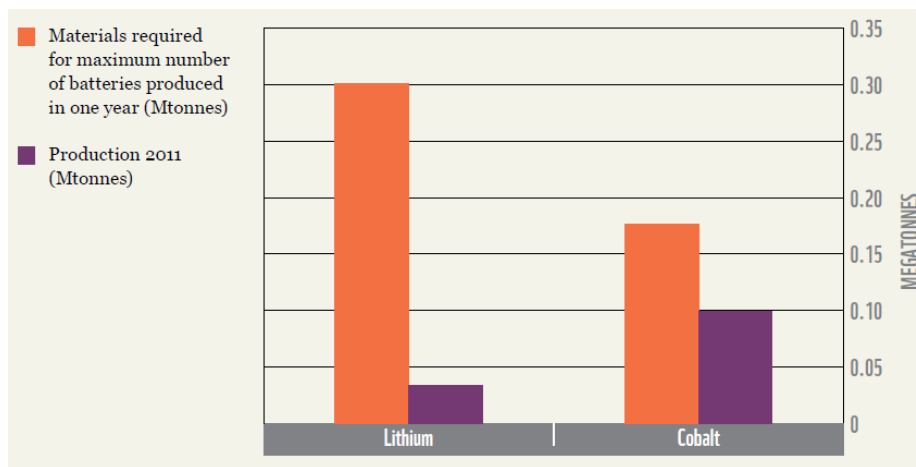
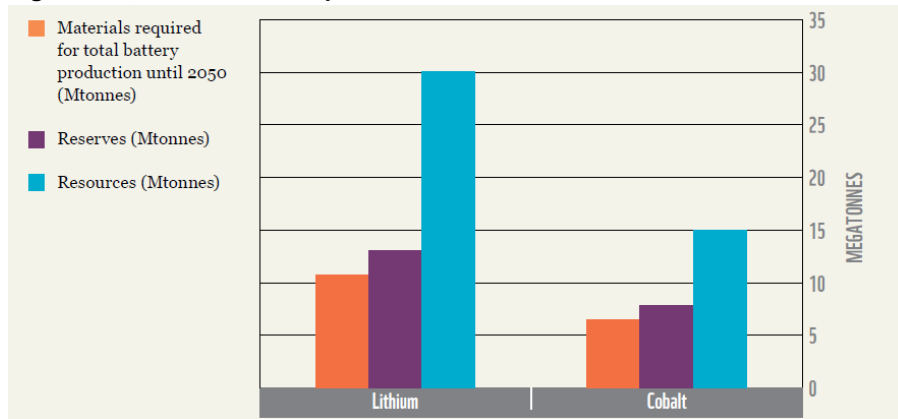


Source: <http://www.european-aluminium.eu/>

Lithium and cobalt needed in high density batteries

According to prognosis in the year 2050 there will be 3,3 billion vehicles dependent on high density batteries. The average amount of lithium and cobalt in a battery is 3,2 kg and 1,9 kg respectively. As the capacity of the batteries depends on the volume of active materials, a decrease of dependence on lithium and cobalt thanks to technological innovations is not to be expected. Figures 15 and 16 show material demand estimations for batteries in new electric and hybrid vehicles from 2000 until 2050. These are compared to the current production of lithium and cobalt.

Figures 20, 21: Materials requirements for 2050



Source: WWF

In comparison to reserve and resources expected demand is very high. According to the WWF report current lithium production mainly takes place in Chile, Australia, China and Argentina. Lithium brines formed by evaporation are commonly found in salt flats. Salar de Atacama in Chile is at present the world's largest currently exploited lithium deposit producing almost 40% of the world's lithium. Demand for lithium has grown continuously over the last ten years and is expected to continue growing by 5 to 10% annually during the next decade. Therefore, recycling of lithium is a key issue.

Cobalt is primarily produced by the Democratic Republic of Congo, Australia and Cuba. Political instability in the Congo could cause rapid changes in production and there is a high risk of human rights violations against workers.

Key mitigation measures according the WWF

Lithium - Lithium prices are not high enough to make recycling profitable. The expected price increase, technological development and legal actions to make battery recycling compulsory could increase recycling rates. In the non-energy sector lithium can often be substituted by other materials. This could ease a depletion problem.

Cobalt - Technologically it is possible to decrease the amount of cobalt in batteries, which could greatly reduce the demand. Recycling, which is already taking place in the case of rechargeable batteries can be expanded without major technological obstacles.

PGMs - Platinum group metals

Since the second half of 20th century various devices have been developed in order to reduce the harmful substances emissions from combustion engines²¹. Catalytic converters designed to abate the emissions of carbon monoxide, nitrogen oxides and unburnt hydrocarbons can only function thanks to precious metals - mainly platinum, rhodium and palladium, which exists only in limited supplies. Considerable effort has been dedicated, but practical solutions that could substitute PGMs in catalytic converters have not been found. The cost of the active metals in catalytic converters is nowadays around 200-300 EUR. According to the study (Bardi, 2014) mentioned above it appears that in the past several years PGMs reached their "production peak". Therefore an upward trend in price is expected to continue and the cost of the converters may become a major fraction of total car cost. Even with an increase in the recycling and reduction in the amount of precious metals in catalytic converters we can not expect a definite sustainable solution. In the long run the problem is unsolvable and we will need to explore alternatives- sooner rather than later.

Consumption of PGMs

According to table 1 in the back, 0.0003 kg of platinum is needed for one car, and as a result nowadays catalytic converters use more than half of the world's mineral production of platinum. It is not possible to provide a concrete number on platinum consumption in the V4 group, but if we count it on the baseline car according to Table 1 and the share of the V4 group in global production - the share of V4 in the global consumption of platinum would be around 2.5% - 3,0%.

Even though the lithium and cobalt used in electric cars has its limits as well from a depletion point of view it is a more sustainable choice and much more sustainable choice from the global warming impact standpoint as electric transportation emits much less greenhouse gases.

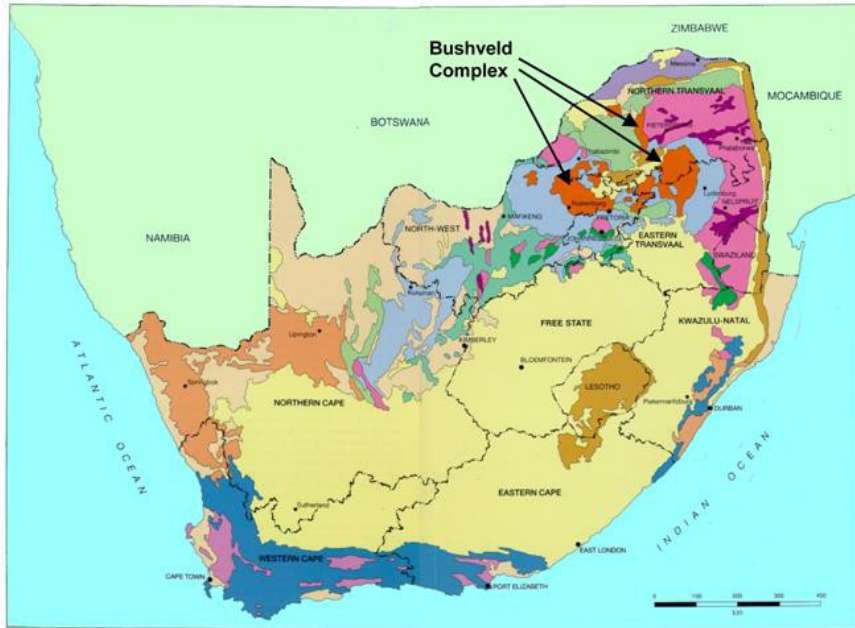
Production locations

The production of PGMs is concentrated in a few mines – the main ones being the Bushveld igneous complex (South Africa), the deposits of Norilsk Russia, the Ural mountains in Russia, the Sudbury mine in Ontario, the Hartley mine in Zimbabwe, the Still-water complex, Montana, and the Zechstein copper deposit in Poland.

South africa produces about 85% of the total PGM production figure and has 82 % of all the resources.

²¹Bardi, Ugo, and Stefano Caporali. *Precious metals in automotive technology: An unsolvable depletion problem?* Firenze: Dipatimeuto di Scienze della Terra, Universita di Firenze, 2014. 25 Apr. 2014. Web.

Figure 18: Location of Bushveld igneous complex



Production forecast

According to the US Geological Survey the total reserves of PGMs amount to 66 million tonnes. In 2011 the total combined use of platinum and palladium was estimated at 400 000 Mt. at this rate 130 years of production should be left. It is probable that in the future production costs will increase and production will not be constant as it is nowadays. Even though 130 years seems like long period of time the well known economic effect of “diminishing returns” has to be accounted for - as the ores become less and less concentrated the energy needed for extraction increases, and the price of the material goes up.

Mitigation measures:

As mentioned above developing a catalytic converter free from noble metals does not appear to be a plausible option. Reducing the amount in a converter is a possibility, but a very limited one as the PGMs are crucial for the chemical processes that occur in the converter. In recycling there exist established procedures on how to recover PGMs from converters. The concentration of Platinum in converters may be around 2 g/t. Recycling rates of platinum in global reach only 50% - 60%. This low rate is a result of two factors: the converters suffer from a loss of PGMs through their life cycle (6% exhaust over 80000km) and secondly not all converters are recycled thanks to a lack of recycling facilities. Recycling alone cannot solve the PGM depletion problem. Therefore the most plausible solution appears to be a transformation to low carbon electric transportation. The lithium required for this could also suffer from depletion problems, but there are reserves for 300 years which is twice as much as in the case of PGMs, not to mention the possibility of extracting lithium from the sea which is not performed today, but which is considered a technologically possible task.

Human rights and the platinum mining industry in South Africa:

The mining sector in South Africa is one of the key sectors in the country. It accounts for over 5% of the national GDP and in 2012 1,2 million jobs were connected to mining. It employs 16% of the total labor force in the country.

According to a report from the organisation SwedWatch²² the platinum mining industry in South Africa is associated with severe risk of adverse human rights impacts. The mineworkers are constantly exposed to hazardous working conditions, and there is widespread dissatisfaction over low wage standards.

Platinum is mined mostly by hand and workers often spend more than 10 hours a day in narrow shafts kilometers below surface, without the ability to stand upright. Contracts for workers are often unfair, because they are in most cases short term and do not provide guarantee of a new position. Wages, though higher than in agriculture are often not sufficient even for basic needs.

Figure 22: Work condition during platinum mining



Source: Swedwatch

The Studies in Poverty and Inequality Institute (SPII) calculated that an average worker spends 500 dollars on food a month and his wage is also around 500 US\$, which means that other daily costs are not covered. In south africa there is high unemployment and many people move close to mines for jobs. As a result near mines many informal settlements are created with unsuitable standards of living. In the Bojanala District, where all of the three largest mining companies conduct operations, a third of all inhabitants lack access to clean water.

Swedish companies with ties to the industry failed to find out how these risks are dealt with. In the Swedwatch report the approach of Scania (which has a plant in Poland) is analyzed. Scania has over 1000 direct suppliers globally. Scania requires them to comply with their sustainability policy and to do the same with their sub-suppliers. According to Scania the best way to impact sustainability in a supply chain is through supplying contracts.

22Jaekel, Théo. *Problematic Platinum The responsibility of Swedish companies in South Africa*. N.p.: SwedWatch, 2013. [Http://www.swedwatch.org](http://www.swedwatch.org). Web. 26 Feb. 2017. <<http://www.swedwatch.org/en/reports/problematic-platinum>>

Through contracts, Scania obligates direct suppliers to place the same requirements on subcontractors. The problem according to Scania is the issue of traceability. Scania do not know from which mines is the platinum they use is extracted. The problem is that the mining companies do not provide access and information to their customers. As a reaction to the Swedwatch report Scania initiated talks with mining companies about human rights standards within their operations.

Side note: During 2012 the dissatisfaction of workers with unemployment, low wages, work and living conditions lead to series of wild strikes, which started at an Impala mine in the Bojanala District. The protests spread to other districts as well. The basic demand was to increase wages (from 275 to 825 US\$). The protests resulted in local police officers opening fire, with two casualties among workers. Thanks to this incident violence escalated and in the summer of 2012 tens of trade union representatives, workers, security guards and police were killed in the confrontations. The strikes climaxed on august 16th 2012, when workers armed themselves with traditional weapons/tools such as spears and confronted the authorities. In the violence that followed the police shot 34 people and injured 78 workers.

3.4. TTW phase and usage of spare parts

The average petrol car has a total driving distance in its lifetime of 211 250 km. For diesel cars this rises to 238 750 km. The average petrol car produces 173 grams of CO₂ per km. For diesel it is 160 grams. Therefore a petrol car in its lifetime is on average responsible for more than 36 tons of CO₂. Diesel cars produce 0,014 grams of PM particles per km. In their lifetime they are therefore responsible for more than 3 kilograms. Petrol cars produce 0,41 grams of CO per km, which is per lifetime more than 86 kg of CO. NO_x production for a diesel car is 0,204 grams per km, therefore for 238 750 km of driving distance diesel cars produce almost 49 kilograms of NO_x.

Figure 23: Work condition during platinum mining

Spare parts	Travelled distance (km)
Tyres	40 000
Batteries	80 000
Lubricants	10 000 (density 0.9 kg/l)
Refrigerants (R134a)	100 000 (density 0.000464 kg/l)
Brakes	40 000 (materials not quantified)

Source: <http://ipts.jrc.ec.europa.eu>

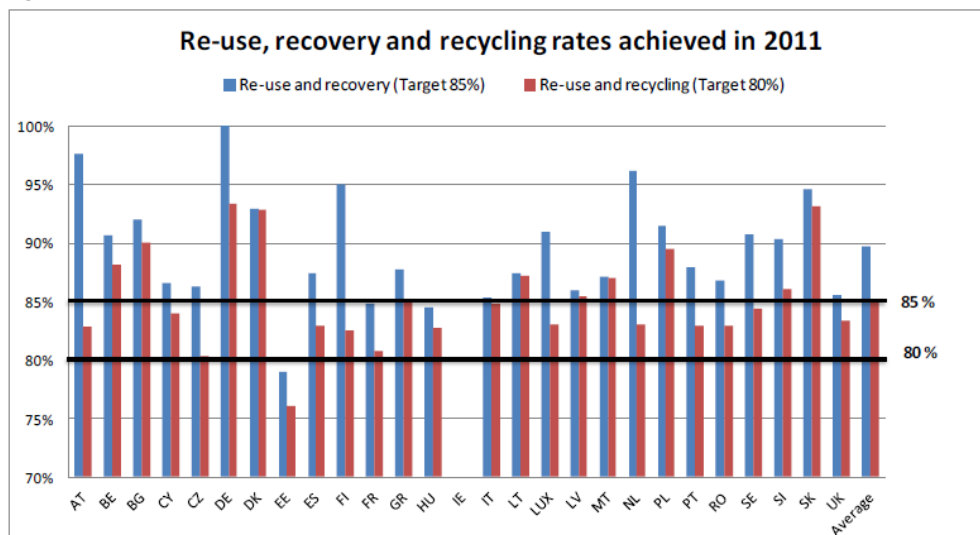
3.5. End of life of vehicle - Recycling and reuse

In the European Union the End of life vehicle (ELV) directive determines the practice of collection, storage, dismantling and treatment of ELVs in EU. The directive sets standards for the reuse and recycling of materials in ELVs and also the removal of hazardous substances such as oil, antifreeze and batteries. An end of life vehicle according the EU directive is any vehicle that the holder discards, intend to discard or is required to discard.

Each year the disposal of cars creates 8 to 9 million tons of waste in the European Union. 25% of car waste is classified as hazardous. Hazardous waste from cars creates almost 10% of all hazardous waste. The aim of the directive is to reduce hazardous waste and encourage reuse, recovery and recycling. Each member state is obliged to meet the standards set by the ELV directive - By 1 January 2015 - Every newly manufactured M1 and N1²³ vehicle must be designed in a way that a minimum of 85% of its weight can be reused and recycled and a minimum of 95% reused and recovered. ELVs can be treated only by authorised facilities.

The major issues in securing the higher effectivity of recycling are firstly the collection and treatment of ELVs by illegal operators and secondly the fact that the illegal shipment of ELVs is still a flourishing business. In 2008 in the EU there were more than 4 million cars with unknown whereabouts, over 6 million cars were reported to the ELVs directive reporting and over 1 million ELVs were exported legally²⁴. From the portion of unknown cars a considerable number of vehicles are illegally exported to Africa and Middle-east. Poland is the leader in illegally recycling and exporting ELVs. In 2010 more than 850 thousand vehicles were estimated to be treated illegally in Poland. The main reason for this is an insufficient number of licensed facilities for recycling and disabling cars. Figure 24 below represents re-use, recovery and recycling rates achieved in 2011 by specific countries. Slovakia and Poland are above average and were able to meet the expectations of the EVLs directive. The Czech republic and Hungary are below average. Hungary did not meet re-use and recovery limits set by the ELVs directive and the Czech Republic had the second lowest recycling rate. The main reason for this is that in Poland and Slovakia high premiums for disposing EVLs were offered to car owners. In the case of Slovakia premiums were introduced only for a short period of time. Often the case was that cars did not reach their end of life, but were sold anyway because the bonus price was higher than the market price of the car.

Figure 24:



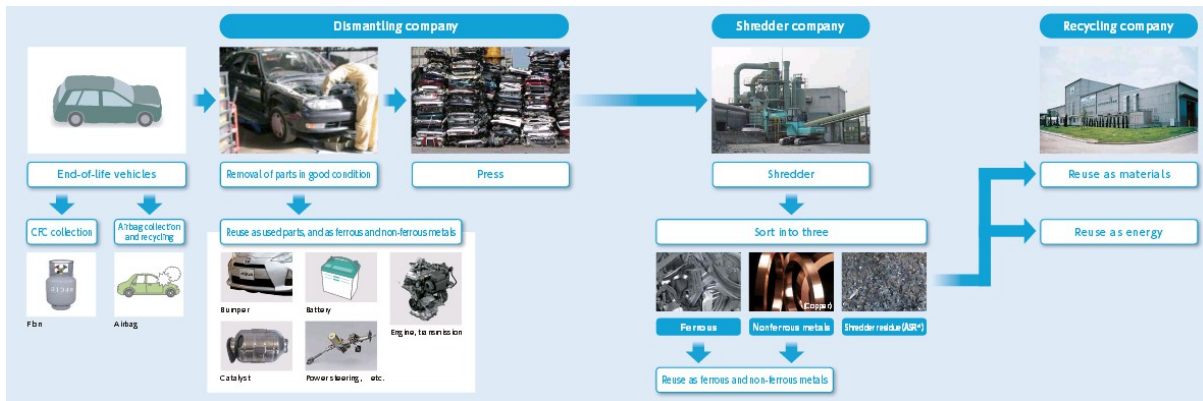
Source: BIO Intelligence Service

23M1 - Vehicles used for the carriage of passengers and comprising not more than eight seats in addition to the driver's seat.

N1 - Vehicles used for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes.

24Ex-post evaluation of certain waste stream Directives. N.p.: BIO Intelligence Service, 2011. Web.

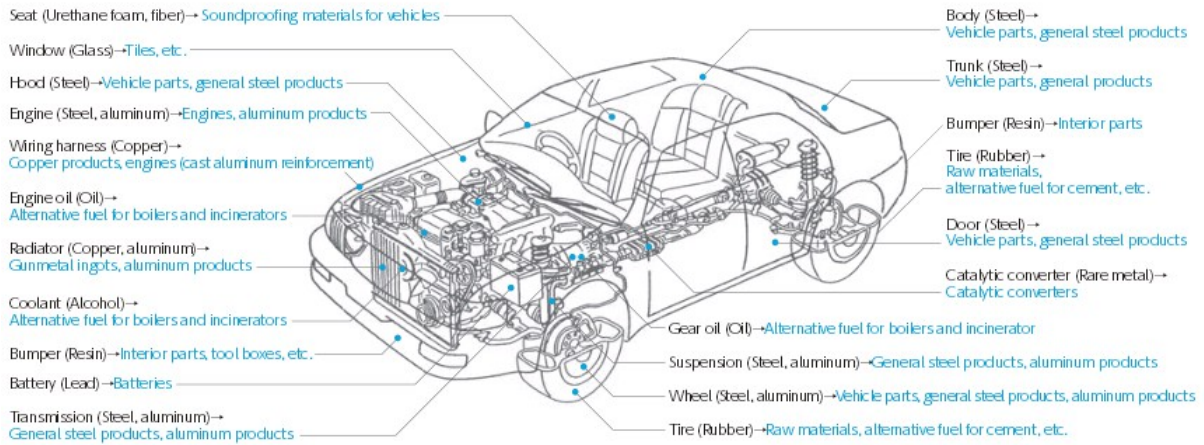
Figure 25: General overview of vehicle recycling



Source: Toyota - Global

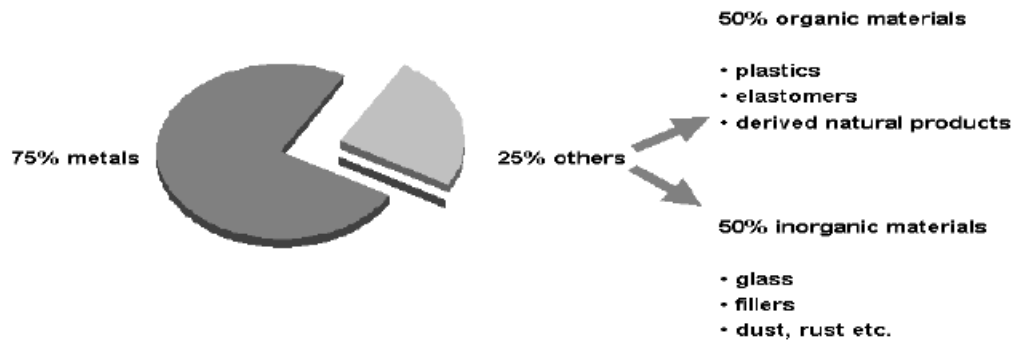
Figure 26: example of car parts recycled and reused

■ Examples of parts being recycled from end-of-life vehicles



Source: Toyota - Global

Figure 27: Composition of materials in end of life vehicles



In current ELV's plastics proportion is around 6% of weight

Source: Wuppertal Institut für Klima, Umwelt, Energie

Table 1 Material composition of a petrol and diesel car

Materials (kg)	Petrol	Diesel
Total content of ferrous and non-ferrous metals	819	1 040
Steel BOF	500	633
Steel EAF	242	326
Total content of iron and steel	742	959
Aluminium primary	42	43
Aluminium secondary	26	29
Total content of aluminium	68	72
Cu	9	9
Mg	0.5	0.5
Pt	0.001	0.001
Pb	0.0003	0.0003
Rh	0.0002	0.0002
Glass	40	40
Paint	36	36
Total content of plastics		
PP	114	114
PE	37	37
PU	30	30
ABS	9	9
PA	6	6
PET	4	4
Other	27	27
Miscellaneous (textile, etc.)	23	23
Tyres		
Rubber	4	4
Carbon black	2	2
Steel	1	1
Textiles	0.4	0.4
Zinc oxide	0.1	0.1
Sulphur	0.1	0.1
Additives	1	1
Sub-total (4 units)	31	31
Battery		
Lead	9	9
PP	0.7	0.7
Sulphuric acid	4	4
PVC	0.3	0.3
Sub-total	14	14
Fluids		
Transmission fluid	7	7
Engine coolant	12	12
Engine oil	3	3
Petrol/diesel	23	25
Brake fluid	1	1
Refrigerant	0.9	0.9
Water	2	2
Windscreen cleaning agent	0.5	0.5
Sub-total	50	52
Total weight	1 240	1 463

Source: <http://ipts.jrc.ec.europa.eu>