Life Cycle Assessment of a Car Tire

Continental

Foreword

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Life cycle assessment is a technique for recording and assessing ecological aspects of the interactions between a product and the environment. Under this life cycle assessment, the authors have examined the complete life of a car tire comprising the

- extraction of mineral and fossil raw materials like crude petroleum, coal, natural gas, iron and other ores
- manufacture of the tire's raw materials like rubber, carbon black, chemicals, steel cord, bead wire and carcass fabric
- production of the tire at the tire plant
- use of the tire on the road
- utilization of the old tire as a raw material or energy provider

The authors have endeavored to find a way of portraying the results that, on the one hand, meets the strict requirements of the relevant standards – in particular those of ISO 14 040 ff – and yet, on the other hand, supplies easy-to-follow information, both for internal purposes and for interested persons outside the company.

Acknowledgement

Acknowledgement

The present life cycle assessment is the result of many individual contributions.
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- Grillo Zinkoxid GmbH,
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Content

1. Reasons for conducting the study
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Approx. 200 million car tires are currently in use in Germany. Each year approx. 600,000 tons of worn tires are removed and replaced by a corresponding number of new or retreaded tires[1]. Throughout its service life, from the acquisition of the raw materials through to the recycling of the worn tire, the tire constantly interacts with the environment. Approaches to effectively reducing the negative environmental impact can be demonstrated only on the basis of detailed knowledge of this interaction. This is why a life cycle assessment quantifies the material and energy turnover in the different stages of a tire's life (life cycle inventory analysis) and describes the interaction with the environment (impact assessment and interpretation).

1.1. Individual goals

The goals of the present life cycle assessment are the following:

1. Presentation of the material and energy flows in the various stages of a tire's life

2. Quantification and evaluation of emissions and waste that could have an impact on the environment (determination of the "ecological backpack" borne throughout the life of the tire)

3. Identification of the main impact on the environment during the life of a tire as starting point for a targeted and efficient reduction in the magnitude of the potential environmental impact.

4. Development of a tool for evaluating the resource requirement and the environmental impact of alternative tire types (alternative raw materials and materials)

5. Quantification of the environmental impact of using worn tires in recycling processes in comparison with the respective equivalence processes.

6. Development of a standardized method for assessing rubber products

The life cycle assessment for passenger car tires has been prepared in compliance with DIN EN ISO 14040 ff. (Figure 1) ([2,3,4,5]). At appropriate points reference is made to special features in the assessment of passenger car tires.

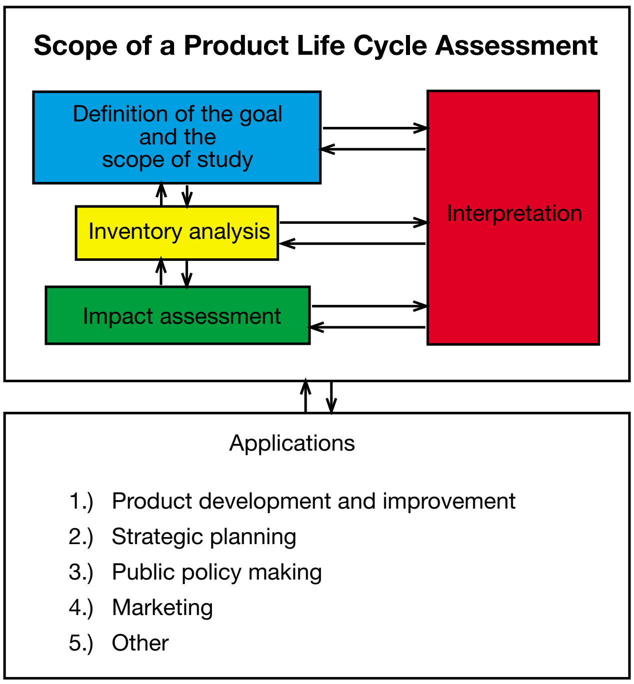

FIGURE 1: COMPONENTS OF A PRODUCT LIFE CYCLE ASSESSMENT (LCA) TO DIN EN ISO 14040.

2. Scope of study

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The general frame-work of analysis is com-prised of all the inputs and outputs of the various phases in the life of a tire, as shown here in dia-gram form.

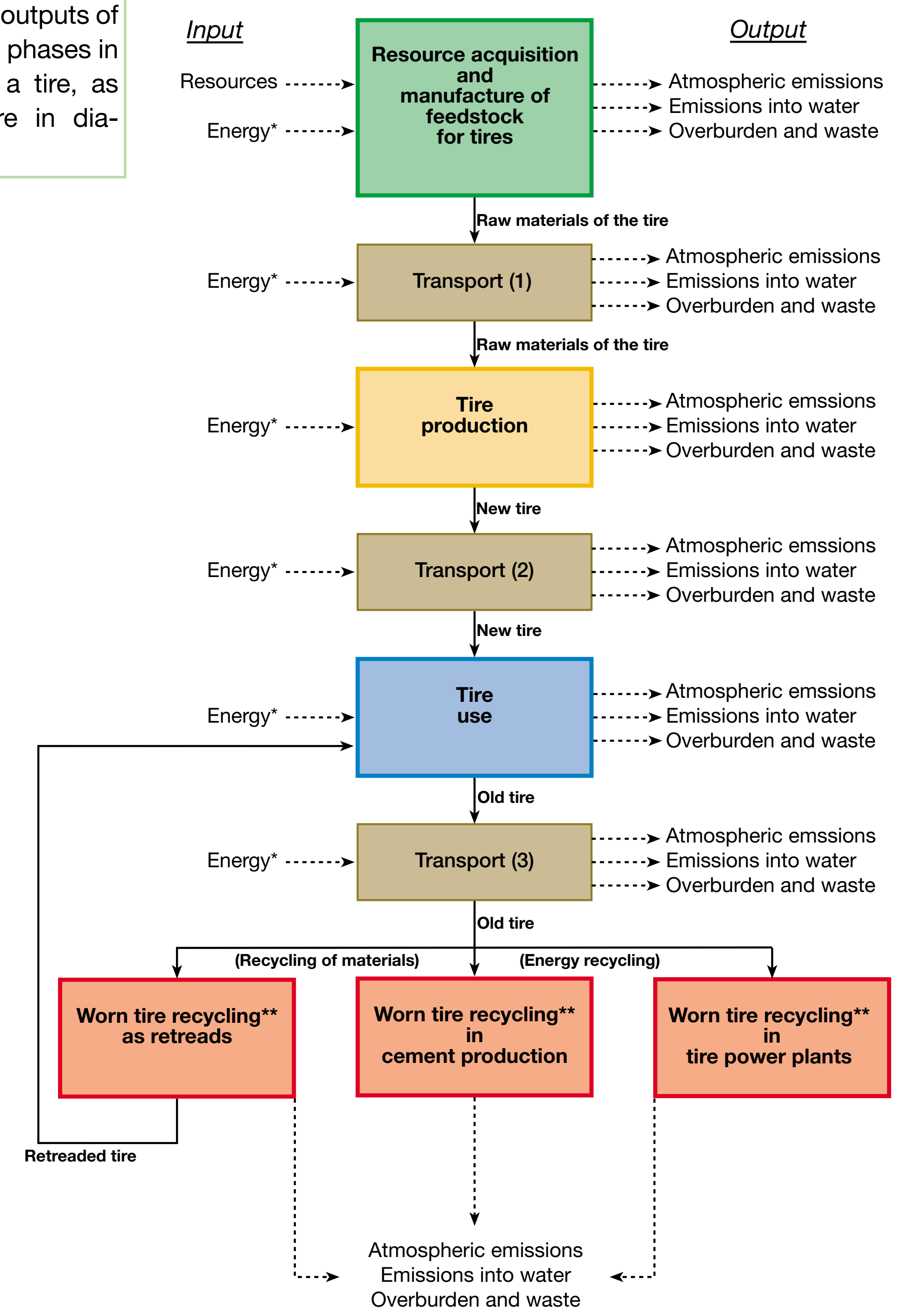

FIGURE 2: SCOPE OF ASSESSMENT

** The energy input is included in the scope of the assessment.*

*** In the case of recycled worn tires, the requisite energy input and likely raw material requirement have likewise been taken into consideration.*

2. Scope of study
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2.1. Assessment modules

2.1.1. Manufacture of raw materials for tires, incl. resource acquisition

The feedstock for tires is manufactured from fossil, mineral and replenishable resources. On the basis of its physical and chemical properties, this feedstock subsequently provides the performance potential for the functioning tire.

2.1.2. Production of the tire

The structural parts are manufactured from the feedstock and assembled to form the green tire, which is then vulcanized to yield the functioning tire.

2.1.3. Use of the tire

The tire is the link between the vehicle and the road, transmitting to the latter all forces acting on the vehicle and emitted by the vehicle. This function determines its design and chemical makeup. Assessment of tire use was based on a standard size vehicle driven by the motorist in the average manner for the average mileage on roads corresponding to the European standard. The tire is assumed to be exposed to the climatic conditions prevailing in central Europe. While in operation, the tire is subjected to constant wear due to tread abrasion. Eventually it forfeits its functional value due to lack of sufficient tread depth and is withdrawn from service.

2.1.4. Recycling of worn tires

The original tire's material composition and its energy content determines the value of the worn tire – and the recycling possibilities open to it. In Germany worn tires are primarily retreaded or used in cement plants. This study will also take a look at the recycling of worn tires in tire power plants. Rubber powder produced from worn tires and rubber granulate consistute less significant uses for worn tires and will not be considered here.

2.1.5. Transport

Between the various life stages – during which the constituent materials undergo changes – the tires must be transported. The transport of the tires is strictly for the purpose of moving the materials under consideration from one location to another. The transport module summarizes all transport operations with the exception of the transport of worn tires to the recycling point. The transport of worn tires is taken into consideration in analyzing the recycling processes.

2.2. General framework, boundaries and data sources

2.2.1. Object of assessment

The object under assessment here is the passenger car tire. The material composition of the tire corresponds to that of a summer tire in Continental's main line. To the extent possible, data from the 175/70 R 13 tire is used. All input material is grouped together in type-related substance categories. Data is compiled for a representative member of each of these substance categories (e.g. a representative antioxidant for the anti-aging substance group). 100% of the constituent elements of a tire are covered. Material alternatives are treated in Chapter 5.

2. Scope of study

2.2.2. Reference variable

The reference variable/functional unit is a single tire with an average service life of 50,000 km over a four-year period.

2.2.3. Assessment boundaries

The assessment boundaries are drawn in such a way as to render the tire assessment easy to grasp and reproducible without, for all that, sacrificing its essential integrity. A detailed study is conducted within these boundaries.

For processes carried out in Germany, the electric energy requirement enters into the assessment on the basis of the energy mix in Germany[6] (e.g. data records from raw material manufacturers located in Germany). The cumulative energy input (CEI), which presents the entire energy quantity regardless of the type of energy acquired, takes into account only the energy required to manufacture the tire but not the calorific value of the product.

The resources category cites both the resources used as material and the resources used as energy. The energy content of the energetically used resources is shown again separately as primary energy input. The acquisition of resources is included in the assessment.

The assessment does not take into account the construction, maintenance and servicing of plant, tools, machines and transport vehicles. Nor does it take into account the expense of producing the cars to be fitted with the tires or of road construction. Nor are the following included in the assessment: noise emissions, tire abrasion during truck transport and expenditures for personnel, administration, planning, research and development.

2.2.4. Allocation

In the case of coupled production, information on the distribution of inflows and outflows is not available for the data drawn from non-corporate sources (e.g. manufacture of feedstock for the tire). For this reason it is not possible to say anything about the allocations made in these data records. No crediting takes place in the case of coupled production. For data from in-house surveys, the allocation is made on the basis of mass distribution of the products of coupled production (e.g. for prior chains of petroleum products). The inflows and outflows in the recycling of worn tires in cement plants is based on the energetic contribution of worn tires to overall energy expenditure.

2.2.5. Special allocation for the use phase

The allocation of the inflows and outflows to and from the tire occurring while the car is being used has an important influence on the results of the assessment. The charges incurred in operating the car are distributed on the basis of the savings potential to be achieved by changing the tire properties.

The fuel consumption required to move the vehicle is composed of the share needed to overcome the tire's rolling resistance, the vehicle's air drag, the drive resistance of the engine and gears and the acceleration resistance of the vehicle. Rolling resistance is determined by the tire's coefficient of rolling resistance and the mass of the vehicle including the tires. The air drag value is dependent on the driving speed and the geometry of the vehicle and the tire. The drive resistance is determined by the internal friction of the drivetrain.

2. Scope of study

2. Scope of study

The acceleration resistance is dependent on the individual driving style and on the mass of the vehicle.

Table 1 shows and explains the category assignments.

	Total share of vehicle fuel consumption [%]	Reference to the tire	Share of fuel consumption attributable to the 4 tires	Contribution of one tire to fuel consumption [%]
Rolling resistance	16	Vehicle weight	16	4
Aerodynamic resistance	36	Wheel and wheel house account for approx. 25% of the vehicle's aerodynamic resistance; about 50% of that amount is assignable to the tires	4.5	1.1
Propulsion resistance (internal friction)	32	No reference to the tire	-	-
Acceleration resistance (loss due to braking)	16	Tire weight and moment of inertia	0.4	0.1
Total resistance	100		20.9	5.2

TABLE 1: ALLOCATION AND EVALUATION OF ROAD RESISTANCE.

The vehicle is assumed to weigh approx. 1250 kg and a tire approx. 6.5 kg. Road resistance is calculated using reference quantities valid for the whole vehicle and thus for four tires per vehicle (7). The functional unit of the present study being a single tire, fuel consumption is calculated per tire. The values shown in the table are calculated on the basis of Continental AG readings. There is a fluctuation of approx. 4% in the determination of rolling resistance.

All told, the tires account for approx. 21% of a car's fuel consumption – or approx. 5.2% per tire to be taken into consideration here as environmental impact.

As Table 1 shows, the allocation is influenced not only by tire-specific characteristics but also by car-specific characteristics (e.g. weight).

2. Scope of study
2. Scope of study

2.2.5. Data sources

The data has been furnished by Continental AG, the raw material manufacturers (Bayer AG, Degussa-Hüls AG, Grillo Zinkoxid GmbH, Shell AG, Textilcord Steinfurt S.A. (now Glanzstoff Austria GmbH)), publications[6,8,9,10] and personal communications from Dr. Entmayr (Continental AG), Mr. Huinink (Continental AG), Mr. Schoppe (Volkswagen AG) and Dr. Schuckert (IKP)). Data on literature is derived from Ullman's encyclopedia[11]. The data is taken from the years 1990 to 1997.

2.2.6. Critical review

A critical review in accordance with the requirements of DIN EN ISO 14040 has been conducted by TÜV NORD (Dr. J. Hanel and Dr. W. Hirtz).

2.3. Degree of detail

The parameters recorded all flow into the life cycle inventory analysis. All relevant and recorded parameters are likewise taken into account for the calculation of the environmental potential. Unless therwise specified (see Table 2), no cut-off criteria have been applied.

2.4. Special methodological features

- After use the worn tires are available for material or energetic recycling. As secondary raw materials, worn tires either provide the basis for new products (e.g. retreaded tires, cement clinker blocks) or are used for a completely different purpose than the original one (e.g. in agriculture or ports). Recycling of the old tire thus leads to an expansion of its utility. This natural interface between the car tire life cycle assessment through to the end of its use and the assessment of the respective recycling process is used for the conception of the present study.

- The most realistic approximation of the results of a worn tire assessment would probably be a recycling mix incorporating all recycling channels with the capacities they make available to the market. This kind of recycling mix is not of much assistance in identifying where the main environmental impact is. The composition of a recycling mix is, moreover, strongly dependent on the market situation and the respective national laws. For these reasons, no assessment of a recycling mix will be made here. Instead, the most important recycling channels for worn tires are regarded separately and compared with the respective equivalence processes (Chapter 6).

3. Life cycle inventory analysis
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The life cycle inventory analysis and the impact assessment are based on an operative carbon black/rayon tire. Other tire types are considered in a separate chapter (Chapter 5).

3.1. Input

The input of the life cycle inventory analysis covers the resources expended and the air and water required.

3.1.1. Resource requirements

The mining of so-called mineral and fossil resources gives rise to so-called dead heap. Although dead heap does not represent a raw material, it is usually classified as one [12]. In this assessment dead heap is not listed under resources, however; there are 232 kg of resources per tire and 28 kg of dead heap.

Approx. 88% of all the resources consumed in the life of a tire are required for the use of the tire by the car (Figure 3).

Approx. 6.9 % of the overall resource requirement in the life of a tire is consumed in the course of extracting the raw materials for the tire. The raw materials silica, synthetic rubber, carbon black and steel account for the largest share of the raw materials consumed in this phase of the tire's life. The resource petroleum, which is used materially and energetically, makes up roughly 24% of the overall resource consumption in the acquisition of raw materials. Natural gas accounts for around 18% of the energy requirement in this phase of a tire's life.

Resources are required in the production of a tire to make available the energy carriers natural gas, petroleum and coal. These energy carriers make up approx. 29% of the resources consumed in tire manufacturing.

3.1.2. Air requirements

The air requirement is related mainly to the need for oxygen when burning the fossil resources to obtain energy. The car tire's use phase accounts for the largest share of overall air consumption (approx. 96.5%) in the life of a tire. The other modules of tire life account for the remainder as follows: raw materials extraction approx. 2.2%,

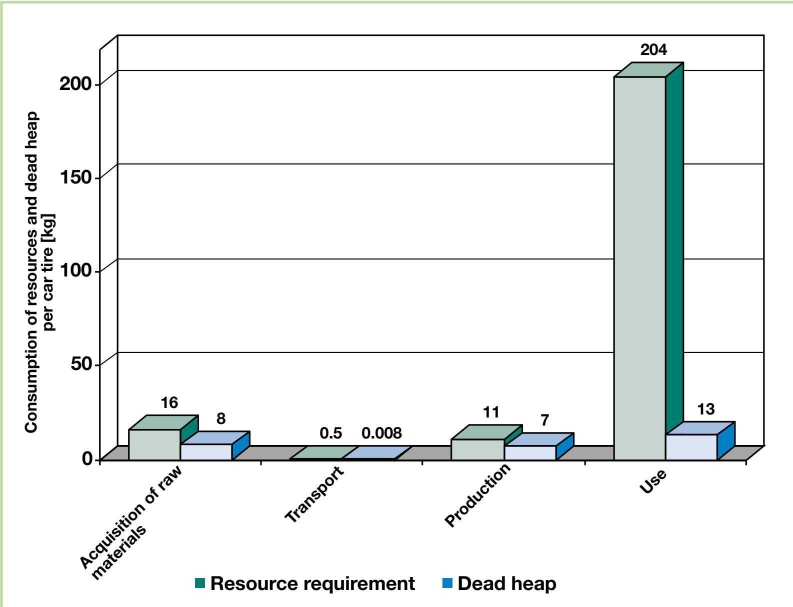

FIGURE 3: PRESENTATION OF RESOURCE CONSUMPTION AND THE QUANTITY OF DEAD HEAP.

All told, approx. 4.8% of the total resources expended in the life of a car tire are used for the production of the tire. The consumption of resources is lowest in the transport phase of the tire's life (about 0.2%).

production approx. 1.0% and transport approx. 0.2% (Figure 4).

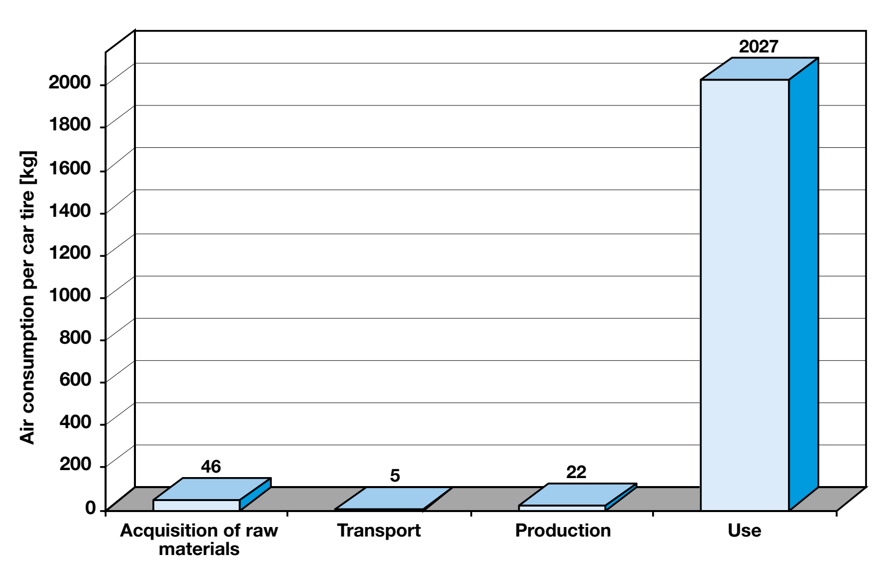

FIGURE 4: PRESENTATION OF AIR CONSUMPTION.

3.1.3. Water requirements

The water consumption is made up of cooling water (approx. 68%), process water (approx. 31%) and service water (approx. 0.2%). Cooling water is usually fed into circuits and can thus be used over a long period of time.

It exhibits a low negative impact factor. Process water is directly involved in the manufacturing processes and is disposed of as waste water. The term service water refers to that portion of the water consumed that cannot easily be classified as either cooling water or process water.

Water is used in all phases that a tire passes through in its life. The largest share – approx. 90% – is required for the acquisition of raw materials for the tire. The remainder is distributed as follows among the other phases of a tire's life: approx. 7.0% during use, approx. 3.8% during production and approx. 0.2% for transport (Figure 5).

The water consumption in conjunction with the acquisition of raw materials for the carbon black/rayon tires under consideration here is as follows: approx. 63% for the manufacture of synthetic rubber (SBR), approx. 18% to obtain rayon, approx. 3.1% for the manufacture of natural rubber, approx. 5.6% for the production of steel and approx. 6.5% for the manufacture of chemicals.

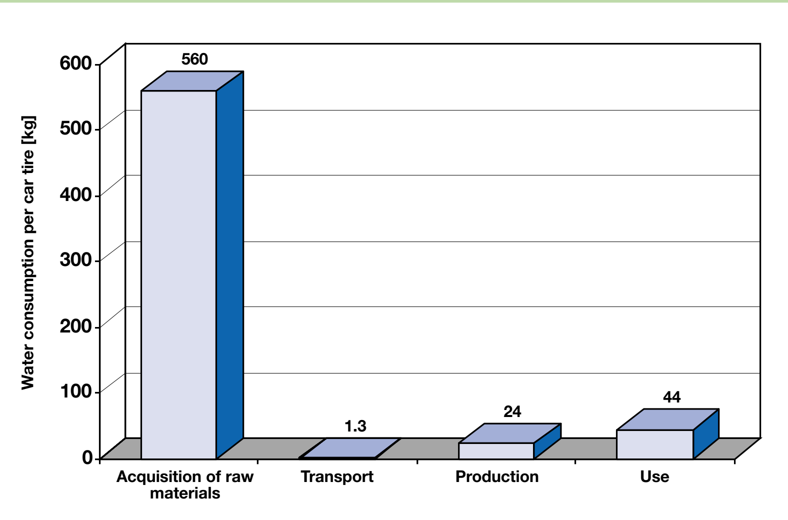

FIGURE 5: PRESENTATION OF WATER CONSUMPTION.

3. Life cycle inventory analysis

3.2. Output

The output of the life cycle inventory analysis is made up of the atmospheric emissions, emissions into water, waste and overburden and tire abrasion.

3.2.1. Atmospheric emissions

Atmospheric emissions are determined primarily by the output of carbon dioxide (approx. 97%). The remainder consists of carbon monoxide (approx. 1.2%) and water vapor (approx. 1.3%). Other emissions are methane (approx. 0.05%), nitrogen oxide (approx. 0.04%), volatile organic hydrocarbons with the exception of methane (NM VOC) (approx. 0.06%), sulfur dioxide (approx. 0.04%), ammonia (approx. 0.02%), nitrous oxide (approx. 0.01%) and dust (approx. 0.17%).

Of all the phases in the life of a tire, the car use phase accounts for the greatest negative impact on the atmosphere (approx. 95.4%) (Figure 6). This negative impact is due almost completely (approx. 98%) to the carbon dioxide emitted when the car is in operation. Carbon monoxide makes up approx. 1.2% of the negative impact on the atmosphere in the use phase.

The other phases in the life of a tire have a considerably weaker influence on atmospheric emissions: tire production approx. 2.5%, obtaining raw materials for the tire approx. 1.8% and transport another 0.3% or so (Figure 6).

Dust is generated almost exclusively in the use phase and consists primarily of particles of various sizes produced by tire abrasion. The particles escape into the air and gradually fall to the ground (see Chapter 3.2.4 for details). Water vapor is released when the tire is manufactured. It is produced as a result of cooling processes in the course of the manufacture of the rubber compounds as well as of components.

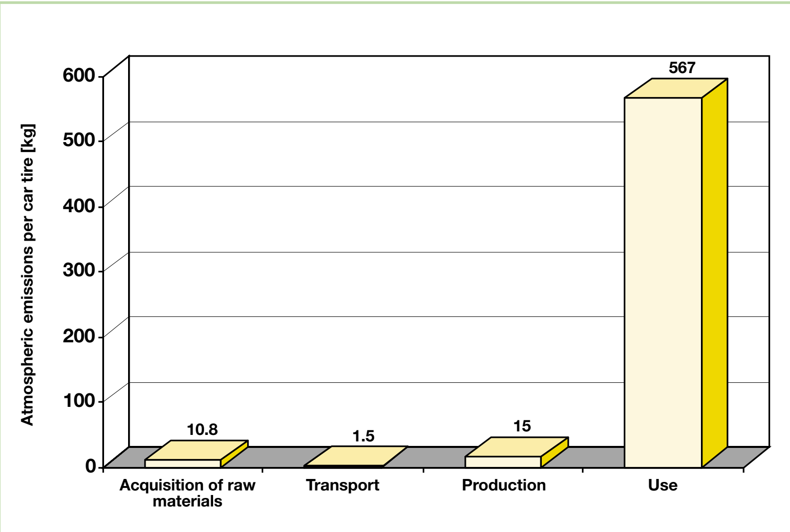

FIGURE 6: PRESENTATION OF ATMOSPHERIC EMISSIONS.

3.2.2. Emissions into water

The negative impact on waste water occurs almost entirely in conjunction with the acquisition of raw materials for the tire (approx. 94.4%) (Figure 7). In the other phases of life the negative impact on the waste water is much lower: approx. 2.8% during transport, approx. 2.8% during use and approx. 0.008% during production.

The negative impact on waste water is due to chloride ions (approx. 58.2%), sulfate ions (approx. 24.6%) and natrium ions (approx. 14.8%). These ions get into the waste water primarily during the manufacture of silica, rayon and synthetic resins.

3.2.3. Overburden and waste

Dead heap accumulates in the process of mining mineral and fossil resources. Dead heap, which remains largely unchanged during ore dressing and during the acquisition of raw materials, is referred to as overburden[12]. A share of the dead heap is chemically changed by ore dressing and raw material extraction. This residue is classified as waste, for which reason all further analyses will make a distinction between overburden and waste.

Roughly 76.2% of the overburden can be ascribed to the use phase of the tire – due to the extraction of crude oil for use as fuel and the provision of electric energy for petroleum refining. 0.23 kg overburden is produced per kg of normal gasoline. The fact that the tire's use phase accounts for such a preponderant share of the total overburden quantity produced in the life of a tire is due to a fuel consumption of approx. 186 kg gasoline per tire for every 50,000 km.

Approx. 11.9% of the total overburden amount occurs during tire production, while another 11.8% or so occurs in conjunction with the acquisition of raw materials for the tire (Figure 8). In these phases of the tire's life, the preponderant share of overburden is due to the mining of coal as energy carrier.

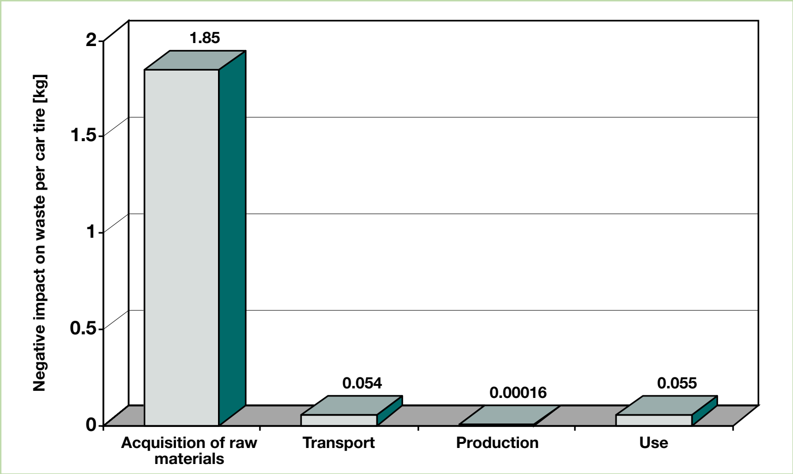

FIGURE 7: PRESENTATION OF THE NEGATIVE IMPACT ON WASTE WATER.

Coal is used either to obtain electric energy or directly in the respective process of obtaining energy.

Little petroleum is needed for the transport of a single tire; consequently the lowest amount of overburden occurs in this phase of a tire's life (approx. 0.01%).

Waste arises in connection with the extraction of raw materials for the tire (approx. 69.4%) and tire production (approx. 26.0%) (Figure 8). Approx. 62% of the waste from raw materials extraction consists of residue from ore dressing. Large quantities of ore dressing residue arise in the production of steel (almost 80% of the entire ore dressing residue incurred in the acquisition of raw materials for the tire). About 64% of tire production waste is household rubbish. The use phase accounts for 4.6% of the total volume of waste in the life of a tire.

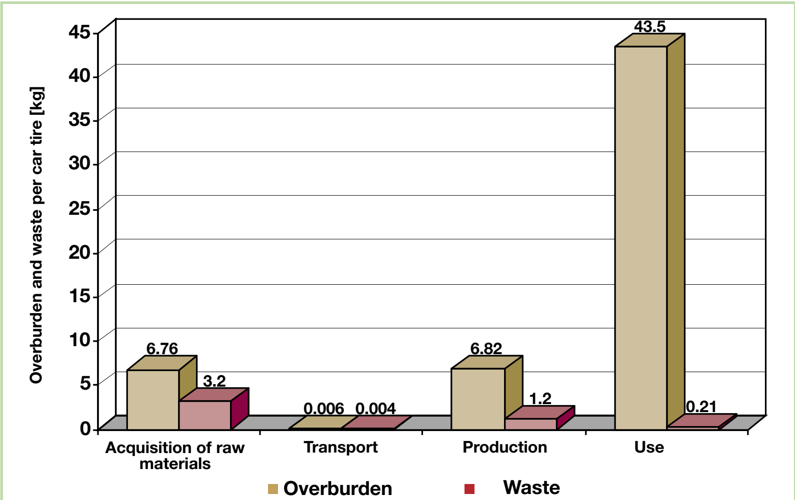

FIGURE 8: PRESENTATION OF OVERBURDEN AND WASTE.

3. Life cycle inventory analysis
3. Life cycle inventory analysis

3.2.4. Tire abrasion

Tire abrasion is already included in the assessment as output in Chapter 3.2.1, “Atmospheric emissions”; a number of additional peculiarities should also be dealt with here. Some of the abrasion is found in the ground and rain water. Emissions of this kind are hard to integrate into the specified systematics of a life cycle assessment.

The quantity of tire wear occurring in the life of a tire – i.e. in the course of the average mileage performance of 50,000 km or in a four-year period – works out to approx. 1 kg per tire; this corresponds to approx. 20 mg abrasion per tire and kilometer traveled (9).

Tire abrasion is composed of rubber (approx. 42%), carbon black (approx. 34%), and mineral oils (approx. 17%) (Figure 9).

The remaining 7% or so is made up of various tread ingredients and substances arising as a result of chemical conversion of the ingredients during vulcanization of the tire rubber compounds.

The tire abrasion is first spread temporarily over the road surface and in the ground to both sides of the road.

Abrasion is subject to the following processes:

- It is washed off the road by rain water.
- Water-soluble substances are eluted.
- Chemical and biological decomposition occurs.

In the analysis of a single tire, the 1 kg of tire abrasion is assumed to be evenly distributed to either side of the road over a period of four years and a distance of 50,000 km. Assuming a biological-chemical decomposition rate of 0.7% per day [13], the abrasion decomposes almost completely within two years of termination of the use of the tire[17]).

To the extent that inorganic components are not converted to metal soap in the course of vulcanization, they remain in the tread of the tire and are the part of abrasion remaining in the ground. This works out to approx. 4 g of zinc oxide – plus approx. 2.3 mg of cadmium oxide and approx. 11 mg of lead(II) oxide as escort substances of zinc oxide – per tire .

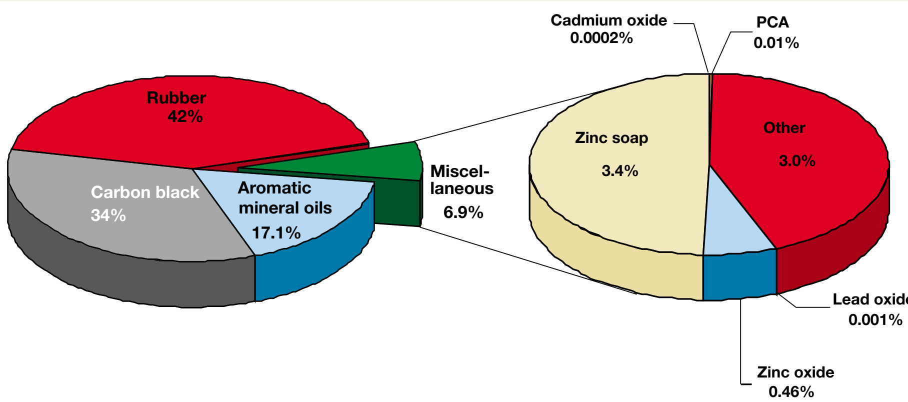

FIGURE 9: INGREDIENTS REFERRED TO AS "OTHER" ARE: SULFUR, WAX, PHENYLENEDIAMINE, CYCLOHEXYLTHIOPHTHALIMIDE, SULFENAMIDES, ANILINE, BENZTHIAZOLE, MERCAPTOBELETHIAZOLE AND MERCAPTOBENZTHIAZOLDISULFIDE. PCA = POLYAROMATIC HYDROCARBONS.

3. Life cycle inventory analysis

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Of interest in this connection is the cumulative negative impact on the ground of the total abrasion from all of the car tires in use in Germany. On the basis of the continuous input and the constant chemical and biological decomposition an equilibrium concentration is established in the ground[17].

46,000 tons of abrasion is left on Germany's 228,000 km of interurban roads each year[2] and distributed in a ground volume[18] of $1.14*10^9$ m^3. In a model calculation, the concentration and decomposition of the abrasion works out to a ground abrasion concentration of 16 g/m^3. Each year the ground absorbs approx. 0.16 g/m^3 of zinc oxide, approx. 0.09 mg/m^3 of cadmium oxide and approx. 0.4 mg/m^3 of lead(II)oxide.

Some of the abrasion components are washed away by rain water parallel to their chemical-biological decomposition. Elution of the components and reaction products of vulcanization contained in abrasion depends, inter alia, on parameters like ground particle absorption of the substances, size of the abrasion particles, composition of the ground, climatic conditions, solubility of the substances in water under ground conditions, migration speed of the water through the ground and the length of the migration route to the ground water. There is a great deal of uncertainty in the determination and impact of these variables on the eluation behavior of the various substances. For this reason, the present study refrains from engaging in any detailed quantitative examination of the elution of tire abrasion.

4. Impact assessment

4. Impact assessment

An input-output list (resources, emissions, waste etc.) is prepared for each phase in the life of the tire. The quantities and environmental impact of the individual components of the input-output list vary. To allow for a comparison of the individual phases in the life of a tire, it is a good idea to define a common reference size. The environmental impact that can proceed from the release of a single component is evaluated on the basis of equivalence factors [12]. The environmental potential is determined on the basis of the quantity and the equivalence factor of the components.

4.1. Impact categories/ environmental potential

The environmental potential generally recognized in the current discussion and taken into account here are: cumulative energy input[14], global warming effect, acidification and nutrification. By selecting this environmental potential, one takes into account global criteria (global warming effect), regional criteria (acidification) and local criteria (nutrification)[12]. Possible contributions to the ecotoxic and human-toxic potential are likewise dealt with.

4.1.1. Cumulative energy input

It should be noted again at this point that the cumulative energy input shown here does not contain the calorific value (i.e. the feedstock energy).

The largest share in the cumulative energy input of a tire is made in the use phase (approx. 95.8%). This energy consumption arises as a result of the car's fuel consumption to overcome the tire-incited traveling resistance. The remaining shares of the energy input are distributed over the remaining modules of a tire's life: raw materials acquisition approx. 2.7%, production approx. 1.3% and transport approx. 0.2% (Figure 10).

4.1.2. Global warming potential

The global warming potential is expressed in CO_2 equivalents with reference to a time horizon of 100 years. Takes into account the components CO_2, CO, methane and nitrous oxide (N_2O).

The global warming potential of a tire is determined almost entirely by the carbon dioxide emissions, CO_2 representing the dominating atmospheric emission in all phases of a tire's life (Chapter 3.2.1.). The highest quantities of CO_2 and CO are released in the use phase. In the life of the tire, they contribute approx. 96.3% to the global warming potential (Figure 11),

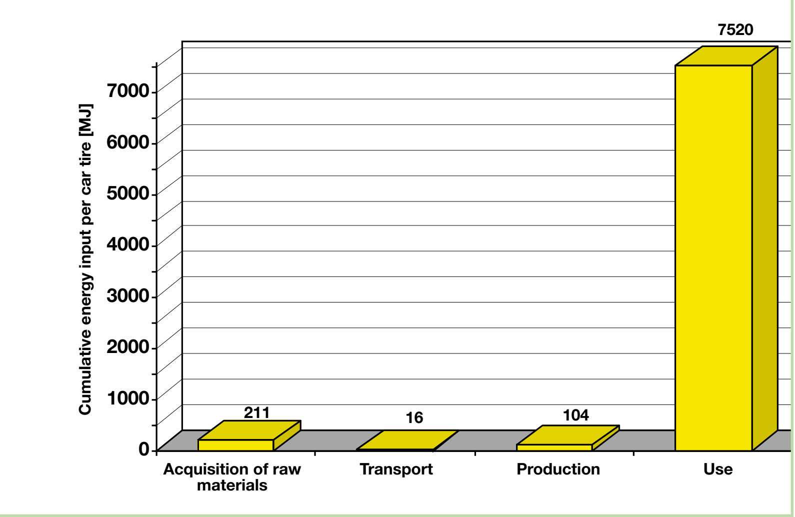


FIGURE 10: PRESENTATION OF THE CUMULATIVE ENERGY INPUT.

4. Impact assessment

while the other phases in the life of a tire contibute the following shares: raw materials acquisition approx. 2.2%, production approx. 1.2% and transport approx. 0.2%.

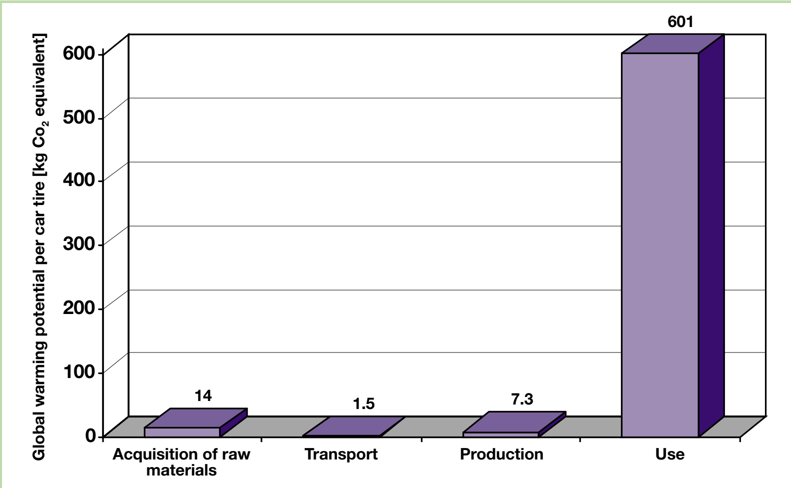


FIGURE 11: PRESENTATION OF THE GLOBAL WARMING POTENTIAL.

4.1.3. Acidification potential

The acidification potential refers to the pollution gases released (sulfur oxide, nitrogen oxide, acids e.g. HCl, HF, H_2SO_4). They are expressed in SO_2 equivalents.

The use phase of the tire shows the greatest share of acidification potential at approx. 85.1% (Figure 12) and is due mainly to the emission of SO_2 (approx. 32.5%), ammonia (approx. 30.9%) and NO_x (approx. 20.8%). Raw materials acquisition for the tire accounts for approx 11.3% of the total acidification potential, due essentially to SO_2 emissions (approx. 5.1%), NO_x (approx. 2.9%) and CS_2 (approx. 2.9%). The transport phase contributes approx. 1.9% to the acidification potential. These amounts are due primarily to SO_2 and NO_x emissions (approx. 0.4% and approx. 1.5% respectively) during the operation of the transport vehicle.

Tire production shows an acidification potential of approx. 1.6%, due mainly to SO_2 (approx. 0.7%) and NO_x (approx. 0.9%).

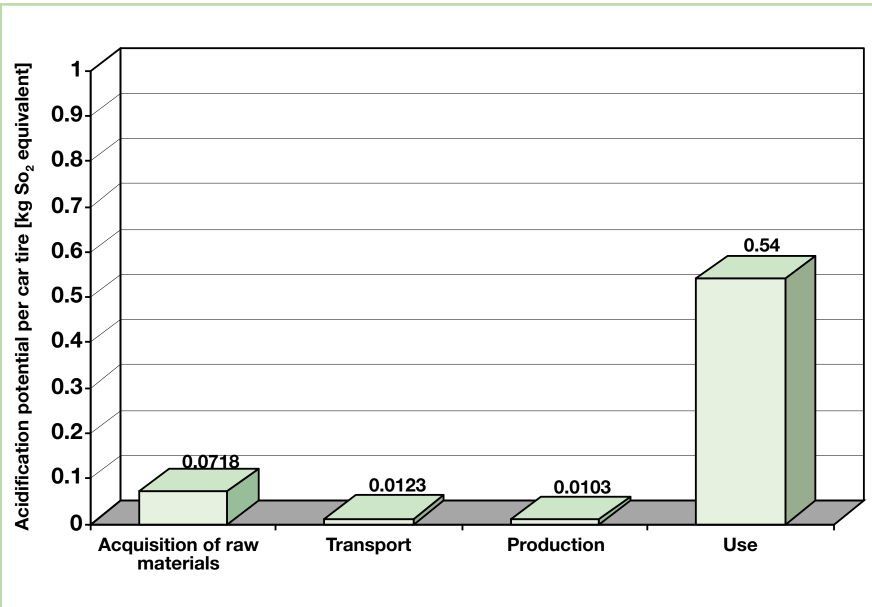


FIGURE 12: PRESENTATION OF THE ACIDIFICATION POTENTIAL.

4. Impact assessment

4.1.4. Nutrification potential

Nutrification refers to the supplying of nutrients to the ecological system. This can occur either via the eluviation from pollution gases out of the air or via water. The nutrification potential is expressed in phosphate equivalents.

All told, the use phase accounts for approx. 89.8% of the nutrification potential in the life of a tire (Figure 13) and is due to the emissions of the pollution gases ammonia (approx. 51.4%) and NO_x (approx. 36.6%). Raw materials acquisition for the tire accounts for approx. 5.5% of the nutrification potential (with airborne NO_x contributing 5.0% and the chemical oxygen requirement (COR) in waste water 0.4%) . Nitrogen oxides are the main chemicals released in the transport phase and accounts for approx. 3.1% of the nutrification potential. Tire production makes the smallest contribution to nutrification potential with approx. 1.5% (nitrogen emissions). It should be noted that the nutrients supplied during the life of a tire are almost completely related to the release of nitrogen oxides and ammonia. The input from phosphate or phosphate compounds is minimal.

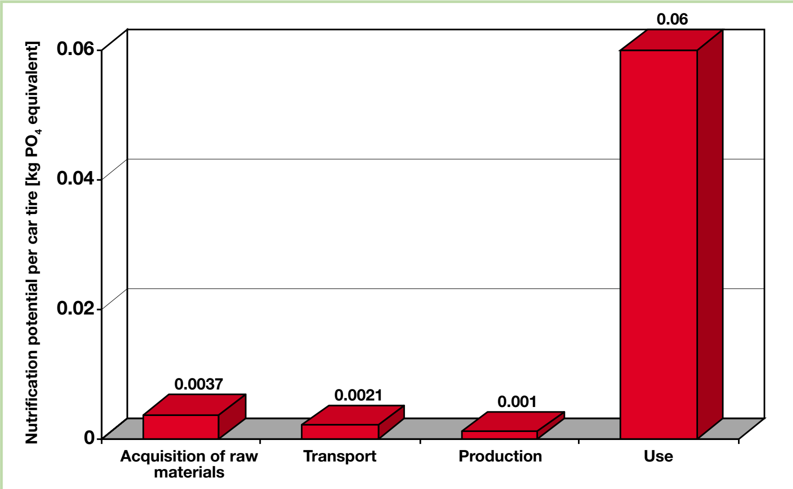


FIGURE 13: PRESENTATION OF THE NUTRIFICATION POTENTIAL.

4.1.5. Ecotoxic and human-toxic potential

To date there is only a very rudimentarily developed standardized method for recording and evaluating the numerous potential toxicological effects of pollution emissions. This is due to the difficulty of pinpointing and qualitatively evaluating the variable factors (exposition, limited local occurrence of the pollutants, metabolization and/or accumulation of pollutants, threshold concentrations, the sensitivity of organisms in ecological systems, the reversability of the effect of the impact). Data on ecological and human toxicity thus represents a risk estimate and should in no case be regarded as an absolute statement of impact potential.

Because of these methodological ambiguities in recording the potential, no quantification is attempted here.

In tire raw materials acquisition, chloride ions and zinc ions are released into the water. These substances can contribute to ecological and human toxicity potential. In the tire's transport, production and use phases, atmospheric emissions of SO_2 and NO_x (from energy input) can contribute to the human toxicity potential and the heavy-metal emissions into the air or waste water (e.g. mercury from energy supply) to the ecotoxic potential.

Tire abrasion can likewise contribute to ecotoxicity and human toxicity (see also Chapter 3.2.4).

5. Tire variant comparison
5. Tire variant comparison

(Life cycle inventory analysis and impact assessment)

Tire raw materials research has resulted in the development of a number of different tire variants, with diverse properties, in the last few years. The assessment data for four different tire variants is compared here (Table 2). The variants differ in their tire raw materials composition.

5.1. Comparison of carbon black and silica as fillers

By partially substituting silica for carbon black as filler, it is possible to reduce the tire's rolling resistance, among other things. This leads to a decrease in a car's energy consumption and to a reduction in consumption of petroleum as resource. As a consequence, the quantity of pollutants released drops, with a concomitant lessening of the global warming, acidification and nutrification potential. What's more, the amount of overburden produced is also lower. Production of the filler silica increases the negative impact on the waste water, however.

Subsituting silica leads to a reduction in the global warming potential of around 9.5%. This is due to a drop in pollutant gas emissions – CO_2 and CO (approx. 9.5% and 9.8% respectively). With the release of the pollution gases SO_2, NO_x and ammonia declining at the same time, the acidification potential is reduced by approx. 6.3%. Nitrogen oxides and ammonia are the main causative factors for the nutrification potential during the life of a tire. The reduction in the release of these chemical compounds thus leads to a reduction in the nutrification potential (approx. 7.5%).

By partially substituting silica for carbon black as filler, it is possible to effect a 9.3% or so reduction in the cumulative energy input over the entire life of the tire .

Mention is made here of the following complementary impact:

- All in all, a reduction of approx. 8.7% in the consumption of resources is achieved, thanks to petroleum savings of approx. 9.8%.
- The incidence of sulfate ions in waste water increases by a factor of 4.3, while the incidence of sodium ions increases by a factor of 2.7.
- The amount of waste increases by approx. 3.4%, due to an increase in the quantities of solid and liquid waste and of ash and slag.

5.2. Comparison of rayon and polyester as textile fabrics

The substitution of polyester for rayon leads to an increase in the global warming potential in the raw materials acquisition phase, thereby increasing the contribution to the global warming effect by about 0.3%, due to the higher level of CO_2 emissions. The acidification potential, on the other hand, declines by approx. 1.6%. This reduction is based on lower atmospheric emissions of CS_2 and H_2S, which are released during the manufacture of rayon. Although SO_2 releases go up, there is a reduction in the overall acidification potential. The nutrification potential is not influenced by substituting polyester for rayon.

Textile fabric ply of a tire

5. Tire variant comparison
5. Tire variant comparison

(Life cycle inventory analysis and impact assessment)

The environment potential does not record all input and output parameters. For this reason, further factors having an impact are additionally cited:

- By using polyester instead of rayon as textile fabric, the resource requirement climbs and the energy input increases slightly (approx. 0.1% and approx. 0.2%).

- The quantity of process waste water declines by about 52.8%. This reduction in the waste water amount is the result of the raw materials acquisition phase. The negative impact on the waste water likewise decreases (approx. 0.73 kg). This decrease works out to around 37.2% for a carbon black tire and approx. 17.3% for a silica tire.

- The total amount of waste is reduced by about 9.6%. This is related to a decrease in the amount of solid and fluid waste occurring as a result of the wood residue left over in rayon manufacture.

The manufacture of cellulose for the production of rayon is characterized by high water consumption and a high ion-related negative impact on waste water. Considerably less water is consumed in the manufacture of polyester and there is less of a negative impact on waste water. The substitution of polyester for rayon leads to a considerable reduction in water consumption and in the negative impact on waste water. These reductions are not reflected in environmental potential values, as the corresponding parameters do not flow into the environmental potential values cited.

The decrease in chloride and sodium ions and in zinc can, however, lead to a reduction in the eco- and human toxicity.

TABLE 2: (see page 19) PRESENTATION OF THE ASSESSMENT DATA FOR FOUR DIFFERENT TIRE VARIANTS. →

The values are obtained by totaling the individual data from the raw materials acquisition, transport, production and use phases. They cover the entire life of a functioning car tire. Recycling of the worn tire is not included in the data. All input contributing more than 1% to the total input sum is shown. 99.1% of all input is recorded. The cut-off criterion for the three output categories was set at 1% of the total of the respective output category. 99.7% of the atmospheric emissions, 98% of the negative impact on water and 99.9% of waste (incl. overburden) are recorded. This cut-off limit gives rise to an inaccuracy of 2%. Raw materials that are relevant for the tire are shown even if they account for less than 1% (e.g. sulfur). Standard emissions (e.g. dust, N_2O, BOD and COD, especially waste that must be monitored) are included even if they make up less than 1%. BOD stands for biological oxygen demand, COD for chemical oxygen demand.

5. Tire variant comparison
5. Tire variant comparison

(Life cycle inventory analysis and impact assessment)

Inputs				
Raw materials (kg):	**Carbon black/rayon**	**Silica/rayon**	**Carbon black/polyester**	**Silica/polyester**
Process water	194.81	195.70	94.77	92.12
Cooling water	434.25	455.44	434.25	455.44
Hard coal	2.16	2.24	2.16	2.24
Lignite	3.46	3.48	3.46	3.48
Natural gas	5.41	5.73	5.36	5.69
Petroleum	205.52	185.43	206.02	185.94
Sulfur	0.20	1.01	0.04	0.84
Dead heap	28.06	26.92	28.06	26.92
Latex	2.57	2.51	2.57	2.51
Iron ore	1.17	1.00	1.17	1.00
Air	2099.37	1904.57	2100.60	1905.85
Outputs				
Products:	**Carbon black/rayon**	**Silica/rayon**	**Carbon black/polyester**	**Silica/polyester**
Mileage (km)	50,000	50,000	50,000	50,000
Worn tire (kg)	5.47	5.68	5.47	5.47
Atmospheric emissions (kg):	**Carbon black/rayon**	**Silica/rayon**	**Carbon black/polyester**	**Silica/polyester**
Water vapor	7.83	7.83	7.83	7.83
Polluted air	1464.53	1329.60	1465.59	1330.69
Dust	1.02	0.95	1.02	0.95
SO_2	0.25	0.23	0.25	0.24
CO	6.81	6.14	6.81	6.14
CO_2	576.74	522.01	578.65	523.99
NO_X	0.24	0.22	0.24	0.23
N_2O	0.057	0.052	0.057	0.052
Methane	0.32	0.29	0.32	0.29
NM VOC	0.35	0.33	0.345	0.32
Water pollution (kg):	**Carbon black/rayon**	**Silica/rayon**	**Carbon black/polyester**	**Silica/polyester**
Waste water	270.31	310.13	174.29	210.71
Waste water - cooling water	422.83	436.14	422.83	436.14
BOD	0.0080	0.0079	0.0062	0.0060
COD	0.02	0.02	0.01	0.01
Sulfate ions	0.48	2.07	0.054	1.63
Sodium ions	0.29	0.77	0.20	0.68
Chloride ions	1.13	1.17	0.94	0.97
Calcium ions	0.000018	0.27	0.000018	0.27
Waste (kg):	**Carbon black/rayon**	**Silica/rayon**	**Carbon black/polyester**	**Silica/polyester**
Overburden	57.08	53.56	57.09	53.57
Ore dressing residue	2.18	2.21	2.18	2.21
Waste. solid and liquid	1.33	1.49	0.97	1.11
Rubber waste	0.19	0.19	0.19	0.19
Waste particularly subject to monitoring	0.055	0.067	0.055	0.067
Household waste	0.80	0.80	0.80	0.80
Slurry	0.081	0.084	0	0
Ash and slags	0.047	0	0.049	0
Environmental potential:	**Carbon black/rayon**	**Silica/rayon**	**Carbon black/polyester**	**Silica/polyester**
Cumulative energy input (MJ)	7851.12	7117.16	7863.48	7113.67
Global warming effect (kg CO_2 equiv.)	623.25	564.15	625.17	566.14
Acidification (kg SO_2 equiv.)	0.63	0.59	0.62	0.57
Nutrification (kg PO_2 equiv.)	0.067	0.062	0.067	0.062

6. Recycling of worn tires
6. Recycling of worn tires

(Life cycle inventory analysis and impact assessment)

A car tire qualifies as a worn tire when, after a certain period of use, it has forfeited its original functional capability (taken here to be the carbon black/rayon version of a size 175/70 R 13 tire). The worn tire can be recycled for its material value and/or as energy carrier. Recycling thus represents an expansion in the use benefit of a car tire. This natural interface is used to functionally separate the life cycle assessment of a car tire from the life cycle assessment of a worn tire.

The recycling of worn tires takes place in different recycling processes. Alongside raw material recycling processes – the suitability of which is established in tests – there are a number of material and energy recycling processes that have been tested in real life situations. This study takes a look at the most significant worn tire recycling processes as case examples.

The three recycling processes under study here – full retreading, cement production, and energy generation in tire power stations – are compared with the corresponding equivalent processes: new tire production, cement production using standard fuels and energy generation in power plants with the help of standard fuels[8]. In a systems comparison of this kind, the uniformity and equivalency of benefits must be guaranteed. The benefit achieved by using the worn tire thus always serves as reference quantity;
i.e. the mileage of the retreaded tire, the amount of cement produced or the amount of energy obtained. This makes possible a direct comparison of resource consumption and the related environmental impact with standard and equivalent processes.

It is important to note that this manner of analyzing a worn tire, which concentrates on its input as feedstock or energy carrier in the recycling process, neglects the negative impact (resources expended, emissions into the air and water, waste and overburden) during its life as a functioning tire).

6.1. Cement plant

The material and energy inflows for the use of worn tires in a cement plant are compared with the same inflows when the standard fuel – hard coal – is used. Fuel engineering considerations limit the use of worn tires to no more than 20% to 25% of the total quantity of energy carriers.

Worn tires being fed into the rotary tubular kiln

6. Recycling of worn tires

6. Recycling of worn tires

(Life cycle inventory analysis and impact assessment)

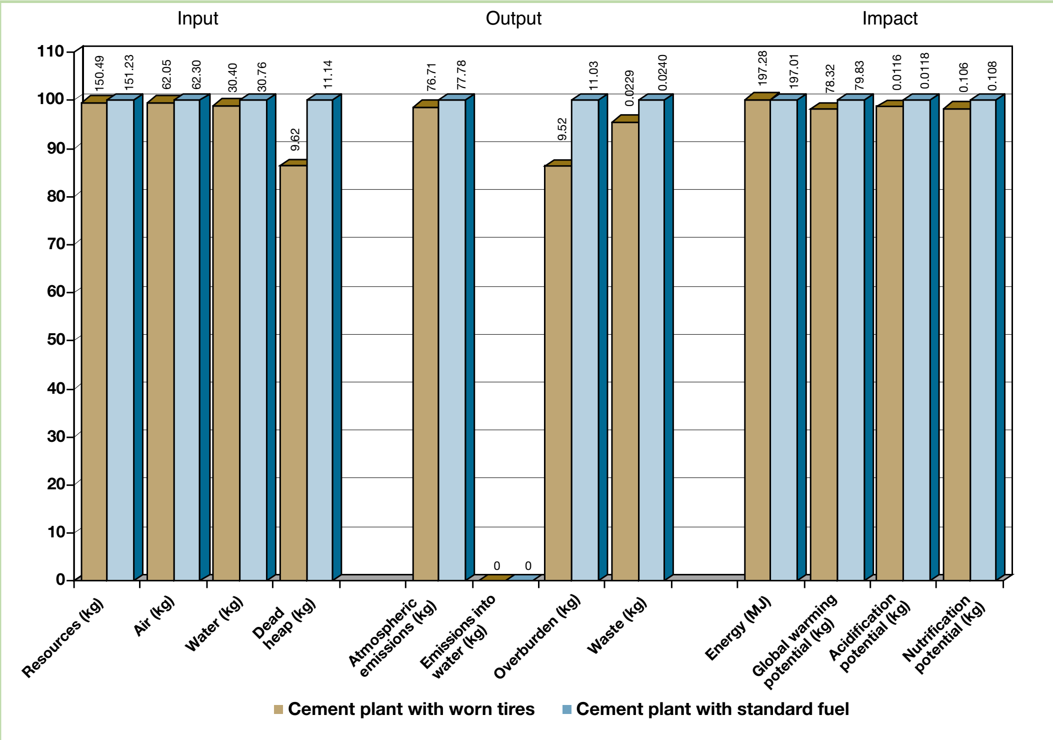


FIGURE 14: RECYCLING OF A WORN TIRE (CARBON BLACK TYPE) IN A CEMENT PLANT VS. USE OF A STANDARD FUEL.
In the cement plant, a worn tire share of 25% is assumed. The individual parameters are presented in summary form in the categories shown. The categories for the use of standard fuel are set at 100% and the data for the use of worn tires as fuel is shown relative to that. The figures for the individual columns indicate the absolute value of the summarized parameters in the categories. They are to be regasded independently of the figures given on the % axis. Results of the life cycle inventory analysis and of the impact assessment are shown in the same chart. Input flows and output flows in the life cycle inventory assessment are overwritten as "Input" or "Output". The calculated environmental potential of the impact estimate is overwritten as "Impact".

The use of worn tires in the cement plant generates considerably lower amounts of dead heap and overburden (14% in each case) (Figure 14). This is because the use of worn tires instead of standard fuel means that less coal needs to be mined.

The use of worn tires leads to a lower level of atmospheric emissions than is the case with standard fuels (about 1.4%), with the global warming potential reduced by approx. 1.9%, the acidification potential by approx. 1.9% and the nutrification potential by approx. 1.7%. As a rule, the worn tire has a lower carbon, sulfur and nitrogen content than the hard coal used, which explains the reduced level of pollution gas emissions (CO_2, SO_2 and NO_x).

In view of the fact that worn tires have a higher specific calorific value than hard coal, a smaller quantity of raw materials can be used (0.5%). Reducing the quantity of raw materials used also reduces the amount of ash and slag generated during combustion. The amount of waste drops by approx. 4.2%.

Using worn tires instead of hard coal does not affect the other input and output parameters to any great extent. Much of the environmental impact is even reduced slightly by using worn tires (see Figure 14 for details). The environmental effect of using worn tires in a cement plant can thus be regarded as "neutral".

6. Recycling of worn tires
6. Recycling of worn tires

(Life cycle inventory analysis and impact assessment)

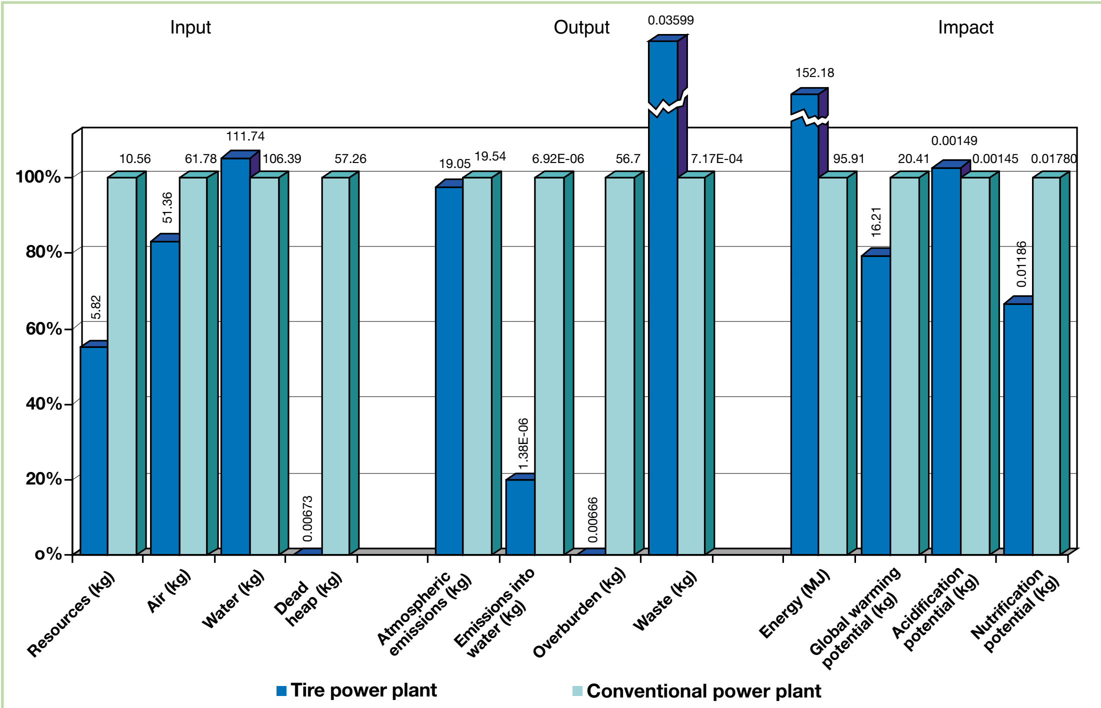


FIGURE 15: RECYCLING OF A WORN TIRE IN A TIRE POWER PLANT VS. ENERGY GENERATION IN CONVENTIONAL POWER PLANTS. The individual parameters are shown summarized in categories. The categories for energy generation in conventional power plants are set at 100% and the data for the recycling of worn tires in a tire power plant is shown relative to that. The figures for the individual columns reflects the absolute value of the summarized parameters in the categories. They are to be regarded independently of the figures given on the % axis. Results of the life cycle inventory analysis and impact assessment are shown in the same chart. Input flows and output flows for the life cycle inventory analysis are overwritten as "Input" or "Output". The calculated environmental potential of the impact assessment is overwritten as "Impact".

6.2. Tire power plant

There are both negative and positive effects on environmental pollution when one opts for burning worn tires in tire power plants rather than combusting fossil resources (the German energy mix of hard and lignite coal, petroleum and natural gas), as is the case in conventional power plants (Figure 15).

For process-related reasons, the energy input in the former case is higher than for conventional power plants using fossil resources as fuel. The energy conversion efficiency of tire power plants amounts to only 25-30%; the efficiency of conventional power plants is much higher.

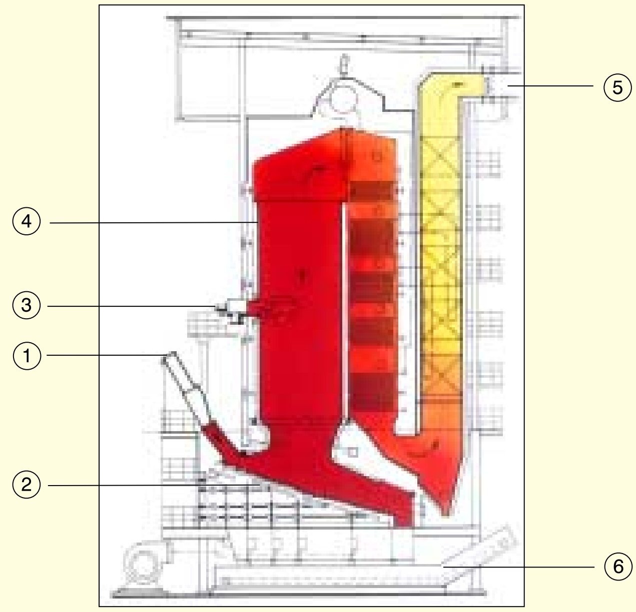
In comparison to conventional power plants, the tire power plant under study has acid flue gas scrubbing, in addition to SO_2 flue gas scrubbing. This has the effect of increasing the tire power plant's water consumption and, in particular, the quantity of waste produced as well. The resulting quantity of waste is, however, very small in comparison to the resulting quantity of overburden. This waste involves sludge (with a water content of approx. 50%) containing heavy metals. Part of the water consumed for flue gas scrubbing escapes into the atmosphere as water vapor (approx. 37%).

6. Recycling of worn tires
6. Recycling of worn tires

(Life cycle inventory analysis and impact assessment)

The tire power plant uses a smaller quantity of resources (45%) because worn tires have a higher specific calorific value than hard or lignite coal. Hardly any dead heap and overburden is produced in generating energy from worn tires. This is because the use of secondary raw materials does not require the mining of any fossil resources.

There are fewer atmospheric emissions (without water vapor) in a tire power plant than in conventional power plants. Insofar as the quantity of resources used in a tire power station is smaller than in conventional power stations, less CO_2 is released (approx. 17%) and a weaker global warming potential generated (approx. 20%). Worn tires release somewhat less SO_2 than coal, thereby reducing the acidification potential (approx. 33%). Reductions in the amounts of the SO_2 and cadmium released can lead to a reduction in the ecotoxic and human-toxic potential.



Tire power plant

6.3. Retreading

A comparative ecological evaluation of a retreaded tire with a new tire poses certain methodological problems. A retreaded tire and an original new tire are not equivalent products in the strict sense of the word. This is because it is not technically possible for a retreaded tire to simultaneously obtain the same level as the base product – a new tire – as regards properties like safety, durability, handling and service life. (This notwithstanding, retreaded tires can attain a high technical level).

Some of the causes are:

- technical limits in roughing the old tread components
- the inevitable additional temperature stressing of the carcass during tread vulcanization
- the varying tire contours of different tire types and/or makes
- the varying growth of the carcass in the tire's first life as a function of service period, load, air pressure and temperature. Nowadays the retreading industry is capable of manufacturing retreaded tires that approximate a new tire in almost all properties – with the exception of rolling resistance. The rolling resistance of a tire of this kind is at least 3% higher than that of a new tire.

6. Recycling of worn tires

6. Recycling of worn tires

(Life cycle inventory analysis and impact assessment)

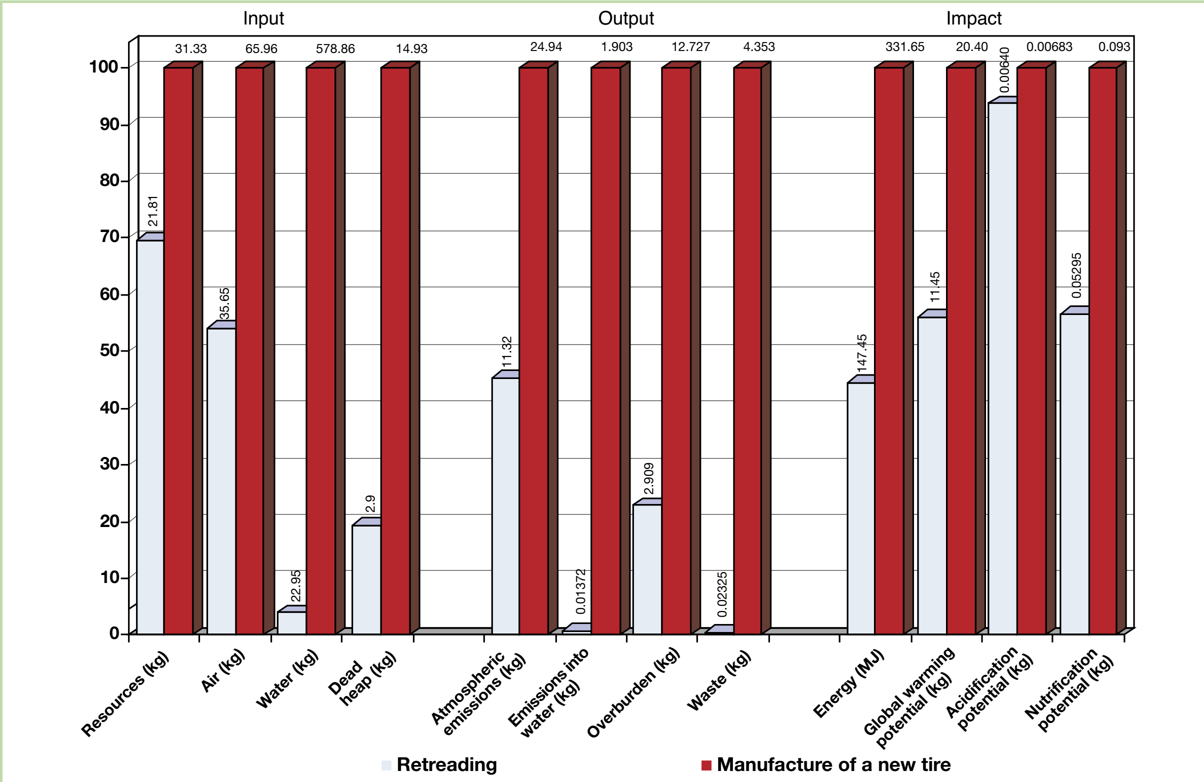


FIGURE 16: MANUFACTURE OF A NEW TIRE VS. RETREADING OF A WORN TIRE.

The individual parameters are shown summarized in categories. The categories for new tire manufacture are set at 100%, with the data for worn-tire retreading presented relative thereto. The figures for the individual columns reflect the absolute value of the summarized parameters in the categories. They are to be regarded independently of the figures given an the % axis. Results of the life cycle inventory analysis and of the impact assessment are shown in the same chart. Input flows and output flows for the life cycle inventory analysis are overwritten as "Input" or "Output". The calculated environmental potential of the impact assessment is overwritten as "Impact".

For this comparison, one assumes the most favorable case for a retreaded tire, namely a rolling resistance 3% higher than that of a new tire but otherwise the equal of a new tire property-wise.

6.3.1. Manufacture of new tires versus full retreading of worn tires

Considerably more energy is required to manufacture a new tire than to retread a worn tire (approx. 2.3 times more), approx. 1.85 times as much air is required, approx. 25 times as much water and approx. 1.4 times as many resources (Figure 16).

Atmospheric emissions, waste water pollution and the amounts of overburden and waste produced are also markedly higher than for a retreaded tire (by approx. factors of 2.2, 139, 4.4 and 187 respectively).

This means that manufacturing a new tire has a much greater environmental impact than retreading a worn tire: the global warming potential is 1.8 times that of a retread, the acidification potential approx. 1.75 times and the nutrification potential approx. 1.07 times higher.

There is a trivial explanation for these major differences: as already mentioned, a worn tire enters into the present assessment as "raw material available", without the expense for its manufacture being taken into consideration.The only raw materials needed in retreading are those required for the new tread.

6.3.2. Service life of a new tire versus service life of a retread

A comparison of new tire manufacture and worn tire retreading yields very favorable results for retreads. This is relativized somewhat when the expense for the use of new tires and retreads is also considered. This manner of viewing things actually violates the assessment framework defined for the present study. The authors regard the inclusion of the use phase in the presentation of the retread as very important, however, and thus view the deviation from the assessment framework as acceptable.

In what follows, two different scenarios are considered: a rolling resistance increase of 3% corresponds to the value that can be obtained with the best retreading technology available; a 10% increase in rolling resistance is average for retreads. In a first step, one compares the environmental impact of using retreads with the impact of using a new tire. In a second step, the environmental impact of the retreading process and of using a retread is compared with the corresponding impact of manufacturing and using a new tire.

6.3.2.1. Use of a retread versus use of a new tire

As Figure 17 shows, the fact that rolling resistance is 3% or 10% higher in the case of a retread means that the overall environmental impact in the retread's use phase is approx. 3% or 10% higher than a new tire's use phase

6. Recycling of worn tires

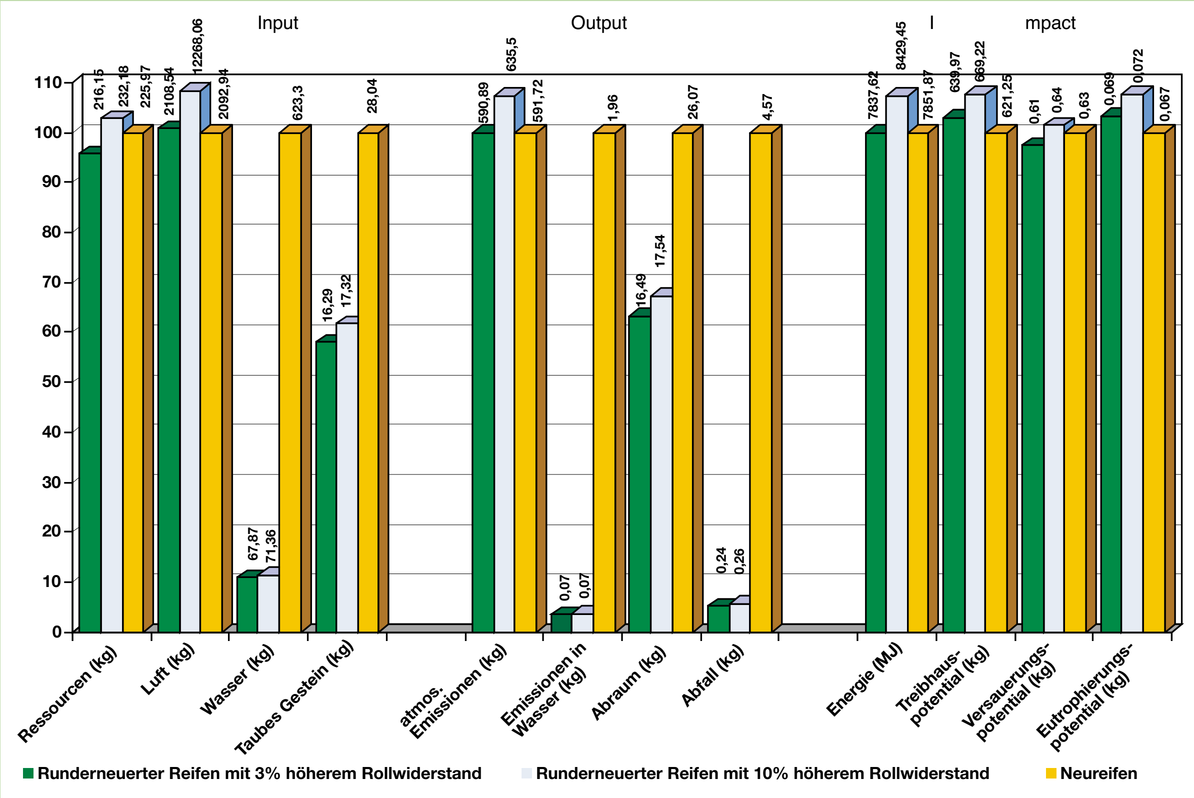


FIGURE 17: USE OF A NEW TIRE VERSUS USE OF A RETREAD (3% OR 10% HIGHER ROLLING RESISTANCE).

The individual parameters are shown summarized in categories. The categories for the use of a new tire are set at 100%, with the data on the retread being shown relative thereto. The figures for the individual columns reflect the absolute value of the summarzied parameters in the categories. They are to be regarded independently of the figures given on the % axis. Results of the life cycle inventory analysis and of the impact assessment are shown in the same chart. Input flows and output flows for the life cycle inventory analysis are overwritten as "Input" or "Output". The calculated environmental potential of the impact assessment is overwritten as "Impact".

6.3.2.2. Retreading and use of a retread versus manufacture and use of a new tire

As Figure 17 shows, the life of a retread exhibits a much lower water consumption rate (approx. 89%) and a much smaller negative environmental impact on waste water (approx. 96%).

This effect is due to the resource savings, especially for rayon and SBR. The reduction in the quantities of dead heap (approx. 42%) and overburden (approx 17%) result from a lower consumption of electric energy. On the other hand, the retread's higher rolling resistance gives rise to greater fuel consumption. This in turn leads to increased overburden in conjunction with the drilling and refining of petroleum.The reduction in overburden is thus smaller than the reduction in dead heap. Waste (approx. 95%) decreases because a retreaded tire makes use of the worn tire's casing; as less steel is used, considerably less ore dressing residue accumulates.

As even the quality car retread exhibits more rolling resistance than a new tire, it consumes more energy and air during its phase of use. The increased

6. Recycling of worn tires

6. Recycling of worn tires

(Life cycle inventory analysis and impact assessment)

consumption of energy and air is more than offset by the savings at-tained in retreading. The consumption of resources drops by about 4.4%. The resource savings attained in retreading is virtually canceled out by the higher petroleum (fuel) consumption .

With the car consuming more fuel, emissions of pollutant gas (CO_2, NO_x and SO_2) and methane are also higher. This is offset by the savings realized in retreading. The consequence is nonetheless an increase in the global warming potential (approx. 3.0%) and the nutrification potential (approx. 3.0%). The acidification potential drops by approx. 2.7%.

The environmental impact as a consequence of higher rolling resistance is particularly marked when the increase in rolling resistance is assumed to be 10%. The energy and air requirement rises by approx. 8% or approx. 9% respectively. The lower resource requirement for retreading is more than canceled out by the increased fuel consumption in the use phase; there is an increase in the resource demand of approx. 3%. With the increase in fuel consumption, pollutant emissions also rise (approx. 7%). As a consequence the global warming potential also grows (approx. 8%), as do the acidification potential (approx. 1%) and the nutrification potential (approx. 8%).

The ecological advantages and disadvantages of the two variants under study do not become evident until the tire is viewed in an overall system.

The sum ecological effect of a high-quality retreaded tire exhibiting a moderate increase in rolling resistance can be said to be virtually neutral, while a retreaded tire of average quality can be expected to generate a greater environmental impact.

7. Interpretation
7. Interpretation

One main goal of this life cycle assessment is to pinpoint what can be done to avoid environmental effects in the life of a tire.

7.1. Dominance analysis

Because of the plethora of parameters under consideration in this assessment, no one phase can be expected to exercise general dominance for all parameters. The greatest negative impact on the atmosphere, for example, is in the use phase (Figure 7); in the case of waste water, on the other hand, raw material acquisition has the greatest negative impact (Figure 7). A summarized comparison can be made on the basis of the cumulative energy input and the environment potential in the various life phases.

The cumulative energy input and the environmental potential values are shown in Figure 18.

In all categories the greatest negative impact on the environment is shown to occur in the use of the tire. Next in importance – with a considerably lower impact – are the raw materials phase and the transport phase. Tire production has the weakest negative impact on the environment. On the basis of the clear dominance of the use phase vis-à-vis raw materials acquisition, production and transport, it is evident that the greatest potential for a reduction in the environmental impact is there: even a relatively slight reduction in rolling resistance can have a major effect.

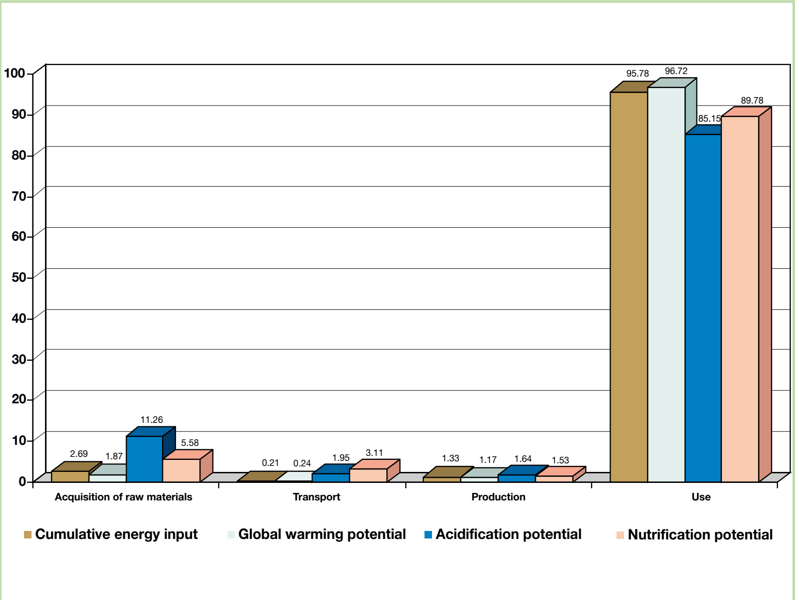


FIGURE 18: RELATIVE COMPARISON OF ENERGY CONSUMPTION AND VARIOUS FACTORS OF IMPACT POTENTIAL IN THE PHASES OF A TIRES LIFE.

7.2. Significance analysis

As the use phase of the tire gives rise to the greatest environmental impact (Chapter 7.1), it is the starting point for an effective reduction of environmental effects by means of material variations. The comparison of different variants shows clearly that the impact on the atmosphere can be lessened by substituting silica for carbon black in the tread compound. This is because the change lowers the tire's rolling resistance (Chapter 5.1). While this substitution increases, in fact, the negative impact on waste water, the overall effect on the cumulative energy input and on the environmental potential is advantageous. A comparison of the rayon and polyester variants (Chapter 5.2) points to a clear significance with respect to the water requirement and to emissions into water in favor of the polyester variant.

For lack of any unambiguous comparative criteria, no comparative evaluation will be made here of the three worn-tire recycling alternatives studied. It is to be noted, however, that all three recycling possibilities allow for savings of mineral or fossil resources to the extent that these resources are replaced by worn tires.

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7. Interpretation

Worn tires are used as a secondary raw material in other product systems. The inherent properties of these worn tires thus yield expanded benefits allow worn tire recycling to fulfill the requirements of the Recycling Management and Waste Act.

7.3. Sensitivity analysis

For methodological reasons, product life cycle assessments are always inevitably subject to a certain degree of "fuzziness" and subjectivity. The reason for this is primarily uncertainty and inaccuracy in recording the data, the delimitation of the scope of the assessment and the weighting and evaluation of the environmental impact. The sensitivity analysis should include an estimate of the impact of possible errors on the results of the assessment.

7.3.1. Possible sources of error

7.3.1.1. General framework of analysis

To ensure the reproducibility of the assessment, it was necessary to define the scope of the assessment (Chapter 2). Indirect and personnel expenses lie outside the system limits. This is because there is still no agreement as to whether these expenses should flow into an assessment. Construction, maintenance and servicing of systems and auxiliary processes are not included in the assessment. This is firstly because the proportional assessment of these expenses relative to a single tire would be miniscule and secondly because these expenses should be taken into consideration in assessing the systems.

Possible noise emissions from a tire are dependent on various parameters. There are differences in the existence and efficiency of noise control measures, the transmission of noise, the distance from the source of the noise, local conditions and the noise-sensitivity of living beings to noise. It is therefore difficult to quantify noise emissions, for which reason they are not included in the assessment.

One can therefore assume that any error that may result from excluding the expenses cited is smaller than the impact that imprecise data and eroneous allocations would have (e.g. in use).

7.3.1.2. Allocations

No information is available on any allocation samples as may have been applied or with respect to data records from external sources. It can be assumed, however, that alternative allocations would not have any significant impact on the assessment results. On the other hand, the allocation of material and energy flows in the tire's use phase is of major significance to the assessment. Distribution on the basis of the road resistance generated by the tire seems plausible because it reflects the tire's effect on the car's fuel consumption. It seems advisable to measure the cement plant's inflows and outflows on the basis of the energy contribution made by worn tires.

7.3.1.3. Cut-off criteria

With the exception of the data in Chapter 5 (caption to Table 2), the data shown in this assessment covers all the individual parameters. In this way errors due to the application of cut-off criteria are avoided.

The assessment drawn up also incorporates data from raw material manufacturers and recycling organizations. As none of the data suppliers indicates the cut-off criteria applied, it is assumed that all essential data has been recorded.

7.3.1.4. Data gaps

Not all the data provided by the raw material suppliers exhibits the degee of integrity this assessment was aiming at. These gaps are filled in by calculations, database records and estimates of our own as derived from chemical processes. It must be assumed, however, that this

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approach does not take full account of the material and energy flows occurring. The remaining data gaps involve only sections of the respective raw material assessments and raw materials that only make up a small share of the tire as a whole.

7.3.1.5. Assumptions/ Averages

For some parameters readings were available or different either not so that assumptions or calculations had to be made on the basis of averages. Due to this approach, the results may fluctuate. There is, however, no danger of this influencing the assessment's core statements.

7.3.1.6. Effects related to processes and techniques

The technical process and procedural conditions prevailing in raw materials acquisition, energy generation and tire production differ from one manufacturer to the next and thus are not absolutely identical in all cases. The data used in this assessment, however, was viewed as representative. Proceeding in this manner does, of course, lead to a certain "fuzziness" in the assessment results; e.g. the use of process data for German or European areas can lead to changes in the absolute magnitudes; this does not, however, significantly influence the assessment's core statements.

7.3.1.7. Data acquisition

The data acquisition for the present assessment covered a period of six years. Changes in materials preparation, technical procedures or new system designs occurring in the timespan through to completion of the assessment can affect the results of the assessment. As far as is known, changes of this kind did not transpire in the assessment timespan.

7.3.1.8. Evaluation method

The environmental impact is evaluated on the basis of equivalence coefficients that determine the contribution made by the relevant pollutant to the respective environmental potential. Those environmental potential values are studied whose weighting coefficients are generally recognized nowadays[15]. It is, on the other hand, hardly possible to scientifically ascertain the weighting coefficients used to determine ecotoxicity and human toxicity (Chapter 4.1.5). For this reason the potential values are described verbally instead of being represented absolutely. In this way it is possible to avoid errors and misinterpretations that could arise as the result of a scientifically unfounded evaluation

7.3.2. Impact of possible errors on the outcome of the assessment

The tires's use phase displays the highest global warming, acidification and nutrification potential in the overall life of a tire (figure 21). This potential is determined primarily by the release of CO_2, SO_2 und NO_x in all phases of a tire's life. A change in the weighting of these pollutant gases in the contributions to the various potential effects would impact evenly on all phases.

Consequently, the tire's use phase would form the phase in the life of a tire in which the evironmental impact is strongest.

The dominance of the use phase over all other phases in the life of a tire is quite marked. Even halving the use phase's contribution to the environmental potential observed (cumulative energy input, global warming potential, acidification potential and nutrification potential) and at the same time doubling the contribution made in the raw materials acquisition phase would not lead to a shift in the phasal topography of the environmental impact. The results of this assessment can thus be regarded as tenable.

The consumption of water and the negative impact on waste water is highest during tire raw materials acquisition (Figure 19). To alter this assessment result it

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would be necessary to halve water consumption during the raw materials phase while at the same time doubling water consumption during the tire production phase. Changes in the negative impact on waste water would have to be more marked to influence this tire assessment statement.

The basic statements arising from a comparison of the different tire variants (energy savings, reduction in atmospheric emissions, changes in water consumption and the negative impact on waste water) (Chapter 5) are not significantly influenced by the possible sources of error cited here.

In the present assessment, the rolling resistance of car retreads is assumed to be 3% or 10% higher (Chapter 6.3.2). Changes in this value have a marked influence on how the ecological advantages and disadvantages in the car retread use phase compare with those in the new tire use phase (Chapter 6.3.2).

The results concerning the environmentally neutral use of worn tires in cement plants is obtained from a comparison of identical plants within the scope of the assessment. The statements arrived at are based on the inherent properties of the worn tires versus those of hard coal, the standard fuel. The difference between energy generation in tire power plants and in conventional power plants is due to differences in the procedural techniques and to the inherent properties of the different energy carriers. There is virtually no possibility that the sources of error cited will in any way influence the results obtained here.

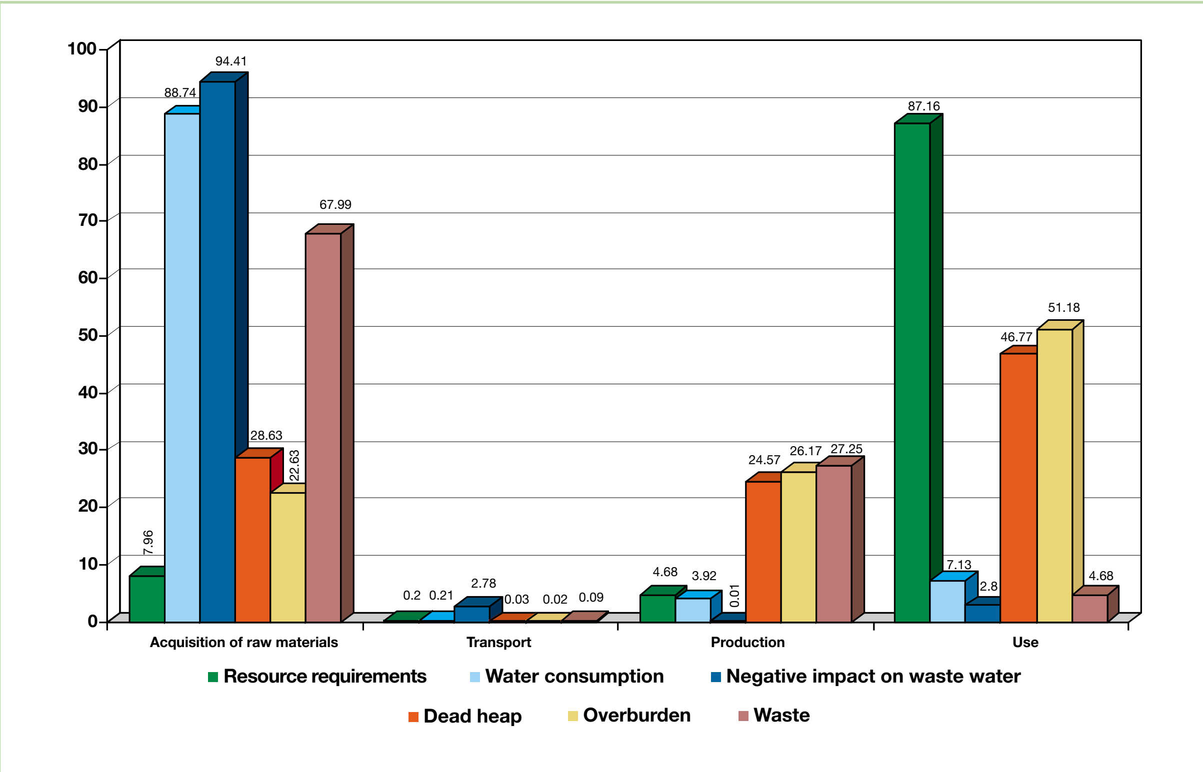

FIGURE 19: RELATIVE COMPARISON IN THE PHASE OF A TIRES LIFE.

8. Opportunities for influencing the impact on the environment

8. Opportunities for influencing the impact on the environment

In this section, the phases in which the environmental impact is greatest – as determined by the study – are to investigated with a view to pinpointing any possible improvements. On this basis recommendations can be derived for corrective action.

8.1. Raw materials acquisition

Raw materials acquisition for a car tire is characterized by a high water requirement (Figure 5 and Chapter 3.1.3). The use of cooling water poses less of a problem from an ecological viewpoint as the negative impact resulting therefrom is much lower than from process water (Chapter 3.1.3). To achieve an efficient reduction in the use of process water, it is advisable to aim at substituting the raw materials rayon and silica. Polyester has, to a certain extent, already replaced rayon in car tires, resulting in a marked reduction in the water requirement (Chapter 5.2). While it is true that a lot of water is required for the manufacture of silica, using silica as filler does lead to a clear reduction in a car tire's rolling resistance. Ranking the environmental impact of using silica is thus a question of evaluation.

Raw materials acquisition is the phase in the life of a tire when the negative impact on waste water is highest (Figure 7 and Chapter 3.2.2). In the geographical area on which this assessment is based, water has not been a scarce resource to date so that reductions in the negative impact on water are not classified as an ecological priority. Substituting polyester for rayon can, however, lead to a reduction in the negative impact on waste water.

Rubber extraction

The raw materials acquisition phase is characterized by a high incidence of waste (Figure 8 and Chapter 3.2.3). The high contribution made by ore dressing residue to the overall incidence of waste does not really present much of a problem, the waste consisting, for the most part, of tailings that need not be monitored. Using synthetic fibers instead of steelcord could represent the right approach in reducing the amount of waste generated, assuming that the environmental impact from the production of fibers does not cancel out the benefits of waste reduction.

8.2. Tire production

The production of car tires generates large quantities of dead heap and overburden (Figure 3 and Figure 8). As this negative impact results more from energy generation than directly from tire production, it is not possible to directly influence it in any way.

The waste generated in the production of car tires (Figure 8) can largely be classified as not requiring any particular monitoring. An attempt should nonetheless be made to differentiate the waste quantities and to then specifically reduce certain types while increasing the share of waste recycled.

Tire production at Continental

8.3. Tire use

Tire use is accompanied by a high consumption of energy and resources (Chapters 3.1.1 and 4.1.1), thereby contributing largely to the global warming, acidification and nutrification potential (Chapters 4.1.2 to 4.1.4). At the moment ecological concern focuses on the depletion point of these resources and the climate[16]. Tire manufacturers can take action to reduce the negative environmental potential by developing car tires with lower rolling resistance. The partial substitution of silica for carbon black as filler has already effected improvements allowing for greater fuel efficiency in this area (see also Chapter 5.1). Automakers can also contribute to a further reduction in the environmental potential – for example, by cutting back the weight of the vehicle – as can motorists by adopting a more economical driving style and by paying more attention to the condition of their tires (e.g. by making sure that the tires are correctly inflated). Tire makers can be of assistance here.

8.4. Recycling of worn tires

When worn tires are used in the cement industry they sometimes replace the standard fuel or other raw materials, thereby helping to conserve natural resources. As recycling is environmentally neutral, and with the law imposing an upper limit of 25% for substitute fuels, there is no possibility of this influencing the environmental impact.

When worn tires are fired whole in tire power plants, the resulting specific energy consumption is higher than for conventional power plants. Appropriate milling of the worn tires to allow for more effective firing systems would eliminate this deficiency. At the moment a lot of waste is produced in the power plants studied due to additional smoke purification facilities. The latter are necessary, however, to reduce gaseous emissions.

An immediately apparent advantage of retreading is the “raw material bonus” that worn tires offer. This advantage is offset, however, by the disadvantage of the retread’s higher rolling resistance and the overall balance is even negative in some cases.

The general picture would be environmentally neutral if the increase in rolling resistance could be held to a moderate level of around 3%. It is clear that further development is necessary to achieve parity in the use of new tires and worn tires (Chapter 6.3).

WORN TIRES ARE DELIVERED AND FED INTO THE FURNACE AT THE CEMENT PLANT.

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9. Bibliography

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weitere Datenquellen siehe Chapter 2.2 Punkt 5 Bezugsquellen der Daten

a To calculate the change in abrasion (A) over time , the following equations and constants were used:

Enrichment ‡	$d(A)/dt = k^1$	(1)	
Degradation ‡	$d(A)/dt = - k^{2(A)}$	(2)	
Law of time ‡	$(A) = (k^1/k2)\{1 - exp(-k^{2t})\}$	(3)	
State of equilibrium ‡	$(A)(= k^1/k^2$ für t = (	(4)	
Constants:	k^1 = 1000/(4*365) = 0,685 [g/Tag]		for one tire
	k^1 = 46*109 /365 = 0,126*109 [g/Tag]		for all car tires on interurban
	k^2 = 0,007 [1/Tag]		roads in Germany

b Soil volume V (=tire-mileage*abrasion-width of deposit*2*wear-depth of penetration)

V = 228*106*25*2*0,1 = 1,14*109 [m^3]

10. Annex
10. Annex

Contributions to global warming potential (timeframe 100 years)

COMPOUND	GLOBAL WARMING POTENTIAL [KG CO_2 EQUIVALENT]
Carbon dioxide (CO_2)	1
Methane (CH_4)	24.5
Dinitrogen monoxide (nitrous oxide, N_2O)	320
Carbon monoxide (CO)	3

Contributions to acidification potential

COMPOUND	ACIDIFICATION POTENTIAL [KG SO_2 EQUIVALENT]
Sulfur dioxide (SO_2)	1
Nitrogen oxides (NO_X)	0.7
Hydrogen sulfide (H_2S)	1.88
Hydrogen fluoride (hydrofluoric acid, HF)	1.6
Hydrogen chloride (hydrochloric acid, HCl)	0.88
Ammonia/ammonium (NH_3/NH_4)	1.88

Contributions to nutrification potential

COMPOUND	NUTRIFICATION POTENTIAL [KG PO_4-EQUIVALENT]
Emissions into the air:	
Phosphate (PO_4)	1
Ammonia (NH_3)	0.33
Nitrate (NO_3)	0.42
Nitrogen oxides (NO_x)	0.13
Emissions into water:	
Phosphate (PO_4)	1
Chemical oxygen demand (COD)	0.022
Ammonia/ammonium (NH_3/NH_4)	0.33

Critical review of the life cycle assessment
Critical review of the life cycle assessment

Report
Critical Review of the Life Cycle Assessment
Life Cycle Assessment (LCA) of a Car Tire

TÜV NORD
ZERTIFIZIERUNGS- UND
UMWELTGUTACHTER GESELLSCHAFT

Order number: 328 227 01

Report
on the critical review of the life cycle assessment
to DIN EN ISO 14040 ff.

Life Cycle Assessment (LCA) of a Car Tire

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LCA prepared by:

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Environmental Protection/Recycling Department
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TÜV Nord Zertifizierungs- und Umweltgutachter Gesellschaft mbH,
accredited by the DAU-Deutsche Akkreditierungs- und Zulassungsgesellschaft für Umweltgutachter mbH, registration no. DE-V-0158
Dr. Johann Josef Hanel, environmental reviewer, DE-V-0058
Dr. Winfried Hirtz, environmental reviewer, DE-V-0151

Order no.: 328 227 01 Date of order: Feb. 24, 1999

Review based on: **DIN EN ISO 14040ff. : 1997**

DIN EN ISO 14041ff. : 1997

DIN EN ISO 14042ff. : 1999

DIN EN ISO 14043ff. : 1999

Critical review of the life cycle assessment

Critical review of the life cycle assessment

1. General remarks

1.1. Object and definition of the assignment

Continental AG's environmental protection function worked out a comparative life cycle assessment (LCA) of a car tire. In a letter dated February 24, 1999 Continental AG commissioned TÜV Nord Zertifizierungs- und Umweltgutachter Gesellschaft mbH (TÜV Nord ZUG), as independent external agency, to critically review the LCA in compliance with DIN ISO 14040 ff.

At TÜV Nord ZUG the review was carried out by the environmental reviewers approved in accordance with the environmental audit statute: Dr.-Ing. Johann Josef Hanel, Dr.-Ing. Winfried Hirtz.

As specified by the customer, the objective of the review was one of verifying the reliability, transparency, relevance and representativeness of the methodology used in the LCA submitted for review with respect to

- objective and scope of the assessment
- life cycle inventory analysis
- impact assessment and the
- interpretation/evaluation of the assessment.

1.2. Approach

Taking into consideration the overriding quality criteria (transparency, reproducibility, quality of data used, identification of source of data), the critical review was carried out as follows:

- review of objective and scope of assessment
  - function and functional equivalence
  - system limits/scope of assesssment (place, time, technology)
  - allocation process with the specific assignment/distribution rules selected
  - selection of significant parameters and materials
- review of the performed life cycle inventory analysis
  - input/output analysis (main chains)
  - input/output data used incl. the reliability of same
  - systematic methods, integrity and plausibility of the input/output analysis
  - sensitivity analysis and estimation of errors
  - plausibility and soundness of the calculations
  - consideration of prior process chains, coupled production and secondary post-use effects
- review of impact assessment
  - selection of impact categories (inventory- and problem-oriented)
  - aggregation of data with respect to impact categories
- review of the interpretation/comparative statements as a consequence of impact assessment

For this review, relevant methodological processes and documents as well as data acquisition and calculation steps were viewed in a representative scope, directly on the computer and elsewhere. Within the limits of what is reasonable, pertinent professional literature on LCA techniques was considered.

Critical review of the life cycle assessment
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2. Outcome of the critical review

2.1. Objective of the study

The objectives of the LCA are clearly and unambiguously defined; external and internal target groups were likewise named for the study. The introductory (concise) description for conducting a life cycle assessment of a tire provides a sufficient amount of relevant information to elucidate the targeted, ecologically holistic mode of analysis in such a way as to render it reproducible.

2.2. Scope of study

The object of this assessment was seen to be a summer car tire in Continental's main product line. It is compared with different tire variants and the recycling of worn tires. The scope of the assessment (boundaries) are defined and delimited within the system as a whole with respect to area, time and technology. The assessment limits are compatible with the selected functional unit of the assessment object, which is defined as a mileage of 50,000 km in the life of a tire (standard mileage).

For the following life cycle inventory analysis, all relevant components, structural parts and processes within the assessment area are ascertained, analyzed and finally consolidated into five main modules typical for the assessment object:

- manufacture of raw materials for tires
- tire production
- tire use
- recycling of worn tires
- transport.

The technologically-related multiplicity in the components, structural parts, and processes composing the modules are transformed to standard components in the current technology generation without effecting any changes in the conditions. We regard this as a reasonable and purposeful approach. The presentation of the individual modules in graphs and tables backs up the systematic procedure and integrity of the approach chosen. A 100% assessment is attained.

The effects and influences that can be overlooked in defining the assessment system are discussed and – to the extent relevant – listed.

By way of summary, the scope of assessment decided upon can be said to ascertain and take into account all relevant variables within the limits of the relevant assessment space limits, in accordance with the present state of ecological assessment techniques.

2.3. Life cycle inventory analysis

The input/output analysis and the documentation of the life cycle inventory assessment of a car tire were effected with the assistance of a computer on the basis of the aforementioned key modules.

2.3.1 Data sources

The processes in the main chains of the individual modules are described realistically. The data used rely partly on generally recognized files (PE/IKP 1998: Holistic Assessment Techniques, GaBi, Version 3) and partly on Continental AG sources. The data base is as comprehensive as the DP systems employed allow. Additional data was added where necessary to ensure data symmetry. This affected, for example, overburden in the case of oil extraction or rubber transports. The data is reproducible and representative for this assessment. All manufacturer data on individual ingredients not contained in the database – e.g. carbon black, silica – was subjected to critical review. It is inherently conclusive.

Critical review of the life cycle assessment

2.3.2. Plausibility and integrity review

The computer imagery of the system boundaries is also systematic and in compliance with the defined assessment areas. The boundaries are drawn wherever no (major) influence on the partial results and no influence on the overall results are to be expected any more (see the sensitivity analyses carried out). A high degree of data quality and data symmetry can be attested to. The data is complete within the limits cited.

Sampling was carried out for all five LC inventory analysis areas (main modules). In so doing, the accuracy of the assessment techniques and the plausibility of the calculations and results were checked for selected parameters (e.g. CO_2 emissions, material input, waste etc.) throughout the assessment. Within the assessment the correct linkage of process chains, the incorporation of partial assessments and the basis for the data was checked. In the case of module changes, the recalculation was actively monitored, as, for example, the calculation of the module “zinc production” instead of “iron production”.

To ensure the retraceability of data back to its source, both the related calculations and the documentation was examined.

Within the framework of the iterative review, the suggestions made by the environmental experts with respect to the complementation of the documentation (100% reproducibility) were incorporated. This concerned, for example, the calorific value of worn silica and carbon black tires or the nonusable thermal energy in tire power plants. Upon termination of the project, all data was completely reproducible.

All significant parameters are in place, representative, systematically designed and completely assessed. The assessments and the data acquisition and calculation processes are transparent and reproducible.

2.3.3. Allocations

Allocations occur primarily in the use phase. They are not available in a generally accessible database and were therefore prepared by Continental AG. They are presented in the documentation in a completely understandable and plausible form. To the extent that allocations from the databases are imported into the process plan, the basis of the data is sufficient.

Allocations from the databases were already taken into consideration there.

Other allocations were made for the recycling of worn tires in cement plants and in the event of prior oil product chains. They are plausible.

2.3.4. Error assessments and sensitivity analysis

Separate uncertainty analyses for the individual parameters were demonstrated to have been carried out and are contained in the documentation. The assertions derived from these possible errors are tenable.

The sensitivity calculations and the appurtenant requisite parameterization were reviewed, with the key use-phase criteria of relevance here being rolling resistance and aerodynamic drag. Other materials added to safeguard the assessement limits – silica, for example – were likewise covered. The sensitivities were plausibly calculated.

2.4. Impact assessment

The impact assessment is based on the data in the life cycle inventory analysis. The life cycle inventory and impact assessments were separated from one another both as regards text and image. The impact indicators were selected in compliance with the review boundaries of the product life cycle assessment.

To even be able to interpret – by means of an impact estimate – the data and information that it was possible to study in the course of the life cycle inventory analysis, the data first has to be summarized using predefined impact categories.

Critical review of the life cycle assessment

Critical review of the life cycle assessment

Taking into consideration the goals of the study, the functional unit selected and the (standard) technologies used in the assessment area, the following impact categories were defined in the study:

- resource consumption in the form of primary energy input
- Global warming potential (GWP)
- Acidification potential (AP)
- Nutrification potential (NP)
- Ecotoxic and human-toxic potential.

These quantifiable impact categories represent the assessment object, including the technology employed, in terms of local, regional and global impact indicators (key categories). The assignment of individual data to the impact indicators has been provided for. The data is grouped by respective environmental impact and is specified in accordance with the scientifically established, data-based dose-impact relationship (Saur + Eyerer 1996). The calculations were subsequently carried out. The factors in the DP system are internationally recognized.

The specific problem of human toxicity and ecotoxicity – in the strict sense of the word – has also been covered in the assessment in the form a risk analysis. The use phase is the main exposition path for human and ecotoxicity. Alongside the inhalation of abrasion particles (individual negative impact path), deposits of toxic substances were also observed on vegetation and along the shoulder of the road. The assessment was not able to arrive at a human and toxicity evaluation score summarizing the toxicity data and substance groups. Because the data was gathered for a large area and incorporated individually, toxicity can be discussed only in the form of models.

Further impact categories are of only secondary importance with respect to the objectives of the assessment.

The study did not consider raw material depletion (petroleum, rubber). We feel this is appropriate in view of the assessment boundaries and the primarily industrial use of these raw materials.

The data was grouped under key categories on the basis of generally recognized equivalence factors in a clear, reliable and easily reproducible fashion. The results for the cases observed in the LCA are presented in a balanced and conclusive manner. The cases in question are:

- manufacture of the raw materials for tires
- production of the tire
- use of the tire
- recycling of the tire
- transport.

2.5. Interpretation

The present interpretation of results of the inventory analysis and the impact assessment is consistently and appropriately focused on the goals defined for the LCA. Recommendations were made with respect to specific users and target groups. The scope of the recommendations was appropriately restricted in line with the current configuration of standard tire manufacturing and the alternatives on which the product life cycle assessment was based.

The recycling of worn tires is addressed in three options representing the major possibilities at the moment. The major environmental effects arising from the recycling of worn tires are analyzed and discussed. This is especially true for the "retread" option. Due to the lack of functional equivalence, a direct comparison is possible here only to a limited extent. The appropriate separate assessment analysis carried out for retreads and new tires provides valuable results and indications in this regard, in particular for the respective use phase of each.

Critical review of the life cycle assessment

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Because certain newer processes – the use of rubber granulate and powder, for example – do not currently enjoy the market relevance we feel they merit, they are not treated in this assessment.

Recommendations are labeled as such and clearly separated from the life cycle inventory analysis and impact assessment.

3. Summary of the critical review

We have critically reviewed the car tire life cycle assessment on the basis of the requirements laid down in DIN EN ISO 14040 ff. The review can be summarized as follows:

- The methods used for the product life cycle assessment comply with the requirements laid down in DIN EN ISO 14040 1999. They are scientifically founded and correspond to what is state-of-the-art with respect to product life cycle assessment techniques.
- The data employed is adequate, useful and qualified with respect to the goal of the study.
- The interpretations take into account the goal of the study and the restrictions recognized.
- The study submitted is inherently conclusive and transparent.

A validity declaration has been issued with regasd to the critical review submitted.

Hannover, July 23, 1999

Dr.-Ing. Johann Josef Hanel
Environmental reviewer

Dr.-Ing. Winfried Hirtz
Environmental reviewer

GÜLTIGKEITSERKLÄRUNG

Dem Unternehmen

Continental AG
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wird bestätigt, daß die vorgelegte Produkt-Ökobilanz

Produkt-Ökobilanz (LCA) eines PKW-Reifens

unter Beachtung der Grundsätze und des Standes der Öko-Bilanztechnik insbesondere hinsichtlich

- ordnungsgemäßer Methodologien
- repräsentativer Bilanzierungs- und Wirkungskategorien
- durchgängiger Transparenz und Konsistenz

erstellt wurde.

Durch eine kritische Prüfung - Bericht 328 227 01 wurde der Nachweis erbracht, daß die Forderungen der Norm-Reihe

DIN EN ISO 14040 ff.

bei der vorgelegten Produkt-Ökobilanz erfüllt sind.

Hannover, den 23. Juli 1999

Dr. Johann Josef Hanel
Umweltgutachter

Dr. Winfried Hirtz
Umweltgutachter

TÜV NORD

ZERTIFIZIERUNGS- UND UMWELTGUTACHTER GESELLSCHAFT

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