SILICA/SILANE TECHNOLOGY

Tires Go Green –
A Life Cycle Assessment

EVONIK
POWER TO CREATE

THIS BULLETIN SUMMARIZES THE POTENTIAL ENVIRONMENTAL IMPACTS of low rolling resistance tires. It is based on the study “Life Cycle Assessment of Silica/Silane and S-SBR used in treads of Green tires including potential differences to carbon black and E-SBR used in treads of Black tires” (Evonik Resource Efficiency GmbH, 2016). This study was conducted in accordance with ISO standards 14040 and 14044 (ISO 2006) and reviewed by a panel of external experts. The panel consisted of Dr. Martin Baitz (chairperson) of thinkstep AG, Matthias Fischer of the Fraunhofer Institute for Building Physics, and Dr. Christian Strübel of Continental Reifen Deutschland GmbH.

INTRODUCTION: What Silica/Silane Technology is All About

Tires are high-tech composites. It is a key challenge for tire developers to master the “magic triangle” formed by the conflicting objectives of wet grip, mileage, and rolling resistance. In the past when tire treads were equipped with carbon blacks and E-SBR rubber grades, improving one part of the triangle resulted in another part deteriorating. With the introduction of S-SBR rubber grades and Silica/Silane technology, it became possible to enhance both rolling resistance and wet grip at the same time and thus to develop low rolling resistance tires, also known as “Green tires”, without concessions in safety (figure 1). Green tires offer comparable durability to E-SBR rubber grade based on carbon black, have significantly better grip – particularly in wet conditions –, and reduce fuel consumption.

Silica/Silane: It’s all in the mix

The secret to success lies in the components’ interaction: The treads of Green tires are mainly made of S-SBR rubber grades. Silica particles serve as active filler which ensures wear resistance in the tire, but are actually incompatible with this kind of rubber. Thus, Silane is added to chemically “couple” S-SBR rubber grades and Silica (see figure 2).

Evonik – innovation partner of the tire industry

Evonik is one of the world’s leading producers of Silica and Silanes and the only company in the world to manufacture and market both. Combining our expertise in these products in our portfolio gives us the advantage of an in-depth understanding of the reinforcement mechanism. New innovations are steadily improving the performance of the Silica/Silane system. The ULTRASIL® Silica line or the Silane Si 363™ are just a few examples of developments with optimized properties which improve the performance of the whole tire.

Figure 1
Comparison of tires based on Silica/Silane and carbon black

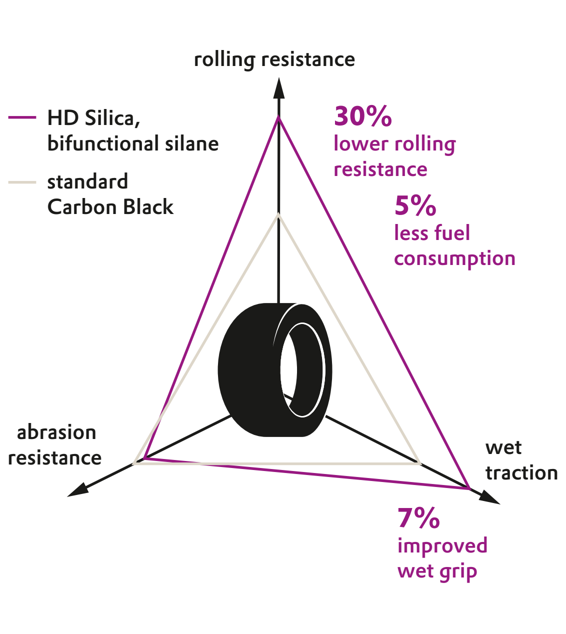
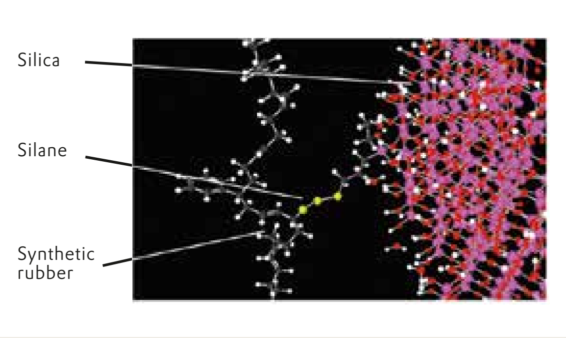


Figure 2
Silica/Silane system in tire tread



THE NEXT STEP: A Life Cycle Assessment

COMPARED TO VEHICLES WITH CONVENTIONAL TIRES USING CARBON BLACK AS SINGLE FILLER, THE FUEL CONSUMPTION OF THE VEHICLE IS REDUCED BY 5%. THIS IS AN IMPORTANT DEVELOPMENT AS IT CONTRIBUTES TO THE REDUCTION OF CARBON DIOXIDE EMISSIONS.

The next logical step is to examine the potential environmental impact of tire treads based on Silica/Silane and S-SBR in Green tires compared with the impact of tire treads based on carbon black and E-SBR over their life cycles. To do so, Evonik has conducted a comprehensive Life Cycle Assessment (LCA) – together with in-house experts in Life Cycle Management – to investigate the entire life cycle, extending from the production of raw material through to tire manufacturing and application to end-of-life (cradle-to-grave LCA).

This study was carried out in accordance with ISO standards 14040 and 14044 (ISO 2006) and reviewed by a panel of external experts which consisted of Dr. Martin Baitz (chairperson) of thinkstep AG, Matthias Fischer of the Fraunhofer Institute for Building Physics, and Dr. Christian Strübel of Continental Reifen Deutschland GmbH.

The construction of production plants and infrastructure was not included in the study; neither were the identical aspects of both technologies, additives and other parts of the tire such as sidewall, belts etc. (shown in grey in figure 3).

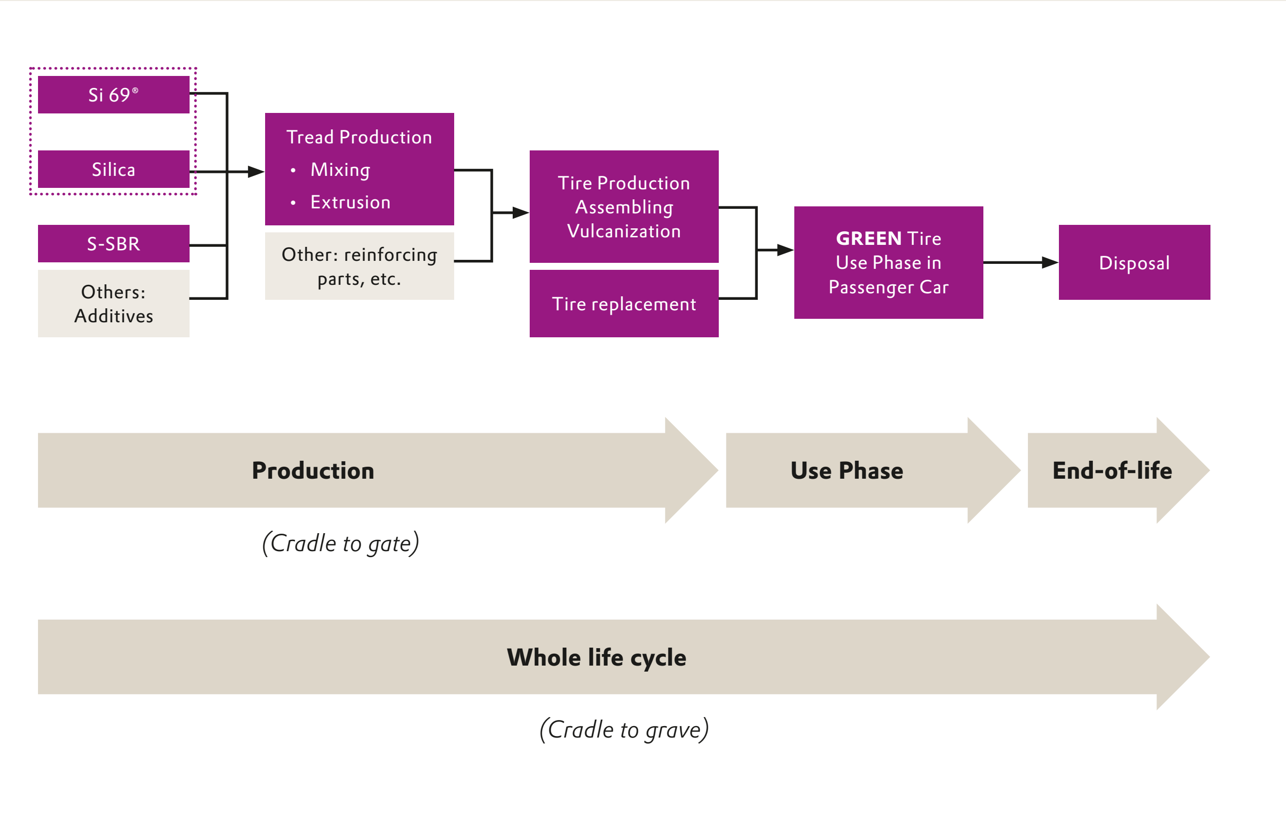
Methodology

The following environmental impact categories were analyzed using the CML collection method of the Institute of Environmental Sciences (CML) of Leiden University.

- **Global Warming Potential (GWP100)/kg CO_2-equivalent***
  The GWP is the global warming potential or carbon footprint (CF). It describes the abilities of different greenhouse gases to trap heat in the atmosphere and thus contribute to climate change.
- **Photochemical Ozone Creation Potential (POCP)/kg ethene-equivalent**
  The POCP is the weight-based ethene (C_2H_4) equivalent of the ground-level ozone, also known as summer smog. This ground-level ozone is formed by such precursors as reactive nitrogen oxides, carbon monoxide, or volatile hydrocarbons (VOCs).
- **Primary Energy Demand (PED)**
  The PED is considered as an indicator for the cumulative energy demand (including renewable and non-renewable energy) for the process chain. It is measured in megajoules.

* "kg substance equivalent" (e.g. kg CO_2e) expresses the amount of a reference substance (e.g. CO_2 for the GWP) that equals the impact of a considered pollutant within the studied category (e.g. the Global Warming Potential on a 100 year scale of an emission of 1 kg of methane is 28 times higher than 1kg of CO_2, thus its Global Warming Potential is 28 kg CO_2e).

Figure 3
System boundaries and scope of the LCA



Assumptions

In this study, the functional unit is defined as the use of Silica/Silane and S-SBR in treads of passenger car tires over a driving distance of 150,000 km. The passenger car considered is a standard gasoline-fueled medium or compact class car (for example a Golf 6) with a displacement of between 1.4 and 2 liters and in compliance with Euro 5 emission standards. A distance of 150,000 km was selected as the basis of the analysis, assuming a representative lifetime for the selected kind of vehicle.

For a realistic but simplified approach, the following composition for the tire tread was chosen (based on literature data and discussion with experts): ~35% filler, ~40% rubber, and ~25% additives.

The lifetime of carbon black tires is estimated to be 50,000 km. The lifetime of Silica/Silane-based tires is conservatively estimated to be 45,000 km. Several end-of-life options exist for tires; for the scenario investigated in this analysis, a thermal treatment in a cement plant was presumed.

Data from the GaBi database[1] was used for gasoline consumption and combustion emissions with a gasoline consumption of 5.24 kg/100 km (i.e. 6.94 l/100 km).

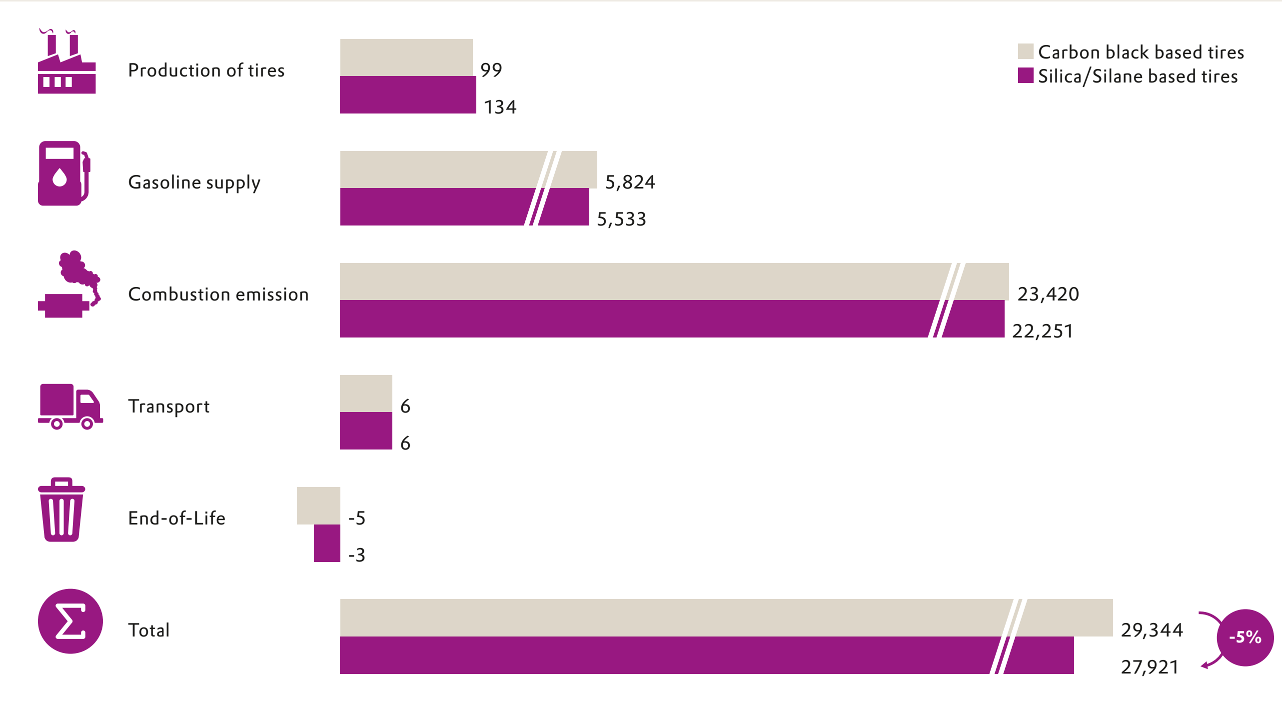
Assumptions on savings which occured due to the reduced rolling resistance were based on extensive literature research and information provided by the tire industry. For the basic scenario of this study, 5% savings were assumed according to a recent study by TCW Transfer Centrum[2].

Lower gasoline consumption results in a reduction of CO_2 and SO_2 emissions from combustion. A linear dependence between CO_2 and SO_2 emissions from combustion and fuel consumption was assumed. Savings were only applied for CO_2 and SO_2 emissions and not for other emissions such as HC, CO, NO_x and particles, as no such linear dependence exists here.

Additionally, a sensitivity analysis was conducted with the following parameters that have the highest impact on the results:

- Gasoline consumption
- Fuel savings
- Lifetime

Figure 4
GWP results for Silica/Silane and carbon black based tires (in kg CO_2e over 150,000 km)



Data collection, software and databases

Primary data from the year 2014 was used for modeling the Evonik's Silica (ULTRASIL® 7000 GR) and Silane (Si 69®). Data for the production of carbon black was taken from the GaBi database[3] by thinkstep[4]. Evonik experts confirmed the adequacy of the production route of the underlying carbon black dataset in relation to the goal and scope of this study. Data concerning tire tread and tire production is based on discussions with experts and supplemented with literature[5] data. The GaBi software[6] was used for modeling with an appropriate database[7]. The preferred data sets used were those of thinkstep[8], with supplemented data from eco-invent[9].

Results: Impact assessment *(cradle-to-grave)*

Figure 4 presents detailed cradle-to-grave results for the GWP impact category for both systems investigated; results for the other impact categories are presented in table 1. In all impact categories (with the exception of the Abiotic Depletion Potential (ADP) and the Ozone Depletion Potential (ODP)), the use phase has a decisive impact (>95 %). Within this phase, gasoline supply has the highest impact in the categories POCP, PED, and in the toxicity categories, while combustion emissions have the highest share in the GWP category. In the POCP category, the production of tires has a slightly higher contribution than for the categories GWP and PED (~3.2 %). Transports, production of tires and the end-of-life treatment only have a minor impact.

[1] thinkstep GaBi, 2015; [2] Wildemann, 2011; [3] Version 6.110; [4] GaBi, 2015; [5] WRAP, 2006, OECD, 2014, GaBi database as well as data concerning the use phase GaBi database as in Wildemann, 2011; [6] Version 6.5.1.12; [7] Version 6.110; [8] GaBi, 2015; [9] ecoinvent, 2008

1.4 METRIC TONS OF CO_2e
emissions could be avoided.

A savings potential is achieved in most impact categories: approx. 5 % for the GWP and PED and approx. 3 % for the POCP. The lower savings in the POCP category result from VOC emissions occurring during the mixing process of the tread production and because the VOC emissions from combustion remain unchanged. The lower amount of savings in the other impact categories can be explained by the fact that emissions other than CO_2 and SO_2 resulting from fuel combustion remain unchanged when the rolling resistance is reduced.

Consequently, approximately **1.4 metric tons of CO_2e** emissions might be avoided by replacing carbon black and E-SBR with Silica/Silane and S-SBR over a driving distance of 150,000 km (see table 1 for all impact categories).

Results: Sensitivity analysis

A sensitivity analysis was performed for +/-20% gasoline consumption. First of all, when the gasoline consumption varies by +/- 20%, the same variation is obtained for absolute values in most of the impact categories of both systems compared to the results of the basic scenario (figure 5).

Consequently, the avoided CO_2e emissions vary by +/- 20% when the baseline for the gasoline consumption for the use phase is varied accordingly and the relative difference stays constant at 5%, which underlines the stability of the results or the dominance of the use phase.

Furthermore, a sensitivity analysis was performed with 3% and 6% fuel savings. As the use phase dominates, fuel savings are directly linked to CO_2e savings over the full life cycle. This parameter is essential: a reduction of 2 percentage points in fuel savings results in a reduction of ~40% of the CO_2e avoided emissions while an increase of 1 percentage point results in an increase of ~20% of the CO_2e avoided emissions (figure 6).

Table 1
Results in all impact categories

Impact categories	Silica/Silane and S-SBR based tires over 150,000 km	Carbon black and E-SBR based tires over 150,000 km
Abiotic Depletion Potential (ADP elements)/ kg Sb e	$2.46 \cdot 10^{-3}$	$2.06 \cdot 10^{-3}$
Acidification Potential (AP)/kg SO_2e	36.7	377
Eutrophication Potential (EP)/kg Phosphate e	7.02	7.16
GWP 100a excl. biogenic carbon /kg CO_2e	27,900	29,300
Ozone Depletion Potential (ODP) . steady state/kg R11 e	$1.14 \cdot 10^{-7}$	$8.46 \cdot 10^{-8}$
POCP/kg Ethene e	4.43	4.77
PED (net cal. value)/MJ	392,000	412,000
Freswater Aquatic Toxicity Potential (FAETP) inf./kg DCBe[1]	143	151
Human Toxicity Potential (HTP) inf./kg DCBe[1]	890	921
Marine Aquatic Ecotoxicity Potential (MAETP) inf./kg DCBe[1]	398,000	414,000
Terretric Ecotoxicity Potential (TETP) inf./kg DCBe[1]	8.63	8.96

[1] 1,4-Dichlorobenzene. It is the reference unit for the impact categories related to toxicity.

Figure 5
Results for the sensitivity analysis with gasoline consumption

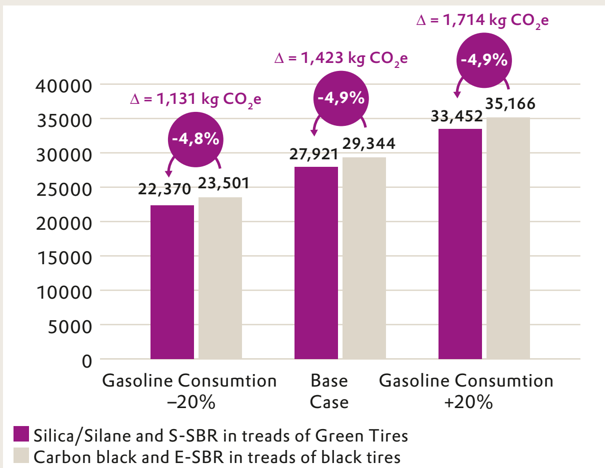
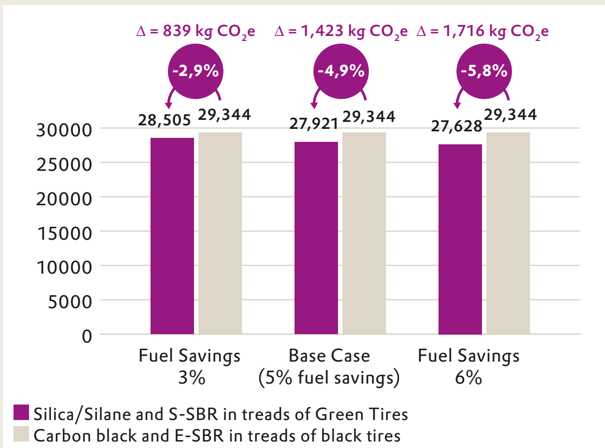


Figure 6
Results for the sensitivity analysis regarding fuel savings



SUMMARY: Key Findings and Conclusion

According to the study, Green tire technology is able to significantly reduce emissions and environmental impacts in the basic scenario in any analyzed impact category considered relevant. Consequently, during the car life cycle, emissions of up to 1.4 metric tons of CO_2e/150,000 km driving distance are avoidable by replacing carbon black and E-SBR with Silica/Silane and S-SBR. Similar results can be confirmed (albeit with fewer savings) for the other analyzed impact categories such as POCP, AP, EP, and FAETP.

The study shows that the use phase has a key impact on the over the whole life cycle in all impact categories. With a share of 0.34% in overall CO_2e emissions, carbon black and E-SBR production has a slightly lower impact than the production of Silica/Silane and S-SBR (0.48%). The reasons are a longer lifetime and higher specific emissions over the whole life cycle. End-of-life and transports of raw material do not have any relevant impact on the overall results in any impact categories.

In order to reduce the environmental impact of the tire over the complete life cycle, the focus should be on the use phase by developing ingredients allowing a reduction of fuel consumption. Additionally, a reduction of VOC emissions at the production stage would have a slight positive impact on the overall life cycle. Results of this study are used to report the avoided emissions of Evonik according to the methodology for balancing avoided emissions recommended in the guidance published by the WBCSD (WBCSD, 2013).

Please visit our websites **www.ULTRASIL.evonik.com** and **www.rubber-Silanes.com** or contact one of our experts for additional information on Silica/Silane systems used in Green tires.

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