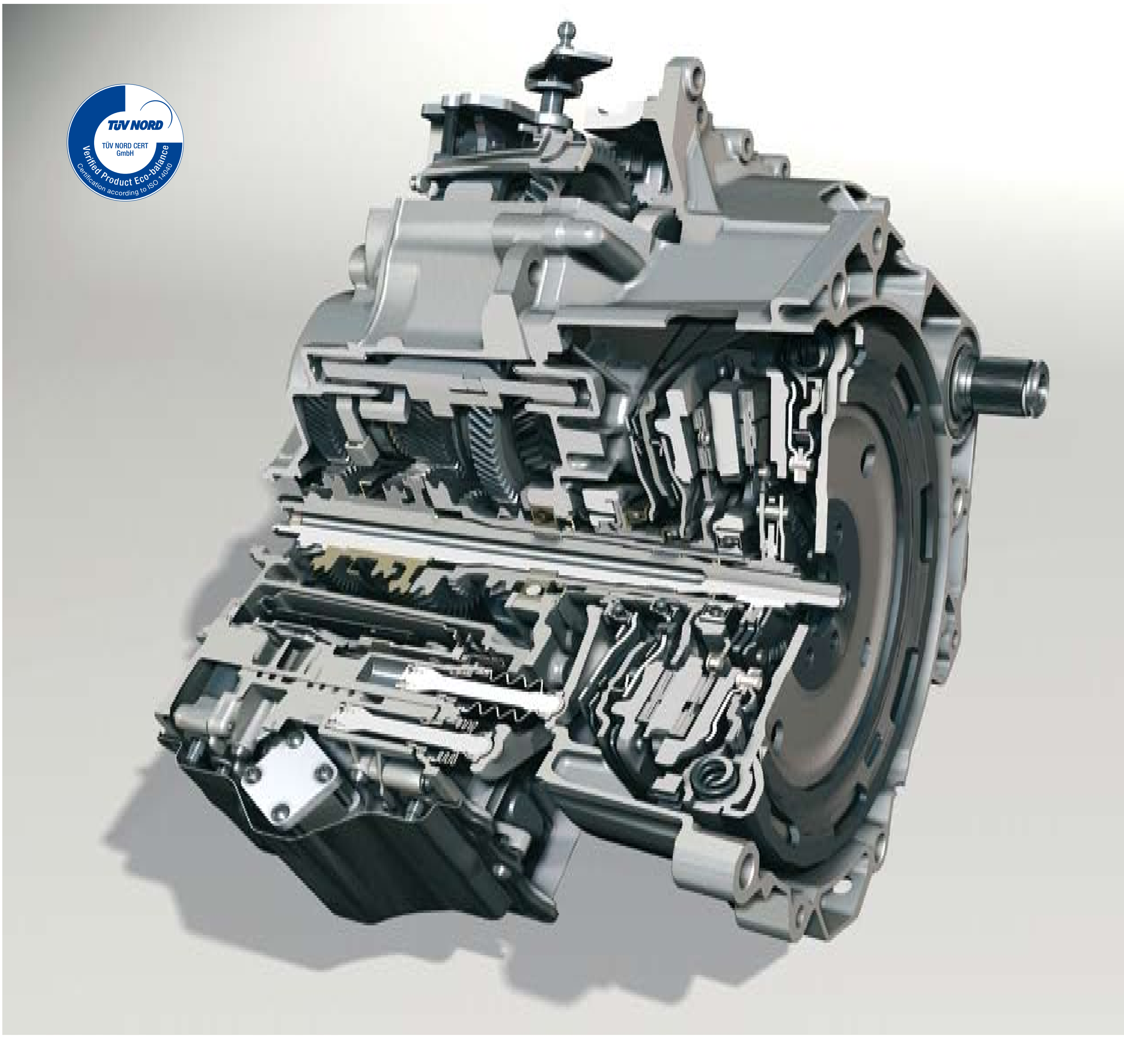
The DSG Dual-Clutch Gearbox

Environmental Commendation – Background Report



Introduction

Volkswagen develops environmentally friendly technologies that help reduce CO_2 emissions and makes them available throughout the product range. That way, all our customers benefit from our development work. Our technologies reduce the carbon dioxide emissions of the vehicle fleet and play a key role in making vehicles more environmentally compatible. The DSG dual-clutch gearbox, designed to replace conventional automatic transmissions with torque converters, is a case in point. DSG gearboxes are to be available with almost all the petrol and diesel engine options in the new Golf range and are considerably more efficient than conventional automatic transmissions. Innovations of this type make our models better and improve their environmental compatibility in particular.

Volkswagen uses environmental commendations to document the environmental progress of its vehicles and technologies compared to their predecessors. Our environmental commendations provide our customers, shareholders and other stakeholders inside and outside the company with detailed information about how we are making our products and production processes more environmentally compatible and what we have achieved in this respect. The DSG dual-clutch gearbox is the first Volkswagen technology to receive an environmental commendation. Our first vehicle environmental commendations, for the Passat and the Golf, were very well received both by the public and by the media.

The environmental commendations are based on the results of a detailed Life Cycle Assessment (LCA) in accordance with ISO 14040/44, which has been verified by independent experts, in this case from TÜV NORD. Volkswagen already has a long tradition in this field: we have been analysing our cars and their individual components for more than ten years, using Life Cycle Assessments to enhance their environmental compatibility. As part of an integrated product policy, the LCA considers not only individual environmental aspects such as the driving emissions of a vehicle, but the entire product life cycle. This means that all the processes from the production and use of a gearbox right through to disposal are considered in the analysis, “from cradle to grave”.

Summary

This environmental commendation compares current Volkswagen DSG dual-clutch gearboxes (6- and 7-speed) with conventional torque converter automatic transmissions. We have assessed the emissions caused by the gearbox not only during use but over its entire life cycle, from production to disposal.

As in the case of the Golf and Passat, the DSG gearboxes show improvements, in some cases significant, in all the environmental impact categories. The greatest advances have been made in the areas of global warming potential (greenhouse effect), acidification and photochemical ozone (summer smog) creation potential. In other respects, such as water and soil eutrophication and ozone depletion, the changeover from conventional automatic transmissions to DSG gearboxes has little impact. It emerged that these improvements were primarily due to reduced fuel consumption and the resultant drop in driving emissions and reduction in environmental impact at the fuel production stage. The reduction in fuel consumption, in turn, is the direct result of the intelligent gearbox management and high efficiency of the DSG gearbox.

Shift up to environmental protection

Volkswagen develops environmentally friendly technologies that help reduce CO_2 emissions. Our TDI and TSI engines, millions of which have been produced, are examples of environmentally compatible innovation. However, the fuel consumption and CO_2 emissions of a vehicle are not only determined by its engine. Volkswagen is committed to tapping all the opportunities for reducing fuel consumption and making technologies even more climate-compatible in the future. Our especially frugal BlueMotion models already meet these targets today. Our Powertrain and Fuel Strategy describes the technologies being pursued by Volkswagen with a view to implementing a long-term changeover to sustainable fuels and powertrains. Biofuels are just as much a part of this strategy as the fuel cell or electric propulsion systems.

Powertrain and Fuel Strategy of the Volkswagen Group

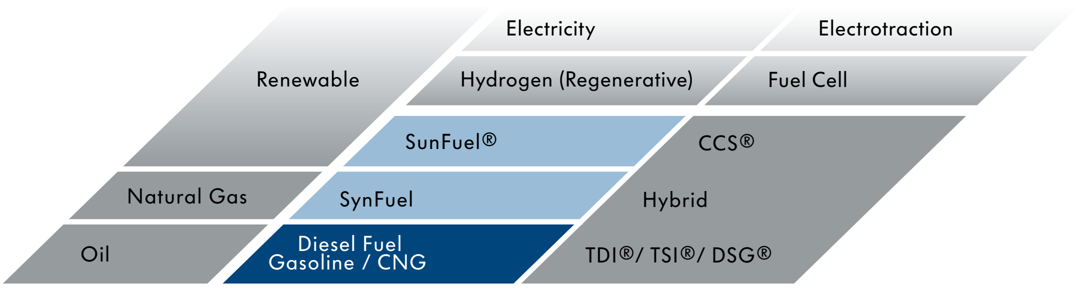


Fig. 1: Powertrain and Fuel Strategy of the Volkswagen Group

The DSG dual-clutch gearbox

The DSG intelligent automatic transmission developed by Volkswagen is also an integral part of this strategy for the future. In 2002, Volkswagen presented the first dual-clutch gearbox intended for series production, the 6-speed DSG. The dual-clutch principle ensures higher efficiency and lower fuel consumption than a conventional automatic transmission. In addition, it also makes for greater comfort and driving pleasure. In the meantime, Volkswagen has introduced a second dual-clutch gearbox, the 7-speed DSG, which is even more economical and will be used in the future on high-volume models with power outputs up to 125 kW and torque values up to 250 Nm.

Since the DSG dual-clutch gearbox was first launched, more than a million units have been sold, resulting in a new boom in automatic transmissions at Volkswagen. The proportion of new vehicles equipped with automatic transmissions has risen dramatically, from 5 to 10 percent with conventional transmissions to as much as 30 percent with the DSG. With the new 7-speed DSG, even more customers will automatically shift up to environmental protection.

Wet or dry

The DSG dual-clutch gearbox developed by Volkswagen combines the comfort and convenience of an automatic transmission with the efficiency and performance of a manual gearbox. Two clutches ensure that shifts take place in next to no time. When a shift is imminent, one clutch disengages while the other is engaging, both in a few hundredths of a second. This is possible because the transmission always preselects the next gear to be used.

Rapid, precise shifting is the key advantage of the DSG over conventional automatic transmissions. With a DSG gearbox, there is no perceptible interruption in tractive force and therefore no jolting during gearshifts. And the dual-clutch gearbox also boasts much higher efficiency, saving fuel and cutting carbon dioxide emissions. And for those who still want to change gears manually, the Tiptronic shift function makes this possible too.

Volkswagen offers the 6- and 7-speed DSG gear-boxes for models with various different engines. While the 6-speed DSG, introduced in 2002, is used for high-torque engines up to 350 Nm, the 7-speed DSG is available for engines with torque figures up to 250 Nm. The key innovation on the 7-speed unit is its „dry“ dual clutch. In contrast to the six-speed DSG, the new transmission does not have a „wet“ clutch with oil cooling. This change results in a whole raft of benefits, all leading to a further improvement in efficiency.

With the dual clutch, the efficiency of the DSG gearbox is significantly higher than that of conventional automatic transmissions fitted with hydraulic torque converters. Thanks to the DSG‘s intelligent transmission control system, its outstanding efficiency and its lower weight, vehicles equipped with the 7-speed dual-clutch gearbox may even present lower fuel consumption than comparable manual vehicles, depending on the individual style of driving.

Life Cycle Assessments for ecological product evaluation and optimisation

The environmental goals of the Technical Development department of the Volkswagen brand state that we develop our vehicles in such a way that, in their entirety, they present better environmental properties than their predecessors (Fig. 2) By „in their entirety", we mean that the entire product life cycle is considered, from cradle to grave.

Umweltziele

der Technischen Entwicklung zu Produkten der Marke Volkswagen

Zur Erreichung der bestmöglichen Umweltziele intensiviert die Technische Entwicklung die stetige Verbesserung der Volkswagen-Produkte bezüglich Umweltverträglichkeit und Ressourcenschonung. Das Handeln und die Prozesse sind auf Nachhaltigkeit und Umweltschonung ausgelegt. Damit wollen wir unserer Verantwortung gegenüber Kunden, Gesellschaft und Umwelt gerecht werden.

Es leiten sich folgende Zielfelder ab:

1. **Klimaschutz**
   - Reduzieren der Treibhausgas-Emissionen
   - Reduzieren des Verbrauchs im Fahrzyklus und vor Kunde
   - Besetzen der Verbrauchsleader-Position in jeder Fahrzeugklasse
   - Unterstützen kraftstoffsparender Fahrweisen
   - Mitarbeit/Bewertung umweltschonender Verkehrslenkungsmaßnahmen
2. **Ressourcenschonung**
   - Verbessern der Ressourceneffizienz
   - Verfolgung der bestmöglichen Recyclingfähigkeit und Kennzeichnung der verwendeten Werkstoffe
   - Einsetzen nachwachsender Rohstoffe und Rezyklatmaterialien
   - Entwickeln und Bereitstellen alternativer Antriebstechnologien
   - Nutzung alternativer Kraftstoffe ermöglichen
3. **Gesundheitsschutz**
   - Reduzieren limitierter und nicht-limitierter Emissionen
   - Vermeiden der Verwendung von Gefahr- und Schadstoffen
   - Minimieren der Innenraum-Emissionen inklusive Geruch
   - Erzielen bestmöglicher Außen- und Innengeräuschwerte

Wir werden in Zukunft jedes Fahrzeugmodell so entwickeln, dass es ganzheitlich bessere Umwelteigenschaften aufweist als sein Vorgänger. Dabei achten wir stets darauf, dass bei der Entwicklung unserer Produkte der gesamte Lebenszyklus berücksichtigt wird.

Die Umweltzielfelder dienen uns als Differenzierungsmerkmale gegenüber unseren Wettbewerbern zum Nutzen unserer Kunden.

Darüber hinaus ist es unser Ziel, ausgewählte Fahrzeuge in Umwelt-Listen zu platzieren.

18.07.2007

Dr. Ulrich Hackenberg	*G. Damme*
Leiter der Technischen Entwicklung	Umweltbeauftragter Produkte
Marke Volkswagen	Marke Volkswagen

Fig. 2: Environmental goals of the Technical Development department of the Volkswagen brand

This environmental commendation considers the significance of the innovative DSG technology for the environmental profile of a transmission. The decisive factor for the environmental profile of a product is its impact on the environment during its entire „lifetime“. This means we do not focus solely on a product‘s service life but also on the phases before and after, i.e. we draw up a balance sheet that includes the manufacturing, disposal and recycling processes. All life cycle phases require energy and resources, cause emissions and generate waste. Different vehicles and technologies can only be effectively compared on the basis of a balance sheet that covers all these individual processes from „cradle to grave“. And this is precisely what Life Cycle Assessments or LCAs facilitate. Our Life Cycle Assessments enable the environmental impacts related to a product to be accurately quantified and thus allow the description of its environmental profile on the basis of comparable data. To ensure that the results meet exacting quality and comparability requirements, when drawing up the Life Cycle Assessments we take our lead from the standard series ISO 14040 [ISO 2006]. This specifically includes the verification of the results by an independent expert. In this case, a critical review was conducted by the TÜV NORD technical inspection agency.

The first stage in preparing a Life Cycle Assessment is to define its objectives and the target groups it is intended to address. This definition clearly describes the systems to be evaluated in terms of the system function, the system limits[1] and the functional unit[2]. The methods of environmental Impact Assessment, the environmental impact categories considered, the evaluation methods and, if necessary, the allocation procedures[3] are defined in accordance with ISO 14040. The individual steps involved in preparing a Life Cycle Assessment are described briefly below.

Life Cycle Inventory – LCI

In the Life Cycle Inventory, data is collected for all processes within the scope of the evaluation. Information on inputs, such as raw materials and sources of energy, and outputs, such as emissions and waste, is compiled for each process, always with reference to the defined scope of the evaluation (see Fig. 3).

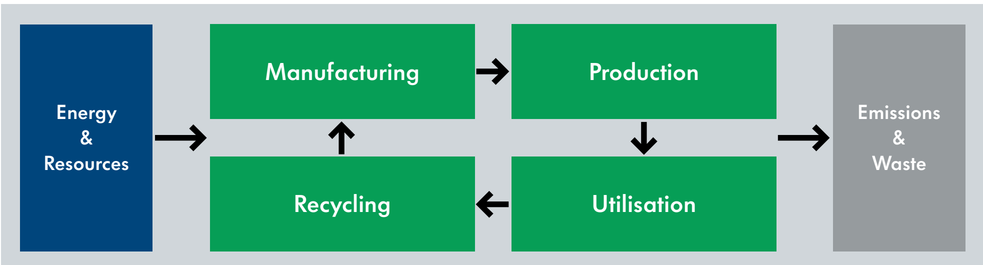


Fig 3: Input and output flows for a Life Cycle Inventory

[1] By defining the system limits, the scope of the Life Cycle Assessment is restricted to those processes and material flows that need to be evaluated in order to achieve the defined goal of the study.
[2] The functional unit quantifies the benefit of the vehicle systems evaluated and further ensures their comparability.
[3] Where processes have several inputs and outputs, an allocation procedure is needed to assign flows arising from the product system under evaluation to the various inputs and outputs.

The Life Cycle Inventory of an entire product life cycle includes numerous different inputs and outputs that are ultimately added up to prepare the inventory.

Life Cycle Impact Assessment – LCIA

A Life Cycle Inventory only quantifies the inputs and outputs of the system investigated. The following step – Impact Assessment – allocates the respective material flows to the appropriate environmental impacts. This involves defining a reference substance for each environmental impact category, for instance carbon dioxide (CO_2) for the impact category „global warming potential". Then all substances that also contribute to the global warming potential are converted to CO_2 equivalents using equivalence factors[4].

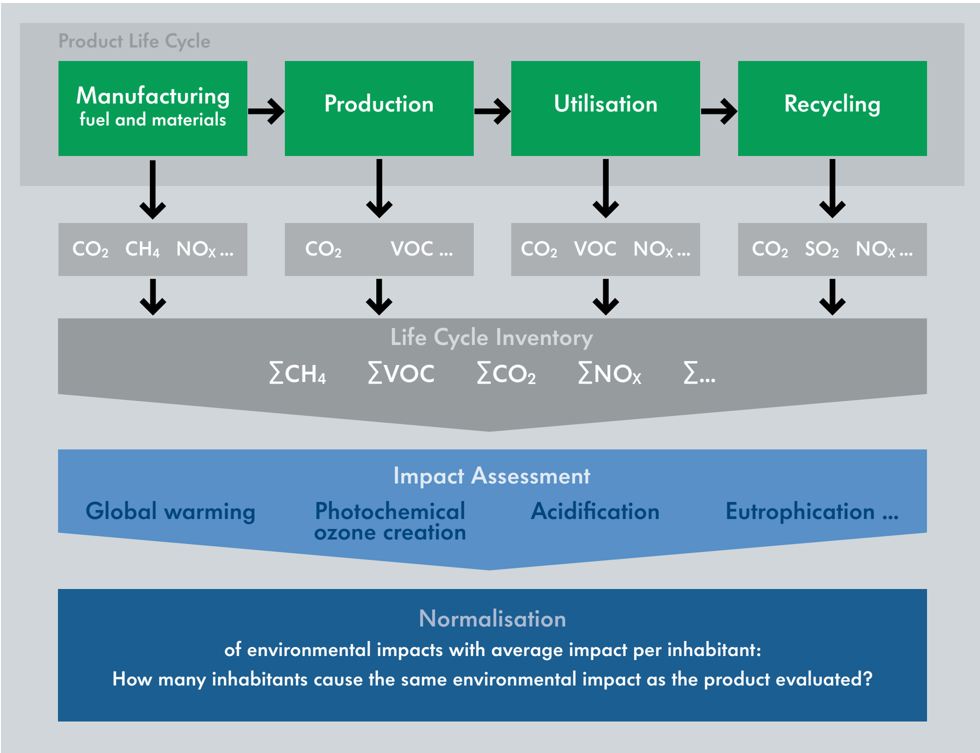


Fig. 4: Procedure for Impact Assessment

Examples of environmental categories are global warming potential, photochemical ozone creation potential, acidification potential or eutrophication potential.

Evaluation

The subsequent final evaluation interprets and evaluates the results of the Life Cycle Inventory and the Life Cycle Impact Assessment. The evaluation is based on the defined goal and scope of the Life Cycle Assessment.

[4] Carbon dioxide (CO_2) is the reference substance for global warming potential. All substances that contribute to the greenhouse effect are converted into CO_2 equivalents through an equivalence factor. For instance, the global warming potential of methane (CH_4) is 23 times higher than for CO_2. In concrete terms this means that the emission of 1 kg of CO_2 and 1 kg of CH_4 leads to a net global warming potential of 24 kg CO_2 equivalents. All the emissions that contribute to the greenhouse effect are measured in this way.

Implementation at Volkswagen

Volkswagen has many years of experience with Life Cycle Assessments for product and process optimisation. We have even assumed a leading role in implementing and publishing life cycle inventories of complete vehicles. For instance, in 1996 we were the first car manufacturer in the world to prepare a Life Cycle Inventory study (for the Golf III) and publish it [Schweimer and Schuckert 1996]. Since then we have drawn up Life Cycle Assessments for other cars and also published some of the results [Schweimer 1998; Schweimer et al. 1999; Schweimer and Levin 2000; Schweimer and Roßberg 2001]. These LCAs primarily describe and identify environmental „hot spots“ in the life cycle of a car. Since then we have broadened the assessments to include production processes as well as fuel production and recycling processes [Bossdorf-Zimmer et al. 2005; Krinke et al. 2005b]. Since 2007, we have used environmental commendations to inform customers about the environmental properties of our vehicles [Volkswagen AG 2007a, 2007b, 2008]. Volkswagen is making long-term investments in further developing and optimising Life Cycle Assessment methods. Thanks to our intensive research we have succeeded in considerably reducing the workload involved in preparing Life Cycle Inventories.

Our research resulted in the development of the VW slimLCI interface system [Koffler et al. 2007]: this interface not only significantly cuts the workload involved in preparing Life Cycle Assessments of complete vehicles by automating the process, but also further improves the consistency and quality of the LCA models produced. This represents substantial progress, since preparing a complete LCA for a vehicle involves registering thousands of components, together with any related upstream supply chains and processes (see Fig. 5).

Fig. 5: Dismantling study of the Golf V

The complexity of the modelling process results from the fact that all the parts and components of a vehicle themselves consist of a variety of materials and are manufactured by many different processes – processes that in turn consume energy, consumables and fabricated materials. In addition, the correct assignment of manufacturing processes to materials calls for considerable expert knowledge, a large database and detailed information on production and processing steps. The VW slimLCI interface system allows these details to be modelled very precisely and sufficiently completely in Life Cycle Assessment models – even for entire vehicles. A Life Cycle Assessment or product model is based on the vehicle parts lists drawn up by the Technical Development department, as well as on material data drawn from the Volkswagen AG Material Information System (MISS). The VW slimLCI interface system primarily consists of two interfaces that transfer the vehicle data from these systems to the Life Cycle Assessment software GaBi[5], using a defined operating sequence (algorithm) (see Fig. 6).

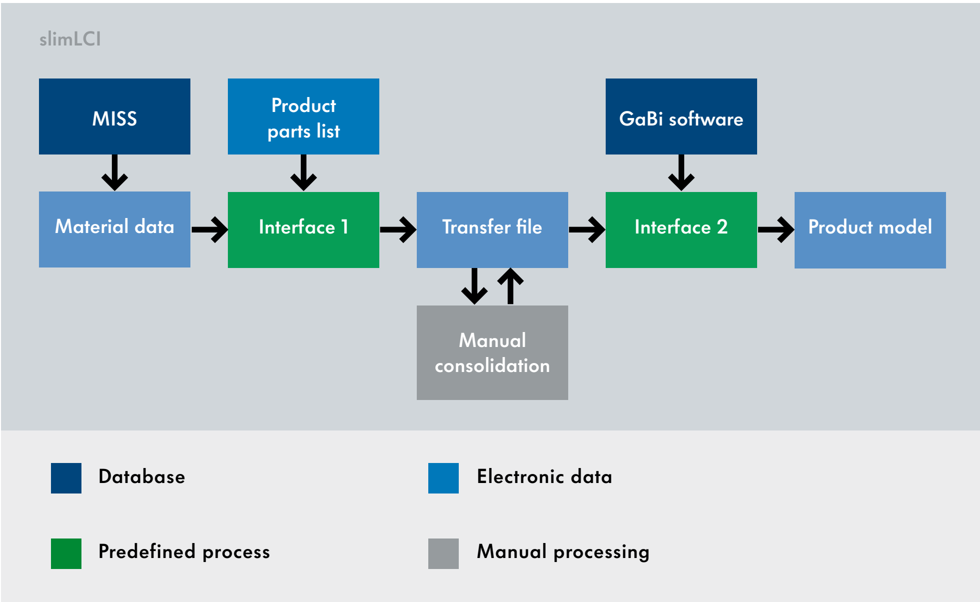


Fig. 6: Process of modelling an entire vehicle with the VW slimLCI interface system

Interface 1 helps assign information from parts lists (part designations and quantities) to the relevant component information (materials and weights) from MISS and converts it into a transfer file which is then quality-tested (manual consolidation). Interface 2 then allows the transfer file to be linked with the related data sets in the GaBi Life Cycle Assessment software. For example, to each material, such as steel sheet, the interface allocates all the material production and subsequent treatment processes listed in the database. The model generated by GaBi therefore reflects all the processing stages in the manufacture of the entire vehicle being evaluated. So with the VW slimLCI interface system we can prepare Life Cycle Assessments in a very short time and use them continuously in order to keep pace with the steadily growing demand for environment-related product information.

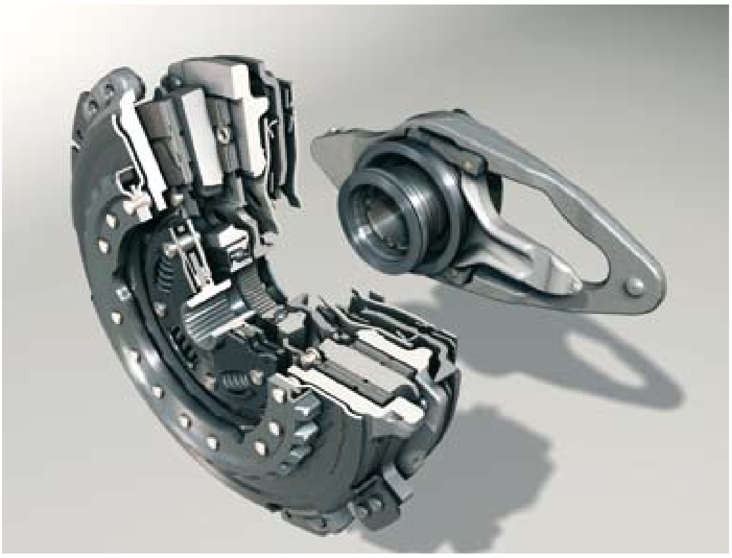
[5] GaBi® is a Life Cycle Assessment software package from PE international.

The automatic transmissions assessed

This environmental commendation for the DSG dual-clutch gearbox describes and analyses the environmental impacts of various automatic transmissions. To this end we have compared the current 6-speed and 7-speed DSG units with conventional automatic transmissions equipped with torque converters. The results are based on Life Cycle Assessments drawn up in accordance with the standards DIN EN ISO 14040 and 14044. All the definitions and descriptions required for preparing these Life Cycle Assessments were drawn up in accordance with the standards mentioned above and are explained below.

Aim and target group of the assessment

Volkswagen has been producing Life Cycle Assessments for over ten years to provide detailed information on the environmental impacts of vehicles and components for our customers, shareholders and other interested parties within and outside the company.



The objective of the Life Cycle Assessment in this case was to compare the environmental profiles of various types of automatic transmission. To this end we compared the current 6-speed and 7-speed DSG dual-clutch gearboxes with a conventional torque converter transmission.

Function and functional unit of the vehicle systems assessed

The "functional unit" for the assessment was defined as the transmission of torque in a powertrain over a total distance of 150,000 kilometres in the New European Driving Cycle (NEDC). However, within the Volkswagen Group, no vehicle is or has been offered with all three transmissions considered. In order to ensure comparability, it was therefore necessary to base the assessment of the service life phase on fuel consumption simulations. For this purpose, the transmissions were „virtually installed“ on the same reference vehicle, a Golf 1.4 TSI with 90 kW[6], and the resulting consumption figures for the entire vehicle were determined on the basis of otherwise unchanged assumptions.

With the exception of the Golf 1.4 TSI with 7-speed DSG, the consumption figures stated are therefore calculated, rather than measured, values[7]. In line with the functional unit defined above, in what follows we only indicate the resulting consumption benefits compared with the torque converter transmission. This differential approach has also been applied to the production and recycling phases. The key technical data of the transmissions compared are listed in Table 1.

[6] 5.9 l/100 km (NEDC), 139 g CO_2/km

[7] The deviation determined in the simulation for the Golf 1.4 TSI with 90 kW and 7-speed DSG (5.9 l/100km, 139 g CO_2/km) was 1.7 %. The simulation is therefore considered to be sufficiently accurate.

Table 1: Technical data of transmissions compared

	Torque converter transmission	6-speed DSG ®	7-speed DSG ®
Number of gears	6	6	7
Max. torque	320 Nm	350 Nm	250 Nm
Clutch	-	Wet	Dry
Gear oil volume	5.8 l	6.5 l	1.7 l
Weight[a]	85 kg	93 kg	77 kg
Consumption advantage[b]	Reference	-0.3 l/100 km	-0.8 l/100 km
Efficiency[c]	83 %	85 %	91 %

[a] including double-mass flywheel and oil
[b] compared with a Golf V 1.4 TSI 90 kW with torque converter transmission (model calculation)
[c] average efficiency in 5th gear

Scope of assessment

The scope of the assessment was defined in such a way that all relevant processes and substances are considered, traced back to the furthest possible extent and modelled at the level of elementary flows in accordance with ISO 14040. This means that only substances and energy flows taken directly from the environment or released into the environment without prior or subsequent treatment exceed the scope of the assessment. The only exceptions to this rule are the material fractions formed in the recycling stage.

The transmission manufacturing phase was modelled including all manufacturing and processing stages for all components used. The model included all steps from the extraction of raw materials and the manufacture of semifinished products right through to assembly.

As regards the service life of the transmission, the model includes all relevant processes from fuel production and delivery through to actual driving. The analysis of the fuel supply process includes shipment from the oilfield to the refinery and the refining process. Vehicle maintenance is not included in the assessment as previous studies demonstrated that maintenance does not cause any significant environmental impacts [Schweimer and Levin, 2000].

The model of the recycling phase includes the dismantling and shredding of the transmission as well as the recycling of material fractions by appropriate processes. In this Life Cycle Assessment, no environmental credits were awarded for the secondary raw material obtained from the recycling process. We only included the environmental impacts of the recycling processes required. This corresponds to a worst case assumption[8], since in reality secondary raw material from vehicle recycling is generally returned to the production cycle. This recycling and substitution of primary raw materials avoids the environmental impact of primary raw material production.

As a general principle, only emissions and fuel consumption actually caused by the transmission are taken into consideration in the Life Cycle Assessment. In order to assess the change in fuel consumption caused by the use of a specific transmission, it was necessary in some cases to use simulated NEDC consumption figures as no vehicle with measured consumption figures for all three transmission variants was available. This differential or consumption advantage approach was also applied to the production and recycling phases. The results of this analysis show the increase or reduction in potential environmental impacts that would be caused by a changeover from a torque converter transmission to a DSG dual-clutch gearbox on the same vehicle (Golf 1.4 TSI 90 kW)[9].

Fig. 7 is a schematic diagram indicating the scope of the Life Cycle Assessment. Europe (EU 15) was chosen as the reference area for all processes in the manufacture, service and recycling phases.

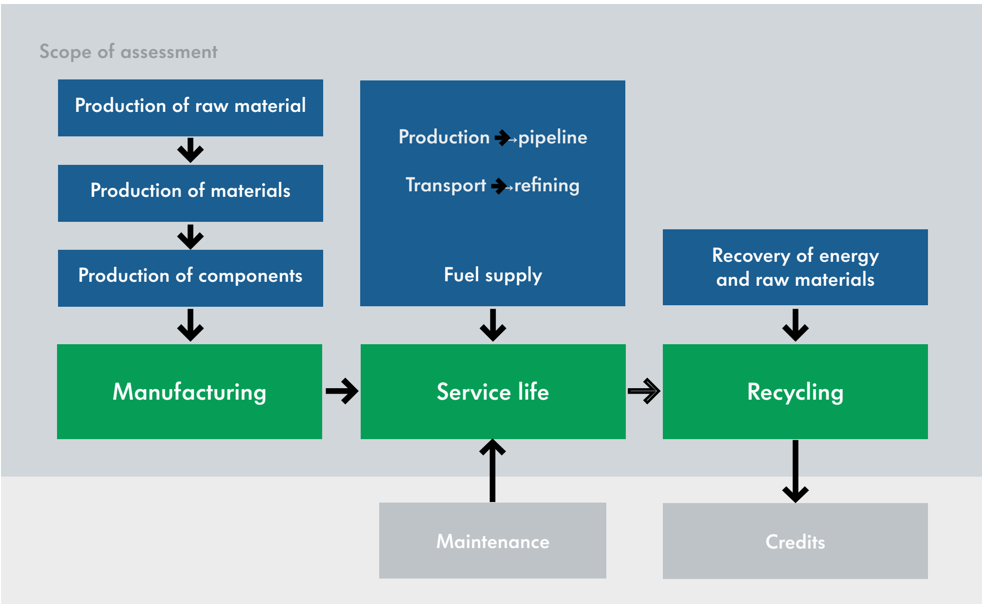


Fig. 7: Scope of the Life Cycle Assessment

[8] Here the worst case is a set of most unfavourable model parameters of the recycling phase.
[9] 5,9 l/100 km (NEFZ), 139 g CO_2/km

Environmental Impact Assessment

The Impact Assessment is based on a method developed by the University of Leiden in the Netherlands (CML methodology) [Guinée and Lindeijer 2002]. The assessment of environmental impact potentials in accordance with this method is based on recognised scientific models. A total of five environmental impact categories[10] were identified as relevant and were then assessed in this study:

- eutrophication potential
- ozone depletion potential
- photochemical ozone creation potential
- global warming potential for a reference period of 100 years
- acidification potential

The above environmental impact categories were chosen because they are particularly important for the automotive sector, and are also regularly used in other automotive-related Life Cycle Assessments [Schmidt et al. 2004; Krinke et al. 2005a]. The environmental impacts determined in the Life Cycle Assessments are measured in different units. For instance, the global warming potential is measured in CO_2 equivalents and the acidification potential in SO_2 equivalents (each in kilograms). In order to make them comparable, a normalisation process is necessary. In this Life Cycle Assessment the results were normalised with reference to the annual average environmental impact caused by an inhabitant of the EU15. For example, in the global warming category, each inhabitant of the European Union caused the emission of about 12.6 metric tons of CO_2 equivalents in the year 2001.

Table 2: Average impact per inhabitant figures in the EU 15,
referred to an inhabitant in 2001 [PE International 2003]

Environmental category	Per capita	Unit
Eutrophication potential	33.22	kg PO_4 equivalents
Ozone depletion potential	0.22	kg R11 equivalents
Photochemical ozone creation potential	21.95	kg ethene equivalents
Global warming potential	12,591.88	kg CO_2 equivalents
Acidification potential	72.85	kg SO_2 equivalents

This normalisation allows statements to be made regarding the contribution of a product to total environmental impacts within the European Union. The results can then be presented in one graph using the same scale. This approach also makes the results more comprehensible and allows environmental impacts to be compared.
In Table 2, we have listed the average figures per inhabitant for the individual impact categories. In this context it must be pointed out that the normalisation does not give

[10] The glossary contains a detailed description of these environmental impact categories.

any indication of the relevance of a particular environmental impact, i.e. it does not imply any judgement on the significance of individual environmental impacts.

Basis of data and data quality

The data used for preparing the Life Cycle Assessment can be subdivided into product data and process data. “Product data” describes the product itself, and among other things includes:

- Information on parts, quantities, weights and materials
- Information on fuel consumption and emissions during utilisation
- Information on recycling volumes and processes.

“Process data” includes information on manufacturing and processing steps such as the provision of electricity, the production of materials and semifinished goods, fabrication and the production of fuel and consumables. This information is either obtained from commercial databases or compiled by Volkswagen as required.

We ensure that the data selected are as representative as possible. This means that the data represent the materials, production and other processes as accurately as possible from a technological, temporal and geographical point of view. For the most part, published industrial data are used. In addition, we use data that are as up-to-date as possible and relate to Europe. Where European data are not available, German data are used. For the various transmissions we always use the same data on upstream supply chains for energy sources and materials. This means that differences between the latest models and their predecessors are entirely due to changes in component weights, material compositions, manufacturing processes at Volkswagen and driving emissions, and not to changes in the raw material, energy and component supply chains.

The Life Cycle Assessment model for transmission production was developed using Volkswagen‘s slimLCI methodology (see Chapter 1). Transmission parts lists were used as data sources for product data, and the weight and materials of each product were taken from the Volkswagen material information system (MISS). This information was then linked to the corresponding process data in the Life Cycle Assessment software GaBi.

Material inputs, processing procedures and the selection of data in GaBi are standardised to the greatest possible extent, ensuring that the information provided by VW slimLCI is consistent and transparent.

For the modelling of the vehicle's service life, representative data for upstream fuel supply chains were taken from the GaBi database. A sulphur content of 10 ppm was assumed for petrol[11].

Transmission recycling was modelled on the basis of data from the VW SiCon process and using representative data from the GaBi database.

In sum, all information relevant to the aims of this study was collected and modelled completely[12]. The modelling of components on the basis of vehicle parts lists ensures that the model is complete, especially with respect to the manufacturing phase. In addition, as the work processes required are automated to a great extent, any differences in the results are due solely to changes in product data and not to deviations in the modelling system.

[11] In some countries, fuel with a sulphur content of 10 ppm is not yet available. However, even if the sulphur content were higher, the contribution of sulphur emissions during the vehicle's service life would still remain negligible.

[12] Completeness, as defined by ISO 14040, must always be considered with reference to the objective of the investigation. In this case, completeness means that the main materials and processes have been reflected. Any remaining data gaps are unavoidable, but apply equally to all the transmissions compared.

Model assumptions and findings of the Life Cycle Assessment

All the framework conditions and assumptions defined for the Life Cycle Assessment are outlined below.

Table 5: Assumptions and definitions for the Life Cycle Assessment

Aim of the Life Cycle Assessment
• Comparison of the environmental profiles of torque converter transmission and dual-clutch gearbox over the entire life cycle
Scope of assessment
Function of systems • Transmission of torque in the powertrain
Functional unit • Transmission of torque in the powertrain in the New European Driving Cycle (NEDC) over a defined total distance of 150,000 kilometres
Comparability • Modelling of consumption differences assuming identical framework conditions / the same reference vehicle (Golf 1.4 TSI 90 kW[13])
System boundaries • The system boundaries include the entire life cycle of the transmissions (manufacture, service life and recycling phase).
Cut-off criteria • The assessment does not include transmission maintenance. • No environmental impact credits are awarded for secondary raw materials produced. • Cut-off criteria applied in GaBi data sets, as described in the software documentation (www.gabi-software.com) • Explicit cut-off criteria, such as weight or relevance limits, are not applied.
Allocation • Allocations used in GaBi data sets, as described in the software documentation (www.gabi-software.com) • No further allocations are used

[13] 5.9 l/100 km (NEDC), 139 g CO_2/km

Data basis

- Volkswagen transmission parts lists
- Material and weight information from the Volkswagen Material Information System (MISS)
- Reports of mileage calculations for computation of consumption
- Technical drawings
- The data used comes from the GaBi database or was collected in cooperation with VW plants, suppliers or industrial partners.

Life Cycle Inventory results

- Material compositions in accordance with VDA (German Association of the Automotive Industry) Standard 231-106
- Life Cycle Inventory results include emissions of CO_2, CO, SO_2, NO_X, NMVOC, CH4, as well as consumption of energy resources
- The Impact Assessment includes the environmental impact categories eutrophication potential, ozone depletion potential, photochemical ozone creation potential, global warming potential for a reference period of 100 years and acidification potential
- Standardisation of the results to average impact per inhabitant values

Software

- Life Cycle Assessment software GaBi, GaBi DfX Tool and VW slimLCI interface

Evaluation

- Evaluation of Life Cycle Inventory and Impact Assessment results, subdivided into life cycle phases and individual processes
- Comparisons of Impact Assessment results of the transmissions compared
- Interpretation of results

Results of the Life Cycle Assessment

Material composition

Fig. 8 shows the material compositions derived from the product data on the basis of VDA (German Association of the Automotive Industry) standard 231-106 for material classification [VDA 1997]. The bar chart shows that all three transmissions have a similar composition. The transmissions consist mainly of steel (shafts, gears, etc.) and aluminium (cast housing), as well as small amounts of plastics and non-ferrous metals and the first fill of transmission oil. The differences are mainly due to changes in overall weights and oil volumes (see Table 1) and the more complex actuation systems of DSG gearboxes.

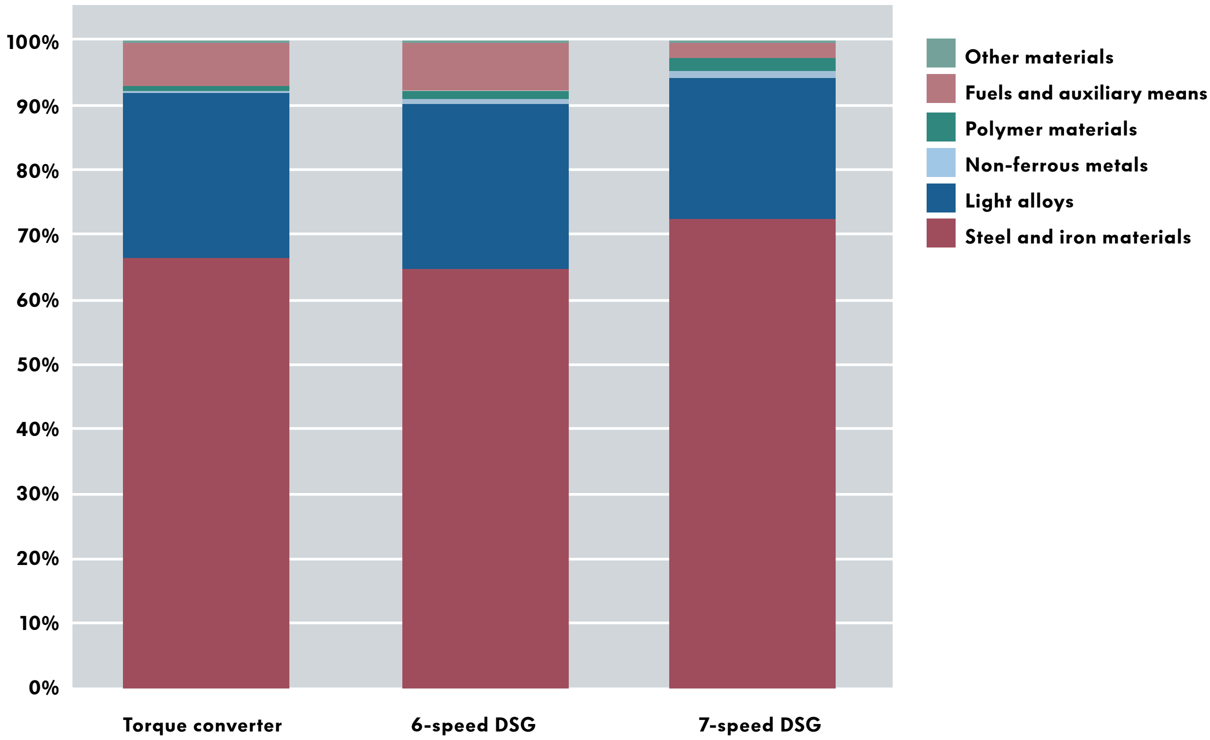


Fig. 8: Material composition of transmissions compared

Results of the Life Cycle Inventory

Table 4 shows the results for selected life cycle inventory values of the differential approach adapted. The figures with a light grey background indicate the differences between the relevant DSG dual-clutch gearbox and a torque converter automatic transmission.

The figures clearly indicate that the environmental impacts caused by the production of the two DSG gearboxes are comparable to or slightly higher than the corresponding figures for a torque converter transmission. In the case of the 6-speed DSG unit, this is largely due to the total weight of the gearbox, which is the heaviest of the three compared. In the case of the 7-speed DSG, it is mainly the higher mass of non-ferrous metals and polymers that outweighs the advantage of lower total weight in terms of environmental impact.

As expected, the lower fuel consumption in the service phase leads to a net reduction in all emissions. As it has been assumed that the same exhaust emission standards applied to all variants, only the stoichiometric emissions CO_2 und SO_2 show a reduction compared with the torque converter transmission.

Table 4: Selected Life Cycle Inventory values (in kg)

		CO_2	CO	SO_2	NO_X	NMVOC	CH_4	Primary energy
Manufacturing	Torque converter	230.5	1.5	0.7	0.4	0.05	0.3	4.0
	6-speed DSG (diff.)	+53.9	+0.4	+0.1	+0.1	+0.0	+0.1	+0.8
	7-speed DSG (diff.)	+5.2	+0.0	+0.0	+0.0	+0.0	+0.1	+0.0
Fuel production	Torque converter	---	---	---	---	---	---	---
	6-speed DSG (diff.)	-200.7	-0.2	-1.0	-0.4	-0.5	-1.2	-17.5
	7-speed DSG (diff.)	-535.1	-0.6	-2.6	-1.1	-1.2	-3.3	-16.5
Driving emissions	Torque converter	---	---	---	---	---	---	---
(stoichiometric)	6-speed DSG (diff.)	-1,085.0	0.0	-0.1	0.0	0.0	0.0	0.0
	7-speed DSG (diff.)	-2,892.0	0.0	-0.1	0.0	0.0	0.0	0.0
Recycling	Torque converter	93.7	0.3	0.2	0.1	0.01	0.1	1.4
	6-speed DSG (diff.)	-1.6	0.0	0.0	0.0	0.0	+0.1	+0.1
	7-speed DSG (diff.)	-20.8	0.0	0.0	0.0	0.0	0.0	-0.1

Comparison of Life Cycle Impacts

On the basis of the Life Cycle Inventory data, Life Cycle Impact Assessments are drawn up for all the environmental impact categories. The interactions of all the emissions recorded are considered and potential environmental impacts are determined based on scientific models (see Fig. 4).

In Fig. 9, the base line represents the emissions of the torque converter transmission. It can clearly be seen that the greatest improvements in environmental impact in relation to the average per capita environmental impact of inhabitants of Europe (EU15) are achieved in the categories of global warming potential, acidification and photochemical ozone creation potential. In contrast, the changeover from torque converter transmissions to the DSG gearbox does not result in any significant improvement in the categories of ozone depletion and eutrophication.

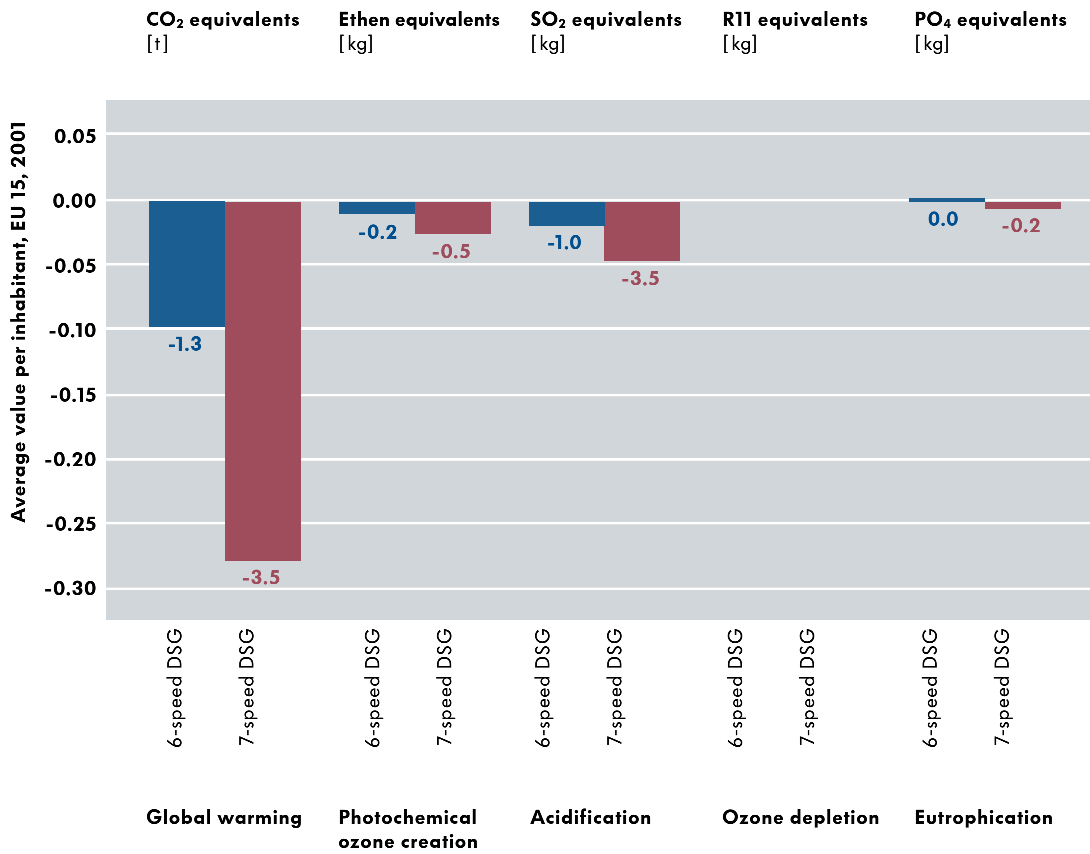


Fig. 9: Life Cycle Impacts (differential) of DSG gearboxes

A more precise analysis of the results shows that the improvements in the environmental profile are chiefly due to the reduction in fuel consumption (Fig. 10). In contrast, the increases and reductions in impacts caused by production and recycling are relatively slight and do not have any significant impact on the overall result.

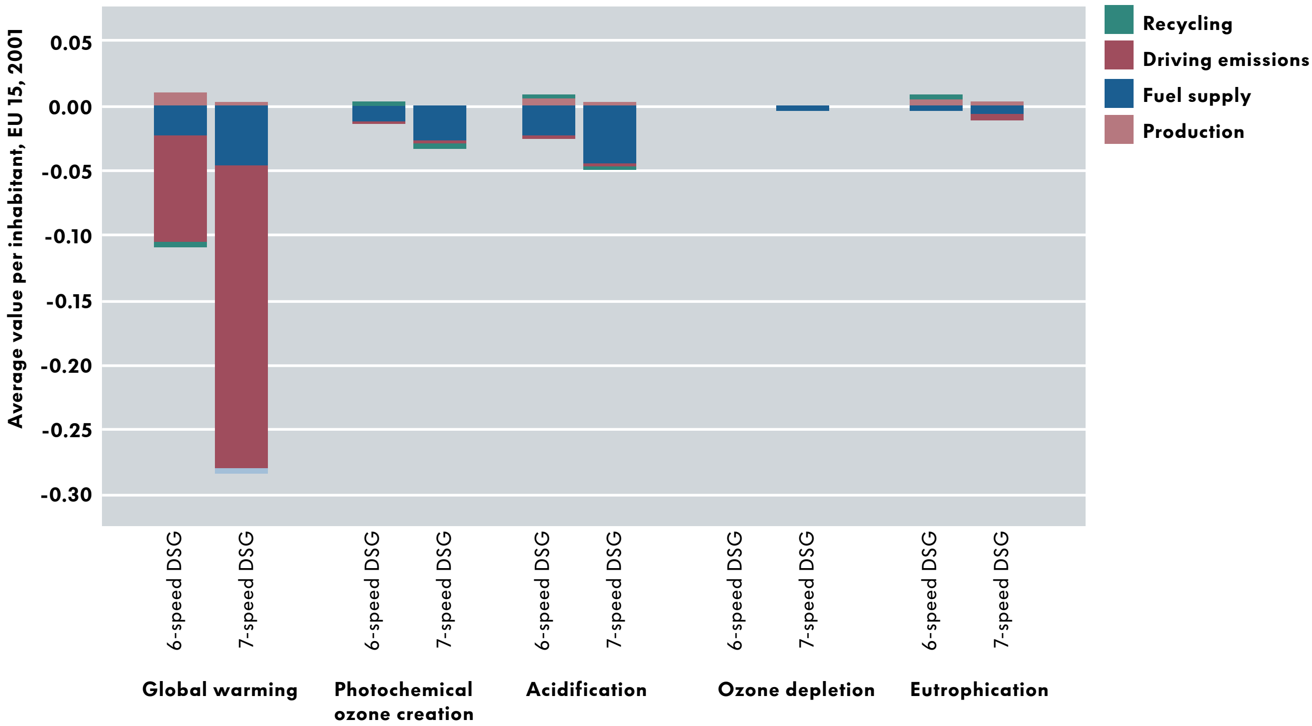


Fig. 10: Life Cycle Impacts (differential) of DSG gearboxes (detail)

Technologies for the future

The Volkswagen Powertrain and Fuel Strategy covers the entire range of present and future drive systems from current petrol and diesel engines via hybrid drives and engines with the Combined Combustion System (CCS) to electric vehicles with batteries or hydrogen technology. In developing our technologies, we are committed to reducing current emission levels and to ensuring zero-emission driving to the greatest extent possible in the future.

As regards fuels, Volkswagen is engaged in a number of projects with partners to produce fuels from various different raw materials. For Volkswagen, the main emphasis is on second-generation biofuels which can be produced from various types of biomass; during combustion, these fuels only release into the atmosphere the same volume of carbon dioxide as was absorbed by the plants as they grew. One example is SunFuel, a registered trademark of Volkswagen. SunFuel can be produced from forest or industrial wood residues, animal waste or straw and therefore does not compete with food production. SunFuel is already being produced in the world‘s first production plant at Freiberg in Germany. In technical terms, both petrol and diesel could already be replaced by SunFuel.

The benefits of hybrid drive are particularly evident in urban driving in large cities or conurbations. Of the various prototypes already presented, the Golf “TwinDrive” is especially promising. The special feature of the TwinDrive is that the internal combustion engine provides assistance for the electric motor, and not vice versa. This means that the vehicle can be driven considerable distances without producing any direct emissions. In electric propulsion mode, the range of the TwinDrive is about 50 kilometres. From 2010, up to 20 vehicles will be involved in an electric mobility fleet test to test electric propulsion in everyday use

The fuel cell is another technology that demonstrates the innovative capabilities of Volkswagen. The research and development team at Volkswagen has developed a unique type of high-temperature fuel cell that eliminates many of the problems associated with previous low-temperature systems. The high-temperature fuel cell will make the entire drive system installed in a vehicle lighter, smaller, more durable and less expensive – and these are the key factors as fuel cells are developed to readiness for industrial scale production. Volkswagen is expecting to test the first prototypes with high-temperature fuel cells in 2010. Current forecasts predict that the first production vehicles will not be launched before 2020.

In the long term, Volkswagen regards the electric motor as the drive system of the future. A key element in the growing trend towards electrification will be the use of energy from renewable sources such as wind or solar energy or hydropower. Ideally, an electric vehicle should be able to „fill up“ directly with electricity. The „tank“ or energy storage device is a rechargeable battery. This drive configuration has the benefit of high overall efficiency as the electric power is used directly for propulsion. In contrast to internal combustion engines, drive systems of this type generate no local emissions. In a zero-emission study of the space up! blue, Volkswagen has already demonstrated an electric motor drawing its power from a lithium ion battery system. Powered solely by batteries, the space up! blue can already cover the average daily distances driven in today‘s urban traffic.

Conclusion

The Volkswagen DSG dual-clutch gearbox not only meets the highest comfort and performance requirements but also, as part of our Powertrain and Fuel Strategy, represents a key step towards sustainable mobility. This environmental commendation documents the progress that has been achieved in this area compared with a conventional torque converter automatic transmission. The information provided in this document is based on the Life Cycle Assessment of the DSG dual-clutch gearbox, which has been verified and certified by TÜV NORD. The TÜV report confirms that the Life Cycle Assessment is based on reliable data and was drawn up using a method in accordance with the requirements of ISO standards 14040 and 14044.

The DSG dual-clutch gearboxes allow lower fuel consumption and emissions than a conventional torque converter automatic transmission during their service life and comparable environmental impacts during the manufacturing and recycling phases. Consequently, in sum, the Life Cycle Assessments of the DSG gearboxes are considerably better than that of a conventional automatic transmission.

Validation

The statements made in this environmental commendation are supported by the Life Cycle Assessment of the DSG dual-clutch transmission. The certificate of validity confirms that the Life Cycle Assessment is based on reliable data and that the method used to compile it complies with the requirements of ISO standards 14040 and 14044.

CERTIFICATE OF VALIDITY

TÜV NORD

DIN EN ISO 14040 : 2006-10
(LCA - life cycle assessment)

Evidence that the application conforms to the regulations was delivered, and is herewith certified according to the TÜV NORD CERT - procedure for

Volkswagen AG
Berliner Ring 2
38346 Wolfsburg
Germany

Range of application

Environmental Commendation Dual-Clutch Gearbox DSG

for the 6-gear- und 7-gear-DSG (year 2008)

The requirements were fulfilled and proven by a critical review concerning

- **Standard methodologies**
- **Representative categories of balancing and effects**
- **General transparency and consistency**

Report no. 3503 5801

Certification office of the TÜV NORD CERT GmbH

Essen, dated 2008-09-09

Environmental verifier

Environmental expert

TÜV NORD CERT GmbH Langemarckstrasse 20 45141 Essen www.tuev-nord-cert.com

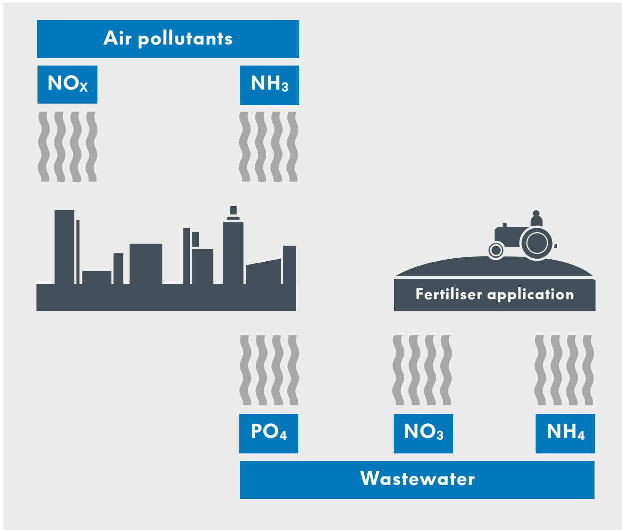
You will find the detailed report from TÜV NORD in the Appendix.

Glossary

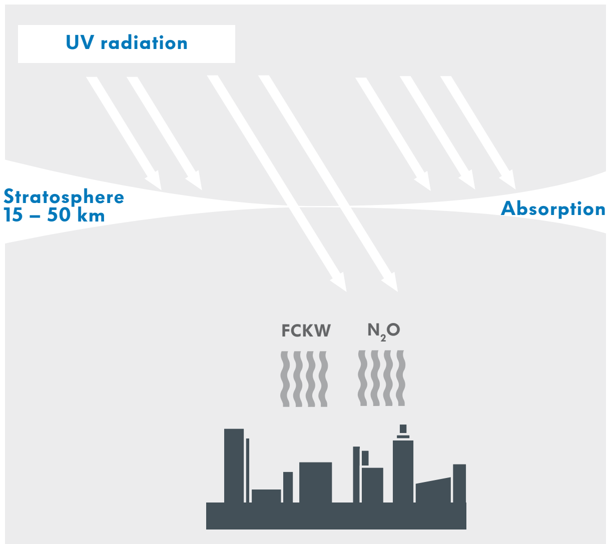
Allocation
Allocation of Life Cycle Inventory parameters to the actual source in the case of processes that have several inputs and outputs.

Average impact per inhabitant figure (EDW)
Unit indicating the normalised environmental impact for a geographical reference area.

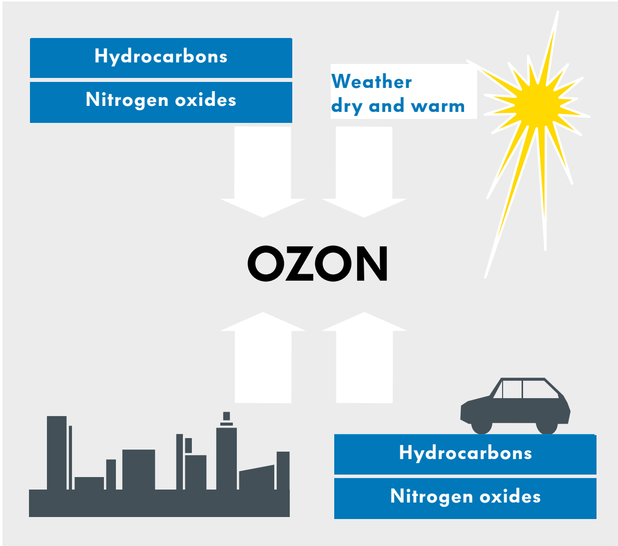
Eutrophication potential
describes excessive input of nutrients into water [or soil], which can lead to an undesirable change in the composition of flora and fauna. A secondary effect of the over-fertilisation of water is oxygen consumption and therefore oxygen deficiency. The reference substance for eutrophication is phosphate (PO_4), and all other substances that impact on this process (for instance NO_X, NH3) are measured in phosphate equivalents.



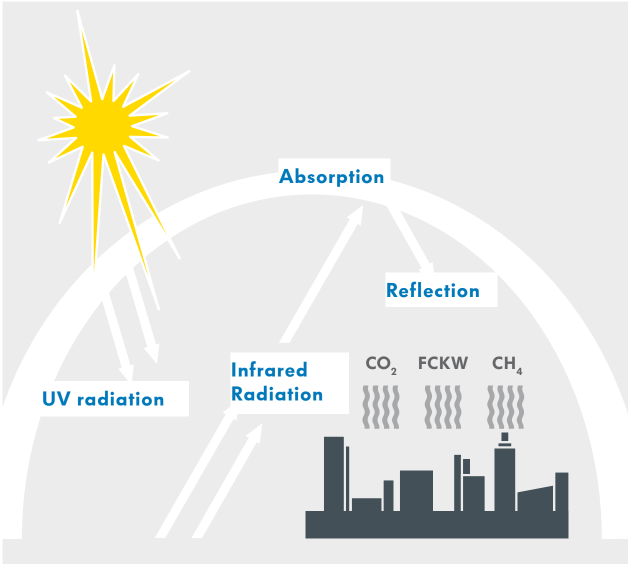
Ozone depletion potential
describes the ability of trace gases to rise into the stratosphere and deplete ozone there in a catalytic process. Halogenated hydrocarbons in particular are involved in this depletion process, which diminishes or destroys the protective function of the natural ozone layer. The ozone layer provides protection against excessive UV radiation and therefore against genetic damage or impairment of photosynthesis in plants. The reference substance for ozone depletion potential is R11, and all other substances that impact on this process (for instance CFC, N_2O) are measured in R11 equivalents.



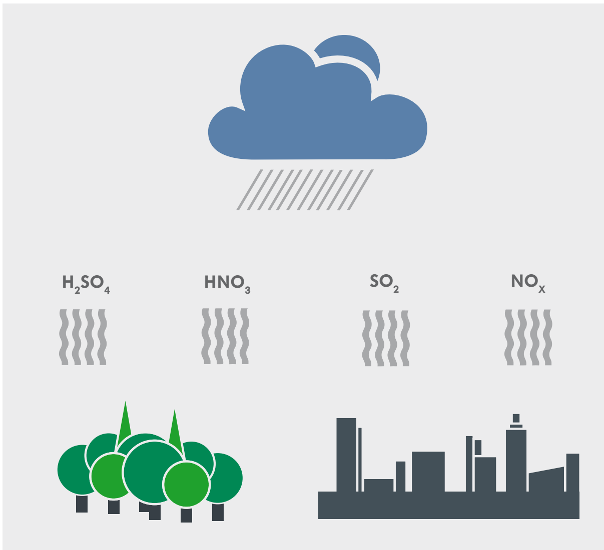
Photochemical ozone creation potential
describes the formation of photooxidants, such as ozone, PAN, etc., which can be formed from hydrocarbons, carbon monoxide (CO) and nitrogen oxides (NOX), in conjunction with sunlight. Photooxidants can impair human health and the functioning of ecosystems and damage plants. The reference substance for the formation of photochemical ozone is ethene, and all other substances that impact on this process (for instance VOC, NOX and CO) are measured in ethene equivalents.



Global warming potential
describes the emissions of greenhouse gases, which increase the absorption of heat from solar radiation in the atmosphere and therefore increase the average global temperature. The reference substance for global warming potential is CO_2, and all other substances that impact on this process (for instance CH_4, N_2O, SF_6 and VOC) are measured in carbon dioxide equivalents.



Acidification potential
describes the emission of acidifying substances such as SO_2 and NO_X, etc., which have diverse impacts on soil, water, ecosystems, biological organisms and material (e.g. buildings). Forest dieback and fish mortality in lakes are examples of such negative effects. The reference substance for acidification potential is SO_2, and all other substances that impact on this process (for instance NO_X and NH_3) are measured in sulphur dioxide equivalents.



Environmental impact category
An environmental indicator that describes an environmental problem (e.g. the formation of photochemical ozone)

Bibliography and list of sources

[Bossdorf-Zimmer et al. 2005] Bossdorf-Zimmer, B.; Rosenau-Tornow, D.; Krinke, S.: Successful Life Cycle Management: Assessment of Automotive Coating Technologies. Presentation at Challenges for Industrial Production 2005. Karlsruhe: Institut für Industriebetriebslehre und Industrielle Produktion der TU Karlsruhe.

[Guinée und Lindeijer 2002] Guinée, J. B.; Lindeijer, E.: Handbook on Life Cycle Assessment: Operational guide to the ISO standards. Dordrecht [et al.]: Kluwer Academic Publishers.

[ISO 2006] International Organization for Standardization: ISO 14040: Environmental Management – Life Cycle Assessment – Principles and Framework. 2nd ed. Geneva: International Organization for Standardization.

[Koffler et al. 2007] Koffler, C.; Krinke, S.; Schebek, L.; Buchgeister, J.: Volkswagen slimLCI – a procedure for streamlined inventory modelling within Life Cycle Assessment (LCA) of vehicles. In: International Journal of Vehicle Design (Special Issue on Sustainable Mobility, Vehicle Design and Development). Olney: Inderscience Publishers (in press).

[Krinke et al. 2005a] Krinke, S.; Bossdorf-Zimmer, B.; Goldmann, D.: Ökobilanz Altfahrzeugrecycling – Vergleich des VW-SiCon-Verfahrens und der Demontage von Kunststoffbauteilen mit nachfolgender werkstofflicher Verwertung. Wolfsburg: Volkswagen AG. On the internet at www.volkswagen-umwelt.de.

[Krinke et al. 2005b] Krinke, S.; Nannen, H.; Degen, W.; Hoffmann, R.; Rudloff, M.; Baitz, M.: SunDiesel – a new promising biofuel for sustainable mobility. Presentation at the 2nd Life-Cycle Management Conference Barcelona. On the Internet at www.etseq.urv.es/aga/lcm2005/99_pdf/Documentos/AE12-2.pdf.

[PE International 2003] PE International GmbH: GaBi 4.2 Datenbank-Dokumentation. Leinfelden-Echterdingen: PE International GmbH.

[Schmidt et al. 2004] Schmidt, W. P.; Dahlquist, E.; Finkbeiner, M.; Krinke, S.; Lazzari, S.; Oschmann, D.; Pichon, S.; Thiel, C.: Life Cycle Assessent of Lightweight and End-Of-Life Scenarios for Generic Compact Class Vehicles. In: International Journal of Life Cycle Assessment (6), S. 405-416.

[Schweimer 1998] Schweimer, G. W.: Sachbilanz des 3-Liter-Lupo. Wolfsburg: Volkswagen AG.

[Schweimer et al. 1999] Schweimer, G. W.; Bambl, T.; Wolfram, H.: Sachbilanz des SEAT Ibiza. Wolfsburg: Volkswagen AG.

[Schweimer und Levin 2000] Schweimer, G. W.; Levin, M.: Sachbilanz des Golf A4. Wolfsburg: Volkswagen AG.

[Schweimer und Roßberg 2001] Schweimer, G. W.; Roßberg, A.: Sachbilanz des SEAT Leon. Wolfsburg: Volkswagen AG.

[Schweimer und Schuckert 1996] Schweimer, G. W.; Schuckert, M.: Sachbilanz eines Golf. VDI-Bericht 1307: Ganzheitliche Betrachtungen im Automobilbau. Wolfsburg: Verein Deutscher Ingenieure (VDI).

[VDA 1997] Verband der deutschen Automobilindustrie (VDA): VDA 231-106: VDA-Werkstoffblatt: Werkstoffklassifizierung im Kraftfahrzeugbau – Aufbau und Nomenklatur. Frankfurt: Verband der Automobilindustrie e.V.

[Volkswagen AG 2007a] Volkswagen AG: The Passat – Environmental Commendation, Wolfsburg: Volkswagen AG. On the Internet at www.umweltpraedikat.de

[Volkswagen AG 2007b] Volkswagen AG: The Golf - Environmental Commendation, Wolfsburg: Volkswagen AG. On the Internet at www.umweltpraedikat.de

[Volkswagen AG 2008] Volkswagen AG: The Golf - Environmental Commendation, Wolfsburg: Volkswagen AG. On the Internet at www.umweltpraedikat.de

List of abbreviations

AP	Acidification potential
CFC	Chlorfluorocarbons
CH_4	Methane
CML	Centrum voor Milieukunde Leiden (Centre for Environmental Sciences, Netherlands)
CO	Carbon monoxide
CO_2	Carbon dioxide
DIN	Deutsche Industrienorm (German Industrial Standard)
DPF	Diesel particle filter
EDW	Einwohnerdurchschnittswert (average impact per inhabitant)
EN	European standard
EP	Eutrophication potential
GJ	Gigajoule
GWP	Global warming potential
HC	Hydrocarbons
KBA	Kraftfahrtbundesamt (German Federal Motor Transport Authority)
kW	Kilowatt
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MISS	Volkswagen Material Information System
MPI	Intake-tube multipoint injection gasoline engine
N_2O	Nitrous oxide
NEDC	New European Driving Cycle
NH_3	Ammonia
Nm	Newton metre
NMVOC	Non-Methane Volatile Organic Compounds
NO_X	Nitrogen oxides
ODP	Ozone depletion potential
PAN	Peroxyacetylnitrate
PO_4	Phosphate
POCP	Photochemical ozone creation potential
ppm	parts per million
PVC	Polyvinyl chloride
R11	Trichlorofluoromethane (CCl3F)
SET	Simultaneous engineering team
SF_6	Sulphur hexafluoride
SO_2	Sulphur dioxide
TDI	Turbocharged direct injection diesel engine
TSI	Turbo- or twincharged direct injection petrol engine
VDA	Verband der deutschen Automobilindustrie (Association of the German Automotive Industry)
VOC	Volatile organic compounds

List of figures

List of figures

Appendix

When this initial detailed version of the Environmental Commendation was printed, the TÜV NORD report had not yet been released for publication. It will appear here as soon as the final version is available.

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