

Chapter 23

Implementing Life Cycle Engineering in Automotive Development as a Helpful Management Tool to Support Design for Environment

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Abstract This chapter describes the implementation of life cycle engineering, a life cycle management component that focuses on the environmental performance improvement, in the context of automotive design for environment. The purpose of life cycle engineering is to derive measurable technical targets from life cycle assessment (LCA). This approach is described using the example of lightweight design. The progress in this methodology is the ability to calculate measurable targets – such as weight reduction, fuel reduction on a vehicle level, or the amount of secondary material – on the basis of LCA results. It is important to note that LCA is not used here for comparing the environmental performance between competing materials or technologies. Instead, life cycle engineering, as a helpful management tool to support design for environment, shows the technical roadmap of measures that must be taken in order to assure environmental progress over the entire life cycle. In doing so, this tool supports putting life cycle assessment results into business practice.

Keywords Life cycle engineering • Automotive • Design for environment • Lightweight design • Life cycle management

1 Introduction

Life cycle management (LCM) is a management concept used by businesses to ensure a continuous sustainable performance improvement of their activities (UNEP/SETAC 2009). It aims at minimize environmental and socioeconomic burdens in the

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entire life cycle of a product (Remmen et al. 2007). The mobility sector is a key branch for the development of technologies that help to minimize environmental impacts. For the Volkswagen Group, the motivation for this is not only driven by external factors like environmental regulations, financial markets, customer requirements, competitors' behavior and the volatility of energy and resource prices, but also because, as a major automobile manufacturer, the Volkswagen Group takes seriously its responsibility for the sustainable development of the economy, the environment and the society. Based on this, the Volkswagen Group set itself the goal to become the world's most sustainable automobile manufacturer by 2018. In order to achieve this, a set of ambitious environmental targets has been elaborated to be pursued continuously in different business units like technical development, production, and sales division. The environmental strategy applies not only to all brands of the Volkswagen Group in all regions, but also to the whole value chain.

1.1 Life Cycle Management at Volkswagen

The aim of life cycle management initiatives in general and environmental management in particular at Volkswagen is to continuously improve the environmental performance of both the company itself and of the products. Consequently, the Environmental Strategy is based on four target areas: Top in intelligent mobility, leaders in eco-friendly products, top in lifecycle-based resource conservation, and consistent anchoring throughout the company (Fig. 23.1).

As leader in eco-friendly products Volkswagen is committed to reducing the CO₂ output of the European new car fleet to emissions below the threshold of 120 g CO₂/km by 2015 and furthermore to 95 g CO₂/km by 2020. Beyond and considering the lifecycle-based approach regarding resource conservation, a holistic view on the full lifecycle of the products is considered. This means that not only environmental issues relating to products are addressed, but the minimization of environmental



Fig. 23.1 Volkswagen Group environmental strategy (Source Volkswagen AG 2013)

impacts along the whole value chain is considered. The goal is to create products that have better environmental properties over their entire lifecycle in comparison to their predecessors. The tool chosen by Volkswagen to implement this approach is life cycle assessment (LCA) in line with ISO standards 14040 and 14044 (ISO 14040: 2006, ISO 14044: 2006).

1.2 Life Cycle Assessment as a Tool to Implement Life Cycle Management at Volkswagen

The LCA is one of the LCM tools used by organization to understand the consequences of their business operations. The LCA methodology was first developed 30 years ago, and since then the technique has been practiced in many different product fields. Early on, Volkswagen was engaged in this process and performed LCAs aimed at optimizing products and processes ever since the early 1990s. As early as 1996, the company was the first carmaker to prepare and publish a life cycle inventory (LCI) for the Golf III (Schweimer and Schuckert 1996). In the following years, LCIs were published for various vehicles of the Volkswagen Group (e.g., Schweimer and Levin 2000).

Conducting LCAs at Volkswagen means to collect all the important facts over the entire life cycle of a vehicle, component, or technology and back them up with relevant figures, e.g., the volume of raw materials, energy for production processes. The data collection process is based on vehicle parts lists, material and weight information stored in the company's own Material Information System (MISS), technical datasheets and drawings. For modeling the use phase, fuel consumption and the resultant emissions are worked out based on the legally prescribed New European Driving Cycle (NEDC). In addition, the amount of energy consumed during the dismantling and/or recycling of the vehicle parts is calculated.

Since 2007 the Volkswagen brand consequently publishes Environmental Commendations which inform customers and the general public about the ecological progress at life cycle level made by new models in comparison to their predecessor. These comparisons are based on detailed LCA studies which are certified by independent auditors in accordance to 14040 (ISO 2006a) and 14044 (ISO 2006b). By the end of 2013, Volkswagen Passenger Cars and Volkswagen Commercial Vehicles had published a total of 18 Environmental Commendations.

2 From Life Cycle Assessment to Life Cycle Engineering

Volkswagen uses the LCA methodology as an effective LCM tool to analyze the environmental profiles of products and processes and to identify ecological hotspots therein. Based on this knowledge it is determined which improvements will have the greatest effect and thus can develop targeted innovations. This is what is called life cycle

engineering (LCE). It is one of the components of LCM. While LCM as a product management system aims to improve the sustainability performance of a company through minimizing environmental and socioeconomic burdens associated with an organization's value chain (Remmen et al. 2007), it has a narrower focus on the management and controlling of measures to improve the environmental profiles of a company's products. It is a helpful management tool to support design for environment.

2.1 Success Factors for Life Cycle Engineering Within the Company

The fundamental aim of life cycle engineering is the management and controlling of measures for the improvement of the environmental profiles of products. However, in order to implement and integrate LCE into corporate processes, there are some key success factors to be considered:

Organization: In order to help assure a consistent implementation of life cycle engineering into the companies' processes, the commitment of the top management is crucial. Thus, the life-cycle based improvement of the vehicle fleet in terms of environmental impact and resource conservation forms an integral part of Volkswagen's corporate policy and environmental strategy.

Analysis: The LCA methodology provides a comprehensive tool to both gain a detailed insight in the environmental profile of a product and analyze the potentials for improvements. However, to be applicable, the LCA must be based on a framework that ensures reliable and robust results derived within a reasonable time frame, despite of the degree of complexity of the product under study.

Optimization: In order to transfer conclusions from the LCA into realistic and convertible improvements, it is necessary to translate the results into technical goals. These have to be expressed in a form that is sufficiently specific to allow decisions and measures from an engineering point of view.

Communication: Environmental improvements in vehicles must be visible for customers and other stakeholders. It is therefore crucial to communicate about new features and to inform customers and other relevant stakeholders about the activities and successes in developing environmentally friendly technologies and products. For this purpose, the Volkswagen brand developed "Environmental Commendations" (Warsen and Krinke 2012).

2.2 Integration of Life Cycle Engineering into Company Processes

To successfully support the development of an ecologically advantageous new vehicle, it is crucial to obtain top management awareness and to implement life cycle engineering in the company's development processes.

Most decisions affecting the environmental performance usually have a financial impact on a vehicle project. Furthermore it is obvious that an environmental decision support should be implemented as early as possible in the development process. The earlier decisions can be supported, the more influence can be exercised.

Life cycle engineering is implemented in the environmental strategy of the Volkswagen Group and in the environmental objectives for technical development of the Volkswagen brand. These objectives are set and tracked by the environmental officer during the development of a vehicle. With the goal in mind to develop each model in such a way that, over its entire life-cycle, it presents better environmental properties than its predecessor, the environmental officer is present in decisive boards and supports decisions from the initiation of project on.

3 Automotive Life Cycle

Like many other products, the automotive life cycle consists of three main phases. In the following the automotive life cycle is described based on the greenhouse gas emission profile of a Golf VII, 1.6 TDI for an assumed running distance of 20,000 km. Three phases are differentiated: production phase (20 % of GHG emissions), use phase (79 % of GHG emissions), and end-of-life phase (1 % of GHG emission). The production phase covers the raw material extraction to semi-finished products or components and finally the car's production and assembly. Within the production phase roughly 21 % of a car's production CO₂-eq. emissions are emitted at Volkswagen plants. The other 79 % are emitted over the entire supply chain back to the extraction of raw materials like iron ore for steel production or bauxite for aluminum production (Fig. 23.2).

The use phase covers the tailpipe emissions (tank-to-wheel) as well as the emissions for fuel extractions and production (well-to-tank). At the end-of-life phase, the vehicle is partly dismantled and then shredded for the reuse of the materials, which accounts for around 1 % of the total greenhouse gas-emissions.

In accordance with the drivers for environmentally compatible product design, the main effort is put into the reduction of emissions during the use.

This is achieved by developments like the electrification of the car, more efficient combustion engines and complex emission control systems. Furthermore, the lowering of running resistances, like mass and aerodynamic drag, are addressed.

But these measures can also increase the emissions in production. This can result in a shift of the hot spots within a car's lifecycle. The usage of energy-intensive technologies, like lithium ion accumulators or lightweight materials, can lead to a higher burden in the production and recovery phase, combined with a lower burden in the use phase.

Therefore the task for life cycle engineering is to assure that, in total, environmental impacts of cars over their entire life cycle is lower than that of their predecessor.

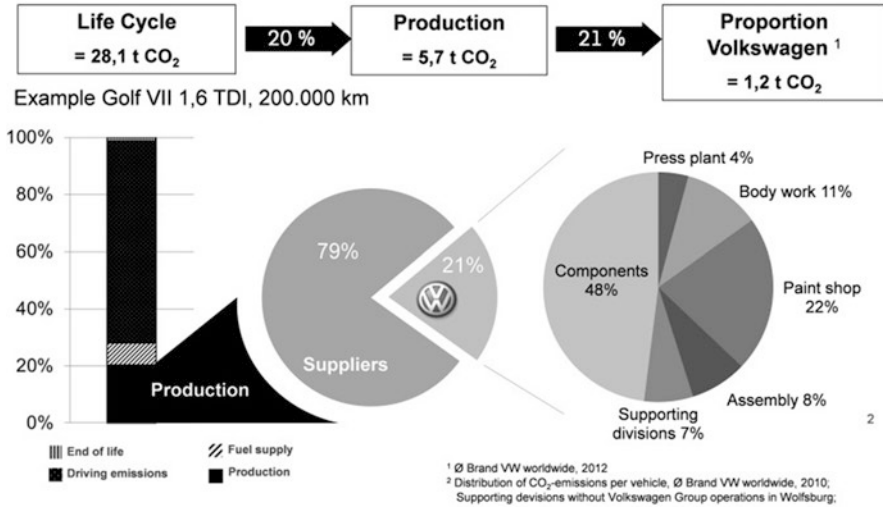


Fig. 23.2 Life cycle perspective: A car's CO₂ equivalents

3.1 Lightweight Design

Lightweight design is one relevant measure for lowering the car's fuel consumption and driving emissions, as the car's mass has the biggest single influence on the running resistances. However, from an environmental life cycle perspective, it is crucial to choose the "right" lightweight concepts and materials in order to avoid the shift of environmental burdens (Warsen and Krinke 2012).

From the environmental point of view, a ground-breaking success factor for lightweight design depends on the realization of secondary weight effects. Reversing the spiral of increasing weight can and should lead to an adaption of powertrain size. For example, the reduction of 100 kg in a car powered by a turbocharged petrol engine results in a reduction of tailpipe-emissions by 3.6 g CO₂/km, which is equivalent to a fuel reduction value (FRV) of 0.15 l/100 km. With an adapted powertrain (adapted engine displacement and gear ratio), the improvement more than doubles to 8.2 g CO₂/km (Rohde-Brandenburger 2014). At this point it is important to bear in mind that the choice of a powertrain is made on a vehicle perspective and depends on the available powertrain portfolio (Krinke et al. 2010, p. 38).

3.2 Example: Hot Stamped Steel

Usually the most common way to assess the environmental impact of lightweight design is the comparison of two materials in the context of a real application. On the one hand the specific constraints and assumptions are set, but on the other hand the assessment is not valid outside these constraints and assumptions.

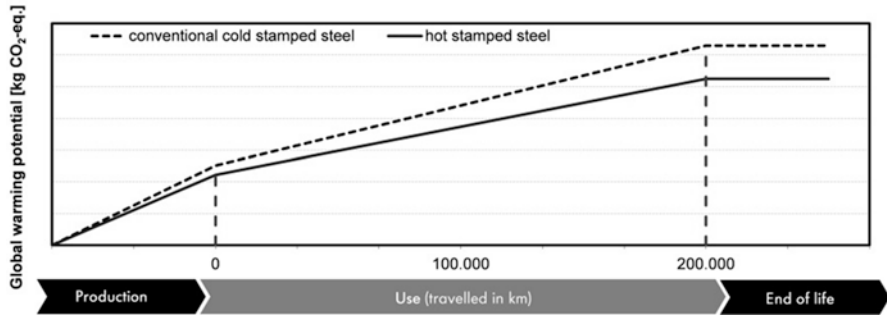


Fig. 23.3 Carbon footprint comparison: cold stamped steel vs. hot stamped steel

One good example is the analysis of hot stamped steels in comparison to conventional steel. Hot stamped steels are low-alloy steels with a special aluminum-silicon coating that is heated to 900 °C before the forming process. While the steel is formed, it is hardened by cooling it down abruptly. Therefore the forming process is clearly more energy-intensive than the conventional cold stamping process. The advantage of hot stamping is the much higher strength of the steel part. This property enables thinner and lighter steels that still have the same or even better crash performance than conventional steels. All in all, for an exemplary part, this results in a weight reduction of 20 % and a corresponding lower demand for raw materials. After considering the entire life cycle and the realized weight reduction, the hot stamped steel is advantageous in comparison to the conventional steels as shown in Fig. 23.3. Due to lower material demand and the resulting reduction for raw material extraction and steel production, in this case the lightweight alternative is at an advance even before the first meters are driven with the car. With each driven meter the lightweight effect can unfold on top.

Therefore hot stamped steel is a good example for lightweight strategy which offers environmental advantage from the first mile on.

4 Analysis and Derivation of Measurable Technical Targets

The statement of more or less abstract results from different environmental impact categories as a result of a LCA is barely promising. To enable change in development and to influence new developments, a derivation of measurable technical targets and indicators is needed. In addition, these targets must be based on crucial success factors for LCE that considerably influence the vehicle's environmental impact. With an ideal conception, the targets can be used on a universal scale and are not bound to specific concepts or assumptions.

Only technical targets in the language of the recipient can be used to support the developers and decision makers in charge. Thus, the target will not be in direct context of environmental impact categories like global warming potential (kg

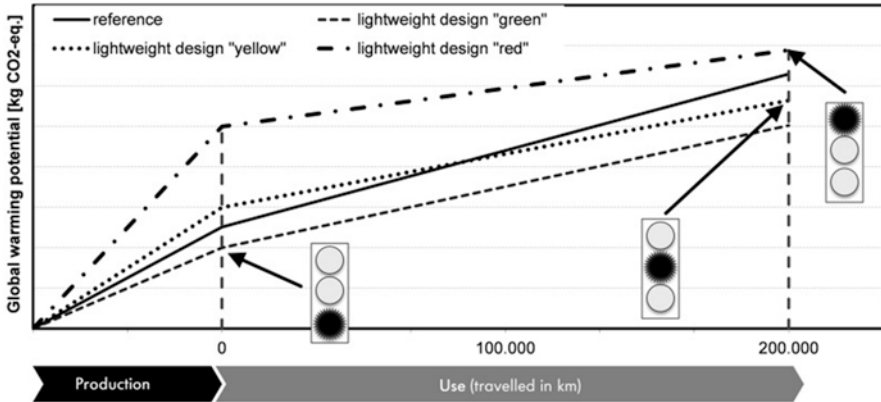


Fig. 23.4 Derivation of traffic lights from the life cycle illustration

CO₂-equivalent) or photochemical ozone creation potential (kg ethene-equivalent), but in the context of vehicle engineering like fuel consumption (liter per 100 km), or mass reduction with lightweight design (necessary weight reduction in kg or %). In addition to such use-phase-oriented targets it is useful to express targets in the context of production engineering, too. Targets with a high influence factor can be material efficiency or share of secondary material from closed-loop recycling.

A very intuitive form for the communication of targets can be the visualization as traffic lights. The traffic lights are derived from the LCA-common life cycle illustration to rate lightweight designs as shown in Fig. 23.4.

The green traffic light is reserved for the best case – an alternative design performing better than the reference right from production (as in the hot stamping example). If the advantage is realized during use, for example by reduced fuel consumption, the alternative will be awarded the yellow traffic light. In this case there will be a break-even at a certain kilometrage. However, if an alternative cannot show its advantage over the use of the product phase, the red traffic light appears.

As this illustration is still linked to a specific part or situation, the illustration has to be generalized. How a general approach looks like will be shown with the help of the press hardening steel example.

4.1 Calculating Targets for Hot Stamped Steel

Lightweight design may be the ideal case to show the need of a general target and illustration. The decisive factor to assess a design in advance is the weight reduction in comparison to a reference. Usually this factor is not available until the design is actually construed and the design process finished. To support the design from the

beginning, a target value for a necessary weight reduction is required. How to quickly calculate a target for lightweight design (w_{rel}) is shown in Eq. (23.1):

$$w_{rel} = \frac{EIP_a - EIP_r}{EIP_a + EIRV_{LC}} \tag{23.1}$$

Thereby the environmental impact for the production of 1 kg of a reference material (EIP_r) and 1 kg of an alternative material (EIP_a) plus an environmental impact reduction value over life cycle ($EIRV_{LC}$) is needed. This value reflects the reduction of an environmental impact per km (e.g., g CO₂/km) over an assumed running distance in km for a weight reduction of 1 kg.

The calculated target shows the relative weight reduction needed to perform better than the reference after the use phase, parallel to the transition of the yellow to the red range shown in Fig. 23.5. With the ratio of EIP_r to EIP_a the value can also be calculated for the transition from production to use (green to yellow range). These calculations are conducted on the example of hot formed steel in comparison to cold formed steel in crash applications for global warming potential.

With a typical weight reduction of around 20 % it is obvious that the technology in this case is not critical and the hot formed part is in advance already after production. Furthermore, developers and decision makers can easily see that a weight reduction of less than 5 % is critical. In this case the savings in material and fuel do not compensate the higher burdens of the hot forming process. A weight reduction between roughly 5 % and 10 % is sufficient to obtain an advantage over lifecycle but depends on the usage of the vehicle. It may be appropriate to analyze this case in detail.

If a light weight alternative’s typical weight reduction is outside the desired ranges, measures have to be considered to lower the environmental impact. Those measures can be rated again with the illustration in Fig. 23.6.

A measure in the use phase, e.g., a powertrain adaption, and the resulting higher fuel reduction, will cut the red range towards a lower necessary weight reduction. The use of more secondary materials as a measure for lowering the impact in production would even expand the green range and thus enable the use of a lightweight design even more. That is how the best and most efficient measures can be identified and compared in a very neat way.

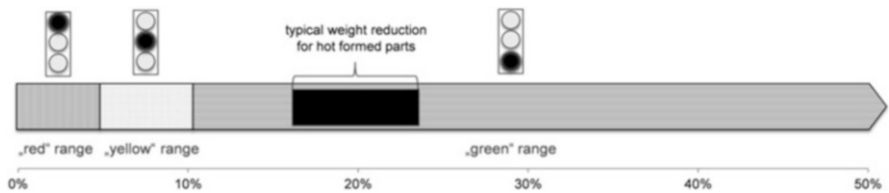


Fig. 23.5 Necessary weight reduction for a hot formed part in comparison to a cold formed part

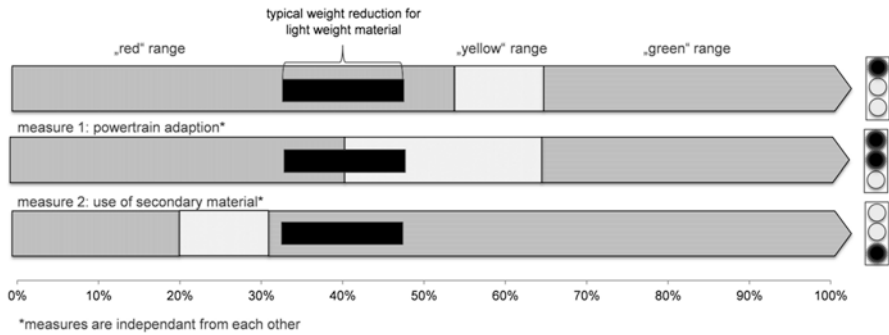


Fig. 23.6 Comparison of measure with target value in sight

5 Conclusion

The developed life cycle engineering approach is a helpful environmental management tool to support design for environment. The progress in this methodology is the ability to calculate measurable targets – such as weight reduction, fuel reduction on a vehicle level, or the amount of secondary material – on the basis of LCA results. With the help of an example in lightweight design, the successful implementation and application of LCA derived technical targets in a company was shown. It is important to note that LCA is not used here for comparing the environmental performance between competing materials or technologies. Instead, life cycle engineering shows the technical roadmap of measures that must be taken in order to assure environmental progress over the entire life cycle. In this way, life cycle engineering mainly focuses on the management and controlling of actions to improve the environmental performance of products. Environmental performance improvement is key for a life cycle management initiative in a company.

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