Product Sustainability Index

FordS-MAX
FordGalaxy

Feel the difference

Foreword

Sustainable development is one of the key global issues facing society in the 21st century. Ford Motor Company sees this issue as not only a key business challenge but also as an important opportunity to facilitate sustainable growth in our business. Sustainability is one of management's central responsibilities and high on the list of our corporate values.

Demonstrating that we put sustainability at the heart of everything we do is Ford of Europe's new Product Sustainability Index (PSI). The Ford PSI is the first example in the automotive industry of how sustainability can be integrated into mainstream product development.

The main challenges of sustainable development – or for us, sustainable mobility - are to continuously make our products more sustainable by further reducing their environmental impact, enhancing their value to society and keeping our focus on efficiency and affordability. And this along the entire life-cycle of our products.

As several of the challenges involve a multitude of - often conflicting - issues, we felt it necessary to develop a comprehensive range of vehicle-related sustainability criteria and integrate them right at the beginning of our product development process. From this was born the Ford PSI.

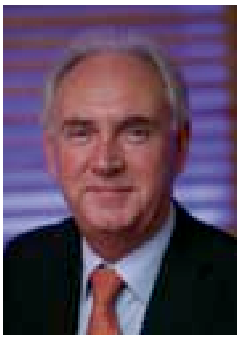
The new Ford Galaxy and Ford S-MAX are the first vehicles developed using this new holistic approach. All future Ford of Europe vehicles will also be developed with PSI in mind, as revealed with the new Ford Mondeo this year.

I am proud of my team – they are developing good-looking, desirable passenger vehicles whose environmental and societal characteristics and affordability have been improved compared to previous models.

I am also proud that the integrity of the Ford PSI initiative has been confirmed by independent, external assessments. Furthermore, our work and results are in line with international standards such as the ISO 14040 Life Cycle Assessment Standard.

Ford's Product Sustainability Index will help make mobility more sustainable. However, it is also clear that to fully address this issue, society will increasingly need a fully-integrated approach with all stakeholders in the transport sector contributing.

We are all part of the problem, and we are all part of the solution.



**John Fleming,
President and CEO,
Ford of Europe**

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1. Executive Summary

Ford of Europe introduced a sustainability management tool, the Ford Product Sustainability Index (hereafter 'PSI') into the product development of the new Ford Galaxy and Ford S-MAX. Ford's PSI considers environmental, economic and societal aspects based on:

- Externally reviewed environmental and cost aspects such as a Life Cycle Assessment (LCA) and Life Cycle Cost
- Externally certified aspects such as an allergy-tested interior
- Other relevant aspects, including sustainable materials, safety, mobility capability and noise

The new Ford Galaxy and Ford S-MAX show significant improvements over the previous model Galaxy regarding the lifecycle air quality* , use of sustainable materials, restricted substances and safety. Their affordability (Lifecycle Cost of Ownership) has also been improved when looking at comparable engine types. Thus, Ford can show that indicators from all three major areas of sustainability - environment, social and economic - have been improved. Following the S-MAX and Galaxy, all future Ford of Europe vehicles will be developed in line with PSI, including the 2007 Ford Mondeo.

*Covering certain air emissions (for example NOx, VOC) along the life cycle, i.e. from raw material extraction via production and use through to recovery of the vehicle. PSI also shows to what extent CO_2 equivalent emissions are reduced along the vehicle life cycle.

2. Product Sustainability Index

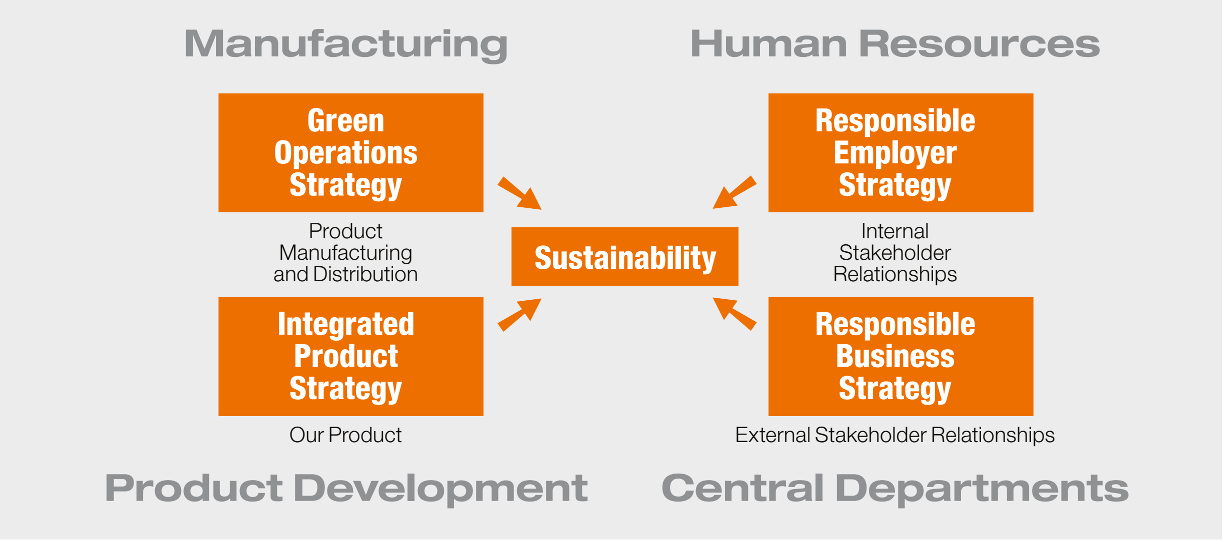
2.1 Introduction

Sustainable development is development that meets the "needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission; [1]). The concept is to improve environmental, societal and economic aspects simultaneously. Within this context, Chairman William Clay Ford Jr. said, "Ford Motor Company once provided the world with mobility by making it affordable. In the 21st century, we want to continue to provide the world with mobility by making it sustainable" (Bill Ford [2]). Ford of Europe's PSI is one way to implement this vision. It defines a workable number of key, controllable product attributes that define the sustainability of a vehicle from a Product Development (PD) perspective.

Other Ford of Europe sustainability indices, for example, the Manufacturing Sustainability Index (MSI), present the perspectives of their relevant areas. Each main functional group of Ford of Europe translates the meaning of sustainability to their own area. This is the best way to allocate understanding, ownership and responsibilities in a complex organization (Fig 2-1).

In 2002, Ford of Europe began the planning and implementation of the PSI. PD needs very long lead times, longer than any other functions – changes in methods take several years to trickle through buy-in, cycle planning, kick-off, development and launch. PD also has a greater impact on our products in the use phase than any other single in-house factor.

Figure 2-1: Functional organization of sustainability – Ford of Europe



2.2 PSI – Method

There is not yet an agreed international standard for measuring product sustainability. However, the PSI indicators chosen by Ford are partially based on the ISO 14040 (Life Cycle Assessment - LCA) standard. The Ford PSI is unique in the automotive industry and no automobile manufacturing company has published similar approaches before. However, there are some examples in other industries and organizations of sustainability practices in use. These examples have allowed us to deduce, develop and improve upon the principles they have followed. The PSI's initial methodology was developed by Ford Corporate Citizenship and environmental personnel starting in 2001. Following discussions with PD and modifications, it was approved in autumn 2002 by the Product Development vice president and his senior management team. The new Ford S-MAX and the new Ford Galaxy are the results of these pilot programs. All Ford of Europe vehicles kicked-off following these two vehicles are and will be developed using the PSI.

The principles defining what had to be covered by the PSI were management and methodologically driven:

- All relevant environmental, social, and economic issues have to be addressed
- Only issues that are mainly influenced by Product Development will be dealt with
- The main issues must be integrated from a product perspective
- Status-tracking must be possible based on readily available product development data
- Bottom-line issues must be addressed, not single technologies (i.e. overall Life Cycle performance, not discussions of the use of certain, specific technologies)
- Business principles must be integrated

Other issues relating to sustainable mobility - service aspects, in particular - are not covered by the PSI because they cannot be dealt with at the engineering level. Legal compliance issues including tailpipe emission standards, recyclability, and phasing out of heavy metals for example, are not covered within PSI as these are mandatory regulatory issues.

Ford's PSI is split into eight different indicators. This is considered the maximum number of issues that could be dealt with effectively by management. The PSI cannot be reduced to a single final score - sustainability is by definition not a one-dimensional issue. It is always measured by various sets of indicators. There is no reasonable way to combine aspects as diverse as safety, use of recycled materials, and cost into one number. This would require, for example, a socially acceptable weighting of their relative importance. Global companies with global markets face the challenge of being confronted by differing values in their various markets and production locations. A single weighting of the relative importance will never be universally suitable for all regions [3].

Table 2-1: Indicators of the Ford Product Sustainability Index (PSI)

	Indicator	Metric / Method	Driver for Inclusion
Environ-mental and health	Life Cycle Global Warming	Greenhouse emissions along the life cycle (CO_2 and equivalent emissions from raw material extraction through production, use to recovery) – part of an LCA according to ISO 14040	Carbon intensity is the main strategic issue in automotive industry
	Life Cycle Air Quality	Emissions related to Summer Smog along the life cycle (Ethene and equivalent emissions) – part of an LCA according to ISO 14040	Potential trade-offs between CO_2 and non-CO_2 emissions
	Sustainable Materials	Recycled and natural materials related to all polymers[1]	Resource Scarcity
	Substance Management	Vehicle Interior Air Quality (VIAQ) / allergy-tested interior, management of substances along the supply chain	Substance risk management is key
	Drive-by-Noise	Drive-by-Exterior Noise = dB(A)	Main societal concern
Societal[2]	Safety	Including EuroNCAP stars (including occupant and pedestrian protection)	Main direct impact
	Mobility Capability	Mobility capacity (seats, luggage) to vehicle size	Crowded cities (future issues include: diversity – disabled drivers, etc.)
Economics	Life Cycle Cost	Sum of vehicle price and 3 years service (fuel cost, maintenance cost, taxation) minus residual value (note: for simplification reasons cost have been tracked for one selected market; Life Cycle Costing approach using discounting)	Customer focus, competitiveness

[1] Note: There are, of course, no materials that are inherently sustainable. All materials are linked to environmental, social and economic impacts. However, recycled materials and renewably grown, natural fibers represent an example of how limited resources can be used in a more sustainable way. The overriding factor is whether or not these materials have, in their specific application, a lower environmental impact through the product life cycle than potential alternative materials (see life cycle related PSI indicators and previous paper [24]).

[2] Note: The social aspects are being refined and developed for the future. Please note that aspects related to labor, rights etc. are part of other Ford of Europe sustainability management tools such as the MSI.

2.3 PSI – Implementation

The Ford of Europe PSI was implemented from the top down, with a process-driven approach - from the very beginning it was linked to the normal product development process. For example, the PSI is now specifically included in the “multi panel chart” in which all vehicle attributes (craftsmanship, safety, environment, cost, etc.) are tracked towards the targets given from the beginning through all development milestones.
It was a top-down approach in that it was called for and authorized by senior management. The roles and responsibilities involved, with the exception of the development of initial methodologies, were taken on by PD itself, without relying on a specialist group internal or external to PD. This ensures that PSI is optimally integrated into PD since it is executed by the same people also running other aspects of product development (Figure 2-2).

Process	Lead Responsibility
PSI Methodology	Corporate Citizenship / Product Planning
Data Input	Individual Data Owner
PSI Calculation	Vehicle Integration
PSI Target Setting, Reporting, Compliance	CPE / Project Management / Vehicle Integration
Integration / Awareness / Training	PD Factory
External Communication	Purchasing
Cross Carline Coordination	Product Planning
Governance	FoE Operating Committee

Figure 2-2: Roles and responsibilities within the PSI implementation process and PD integration (CPE = Chief Program Engineer)

A comprehensive but very simple spreadsheet file was developed by Ford’s LCA specialist to enable non-specialists to track PSI progress. With the central input of a few data, the PSI, including the simplified Life Cycle Studies, can be tracked through the product development process from beginning to end. The majority of the data needed is readily available in the above mentioned “multi panel chart”. The very few factors required above and beyond those include main weight actions such as material changes to predecessor, fuel economy impact of the air-conditioning system and leakage rates. The engineers responsible for the simplified PSI tracking were given one hour training sessions that allowed them to understand the fundamental concepts, use the analysis spreadsheets and conduct simplified Life Cycle Studies (regarding environmental and cost aspects) and track the other PSI indicators. The aim of this very lean management of sustainability within Product Development is to avoid unnecessary administrative burdens and the need for additional resources while still ensuring that sustainability is an integral part of the complex product development process.

Through the various stages of product development, the data used changed and evolved along the way:

- Gateway Kick-Off (KO), Strategic Confirmation (SC): Target ranges based on predecessors, benchmark and weight action proposals
- Gateway Program Approval (PA): First engineering data
- Gateway Program Readiness (PR): Engineering data
- Gateway Change Cutoff (CC) Supplier data including IMDS [8] completed by engineering data

Every manufacturer has their own particular automotive product development process. The approach described purposely fits to the Ford design processes and culture. It is not suggested that this approach will also suit other company cultures or markets since the methodologies and approaches cannot be generalized [25]. External regulatory bodies applying mandatory approaches would be counterproductive – sustainable practices can only function on a solid internal basis of understanding, drivers, motivations and commitments – not on rules and regulations. The PSI is a voluntary approach that aims to integrate environmental, societal and economic aspects into product development as part of Ford’s commitment to sustainability.

3 Life Cycle Aspects

3.1 Introduction

The vehicle life cycle covers all phases and processes within:

- Manufacturing and Assembly (from resource extraction through material production, parts production to vehicle assembly and painting)
- Use phase (driving of vehicles)
- End-of-Life Phase (pre-treatment of vehicles, shredding of the remaining vehicle and recycling, recovery and disposal of the resulting materials)

Taking a holistic approach is essential for creating a sustainable vehicle life cycle. Design actions that improve one life cycle phase but have a negative impact on another must be avoided. For example, using certain materials may reduce recycling cost but add weight to the vehicle, thus increasing emissions during the use phase. Measures to reduce fuel consumption will reduce the use phase cost but increase the vehicle price and so on. The aim is to ensure net benefits along the life cycle as a whole – in an environmentally and societally efficient way [4].

The environmental aspects are tracked following the ISO 14040 for Life Cycle Assessment (LCA). During product development, a simplified LCA is carried out by non-specialists. Before vehicle launch, a Ford LCA and LCC specialist verifies the initial results, doing a full LCA based on specialized software and using an extended database [5]. The basic method of this LCA is the same as used in another automotive study [6] that was independently reviewed according to ISO 14040 § 7.3.3 and where the missing details in description (methodology, data) are covered. However, additions have been made to include modern vehicle technologies not considered previously as well as data specific to the current project.

To cover the economic aspects, a conventional Life Cycle Costing (LCC) [7] was performed from a first vehicle owner's perspective. There is no international standard methodology available for vehicles, but the approach taken is in line with the findings of the most recent European scientific working group in this field [7]. It is important to note that these tools are only one part of the PSI and are embedded in the overall interactions between the various life cycle stakeholders (Figure 3-1).

Figure 3-1: Managing sustainability along the vehicle life cycle (cradle-to-cradle).

3.2 Definition of Goal and Scope

3.2.1 Goal, Functional Unit and Assessed Vehicles

Goal – The goal of the Life Cycle Studies is to:

- Support internal Product Development by tracking key environmental life cycle impacts (LCA) and bottom-line economic (LCC) impacts of planned and/or implemented engineering actions throughout the product development process
- Verify the PSI results regarding Global Warming and Air Quality Potential and also check other life cycle environmental impacts not included in the PSI
- Assess the Ford vehicles' environmental life cycle performance from a purely environmental and economic standpoint
- Identify and assess the cost associated with vehicle purchase and maintenance for a typical vehicle buyer in a selected European market assuming a resale after 3 years (typical car ownership trade cycle)

Functional Unit – All data from the life cycle studies are calculated based on a standard functional unit. It is defined as follows: a European, premium, mid-class, van-sized, five-door vehicle for a minimum of 5 passengers including a luggage compartment with a minimum volume of 900 liters, climate controlled interior, modern entertainment and safety standards with an average mileage of 150,000 kilometers over 12 years. Note: The previous and new Ford Galaxies can seat seven passengers, but then have less than 900 liters luggage capacity in that configuration. An additional LCC value is identified for the case of a resale after 3 years.

Assessment Vehicles – The following vehicles have been assessed:

- Previous Ford Galaxy 1.9l TDI, 96 kW, manual 6 speed, economy edition
- New Ford Galaxy 2.0 l TDCi with diesel particulate filter (DPF), 96 kW, trend edition
- New Ford Galaxy 2.0 l, gasoline, manual 5 speed, 107 kW, trend edition
- New Ford S-MAX 2.0L TDCi with DPF, 96 kW, trend edition
- New Ford S-MAX 2.0 l gasoline, manual 5 speed, 107 kW, trend edition

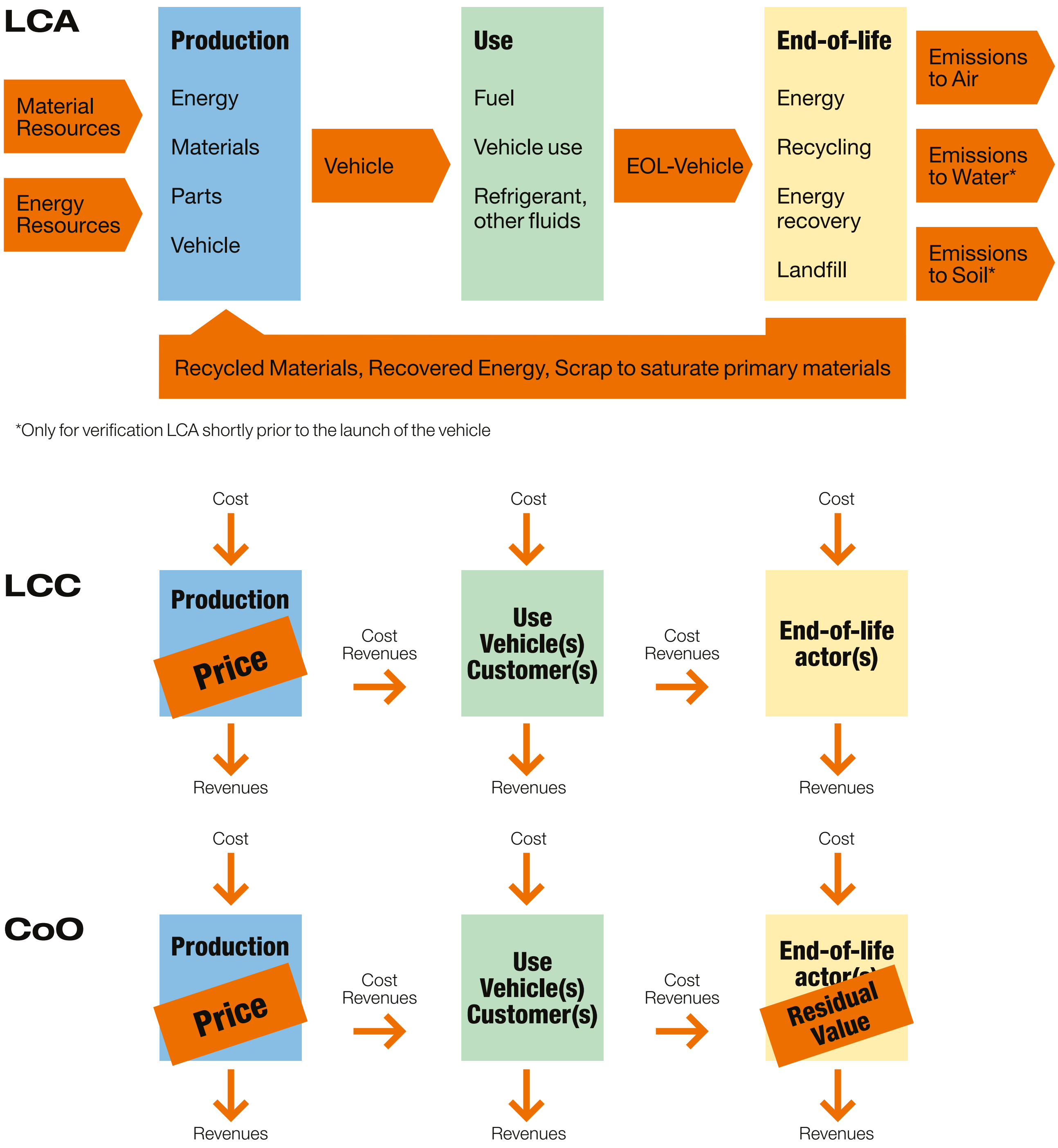
The base data for vehicle production is the material breakdown of the different vehicles. These are derived from:

- Complete teardown of the previous Ford Galaxy in the Ford dismantling center in Cologne.
- Weight assumptions based on the predecessor platform and planned weight related actions (for the first life cycle study at the start of vehicle development for the new Ford vehicle models – from Gateways KO to PA).
- Weight engineering data of the new Ford vehicles models (for life cycle studies during product development – from gateways PA to PR).
- IMDS data of the new Ford vehicles models [8] completed by engineering data – for gateway CC and for life cycle study verification before launch).

Note: To avoid complicating this work beyond the point of practicability, the vehicle models chosen represent the normal weight-control models. Similarly, no additional supplier information has been requested to avoid further complication.

3.2.2 Life Cycle Description

The general scope of the life cycle studies is displayed in Figure 3-2.



*Only for verification LCA shortly prior to the launch of the vehicle

Figure 3-2: System boundaries of the environmental LCA (top) and economic (middle) life cycle respectively Cost of Ownership (CoO) studies (figures based on [6], [8])

Table 3-1 outlines the processes included in the different life cycle stages.

	Included	Not Included	Reason for Omission
Production Phase			
Raw Material Extraction	✓*		
Material Production	✓*		
Material Processing (general)	✓*		
Paint and Assembly Process (vehicle specific)	✓*		
Energy Process	✓*		
Waste Management	✓*		
Use Phase			
Fuel Production and Consumption	✓		
Maintenance Material Production	✓ (oil, R134a)	✓ (other)	
Other Maintenance Processes	LCC	LCA	No data and no differences assumed
Vehicle Taxation and Insurance	LCC	LCA	Not applicable
Energy Process		✓	Not applicable
Waste Management (Maintenance)		✓	No data and no differences assumed
End of Life			
Residual Value	CoO	LCA/C	Not applicable
Shredding	LCC, LCA	CoO	Not applicable
Dismantling	LCC	LCA, CoO	Not significant for LCA [6]
Recovery / Recycling Processes	LCC, LCA	CoO	Not applicable
Disposal Process	LCC, LCA	CoO	Not applicable
Transport Process		✓	Not significant for LCA [6]
Energy Process	LCC, LCA	CoO	Not applicable
Supplementary Materials		✓	Not significant for LCA [6]

*The economic Life Cycle studies are based on a vehicle price that is assumed to sufficiently cover all upstream activities.

This study is very similar to a previous, automotive LCA study [6] regarding modeling of production, use and EOL, but includes the following, making it more comprehensive:
- More components considered (in particular DPF, Catalytic Converter, A/C, electronics)
- Maintenance in use phase (refrigerant and oil refilling)
- Non-tailpipe emissions in use phase (A/C refrigerant leakage)
- Disposal of glass and electronics, recycling of catalytic converter, DPF and R134a

Note: it is not suggested that automotive LCAs should always include these items or that this should become a standard.

3.2.3 Data Requirements

One of the requirements of the study is that the data regarding all the production processes considered – apart from the vehicle assembly and paint shop – must be generic. The global supply chain is flexible and may source its materials and pre-products from different sources and locations during the years of production. This means, for example, that part production is reflected as general processes and does not include either specific dimensions or production locations of individual components. In addition, the data sets have to represent an average technology mix from across the relevant geographical locations. Furthermore, they must be sourced, as much as possible from public data such as material industry association data. The data must also cover at least 95% of the materials used in all vehicle scenarios.

For the environmental elementary flows and impact assessment, the study is similar to [6], focusing on the following for the verification LCA:

- Emissions – Global Warming Potential*, Acidification Potential, Eutrophication Potential, Ozone Depletion Potential, Photochemical Ozone Creation Potentials* according to CML [9]

* both also covered by the simplified LCA in parallel to product development

- Waste – is not an impact category, however, it is shown, divided into figures showing total waste and hazardous waste
- Resources – non-renewable resource depletion of energy and materials according to CML approach [9] as well as an EUROMAT approach [23]

This study does not include information on toxicity, effects on biodiversity, landscape degradation, desertification, etc. There is a lack of scientifically accepted approaches regarding these issues. In addition, any reference to these categories would be misleading looking at the completeness of the intended data sources and the system boundaries.

There is no weighting between the various areas. ISO 14042 [10] explicitly states that weighting may not be done for comparative assertions disclosed to the public and for the corporate reasons outlined above.

3.2.4 Critical Review Panel

This study is targeted at both an internal and external audience and includes comparative assertions. Therefore, an independent, third party, critical review according to ISO 14040 §7.3.3 was undertaken at the end of the project. This was to ensure that the study was conducted in accordance with the international ISO 14040 standard series and is in line with current best practices for the Life Cycle Costing section (see chapters 5 and 10). The chairman of the review panel, Prof David Hunkeler, has had previous experiences in both fields. He was involved in reviewing a similar LCA study [6] and held the chairmanship of an LCC scientific working group. The second reviewer, Prof. Walter Klöpffer, was selected by the chairman, but had not been involved in the abovementioned LCA study [6].

3.2.5 Limitations of the Life Cycle Study

Passenger vehicles are very complex products with up to 180,000 parts, depending on the counting method used. The effort needed to investigate all elementary flows of a vehicle in detail would be tremendous just for one vehicle. This is the reason why even published complete single-vehicle LCIs are simplified and do not reflect every single vehicle detail. In this study, several vehicles must be compared. As a result, it can only go into limited detail, but following experience with several complete vehicle LCIs, it can be stated with confidence that the limitations and simplifications do not affect the ability to draw conclusions within the goals of this study. It does mean, however, that it is not possible to compare the results of this study with results of other complete vehicle studies. The complete LCIs consider different system boundaries, vehicle features included and use phase assumptions - for example, this study also considers the additional fuel consumption of air-conditioning that is not covered by most published complete vehicle LCAs. It is also not possible to derive conclusions from this study regarding specific components or materials since general assumptions have been made for the manufacture and processing of these parts – for example, excluding their precise design parameters such as thickness, etc. [6] This study does not predict the impact of data the quality of which is questionable, such as those related to toxicity and landscape.

Despite the limitations of the study, the chosen model and assumptions allow meaningful conclusions to be drawn regarding the main issues outlined above for the following reasons:

- Central specifics of the vehicles studied are considered
- The assumptions, system boundaries and data approaches for the vehicles studied are fully aligned.
- Data analysis shows how significant and robust potential differences in the results are.

In the Life Cycle Costing section, all figures are based on the set of assumptions about future trends made for the study. They can be considered as broad indicators of tendencies only and are used solely for the purposes of a relative assessment between the vehicles. The figures are not exact and may change significantly in real market conditions. Ford Motor Company makes no guarantee that the cost reflect market conditions.

3.3 Environmental Life Cycle Inventory (LCI) and Cost Data Inventory

3.3.1 Life Cycle Inventory Data Model

For the inventory, data sets have been used that do not pre-date 1994, meeting minimum time related coverage requirements (see Table 3-2). Most data sets meet the geographical coverage requirement using European average data (exemptions: material production data from GaBi (mostly German sources, Austrian data regarding talcum sources) as well as the Swiss BUWAL data. With regard to technology coverage, generally representative average data sets are used. In the cases of individual data sources including copper, tires, magnesium and oil recycling the data do not necessarily cover a fully representative technology mix. The Life Cycle modeling and calculations were performed by Ford Vehicle Integration engineers, parallel to product development using a spreadsheet calculation file as well as by a Ford LCA expert for verification puposes, based on [5], [6].

Table 3-2: Sources of the Life Cycle Model (extended, based on [6])

Data set	Comments	Source
Production Phase		
Steel coils (rolled), steel coils zinc coated (0.75mm), cast iron part (sand casting), stainless steel (steel billet; X12CrNi17 7), aluminum sheet	According to IISI high-strength steel LCI data are similar to normal steel sheet LCI data.	[11]
Aluminum sheet, cast aluminum (primary ingots, re-melting and alloying), aluminum extrusion profiles	Primary/secondary ratio: 50%:50%	[12]
Copper mix (all treated as copper wire; 99.999% electrolyte), lead mix (99.995%)	Only 2% of lead is primary lead	[11]
Magnesium AM 60	65% Norsk Hydro, 35% Chinese	[14], [15], [16]
Plastics: PP, HDPE, ABS, PA 6.6, PA 6, PUR, flexible PUR foam, PVC, PET (sc.), PC, PMMA, EPDM rubber, EP	PUR RRIM part (41% Polyol, 36% MDI, 33% glass fibers); rubber assumption according to PlasticsEurope	[16]
Printed wiring boards, carbon fibers, glass fibers, textile (PP-, PET-fibers), recycled plastics, talcum (Austria), ethylene glycol, sulphuric acid (96%), oil (lubricating oil free refinery) bitumen, textiles; plastics: PBT, PP/EPDM, PPE (PPO), POM, SMC, PVC applications.	Coolants assumption: 40% Ethylene glycol / 60% deionised water	[11]
Glass (white packaging), paper (wood free, coated),	Rough assumption: float glass = 5*packaging glass	[17]
Tires		[18]
Press and body shop (steel and aluminum), copper material processing (wires), lead casting, injection molding, cast iron, aluminum casting, magnesium die casting, metal machining		[11]

Data Set	Comments	Source
Aluminum sheet, aluminum extrusion		[12]
Precious metals, silicon carbide etc. for DPF filter, catalytic converter		[11], [19], [20]
R134a, recycled cotton, natural fibers		Specific supplier data and [21]
painting, assembly		Specific Data for the vehicles adjusting also data on painting [11]
Other material processing (paper, bitumen, glass, ceramics) are assumed to be included in material production		[6]
Use Phase		
Average mileage	15,0000 km	[21]
Average fuel consumption and regulated air emissions of specific vehicles, A/C performance	Referring to 2006 performance of vehicles	Ford homologated data; assumptions for A/C
Premium gasoline, diesel fuel production		[11]
SO_2, CO_2	Calculation based e.g. on sulphur content of fuel	
End-of-Life Phase		
Recycling of aluminum		[12]
Steel electric arc furnace		IISI
Recycling of magnesium		IMA
Recycling of lead		Eurometaux
Recycling of oil, cooling liquid, rubber (incl. tires), copper		Specific [6]
Shredder		EFR
Recycling of thermoplastics (re-granulation + filler substitution), thermosets (Shredding + Filler substitution); recovery of fluids, waste oil, cooling liquid, break fluids energy, rubber and shredder residue (based on incineration, cement works), land filling of ceramics/glass		[11]
Recycling of precious metals / DPF / catalytic converter		Based on [11], [19]
R134a recovery		Specific data
Rubber land filling (PP), shredder-residue land filling, land filling (mix of land filling data sets)		[17]

Note: for PSI calculation, slightly different data sources have been used: all data regarding plastic, copper, lead and magnesium come directly from [11].

Compared to a previous automotive study, [6], additional data sources have been used to accommodate the more advanced material concepts and the consideration of additional vehicle features that require additional types of materials, fuels and substances. These include, for example, air-conditioning (R134a), premium gasoline / diesel (including data for CO_2 / kg fuel), DPF, and catalytic converters (precious metals, ceramic substrate).

As discussed above, weight and other data used came from differing sources depending on availability during product development (Table 3-3).

Table 3-3: Overview of changing weight and material information through product development in kg (example for Diesel vehicles):

	Ford Galaxy 2.0L TDCi with DPF					**Ford S-MAX 2.0 l TDCi with DPF**				
Milestone	Ferrous*	Other metals	Glass and Ceramics	Plastics and Elastomers	Fluids and other	Ferrous*	Other metals	Glass and Ceramics	Plastic and Elastomers	Fluids and other
KO	1034	194	48	355	27	992	187	46	348	21
PA	1068	199	49	366	28	1023	192	48	358	22
PR	1052	197	49	362	34	1025	192	48	351	36
CC	>1005	246	50	<355	37	>981	244	50	<329	27

Milestones: Kick-off (KO), Program Approval (PA), Program Readiness (PR) and Change Cut-off (CC)
* At CC, more details regarding specific alloys were available. For verification, the weight assumptions of the CC gateway CC have been used (Table 3-4).

Table 3-4: Material composition assumptions for the studied Ford vehicles in kg*

	Ford Galaxy 2.0L TDCi with DPF	**Ford Galaxy 2.0L gasoline**	**Previous Ford Galaxy 1.9L TDI**	**Ford S-MAX 2.0 l TDCi with DPF**	**Ford S-MAX 2.0L gasoline**
Ferrous	>1005	>979	1173	>981	>949
Other metals	246	209	190	244	206
Glass and Ceramics	50	50	56	50	50
Plastics and Elastomers	<355	<346	337	<329	<314
Fluids and other	37	27	32	37	27

* based on control model assumptions and (for previous Galaxy only) dismantling center data
All figures may differ from homologated weights. Final weights may change.

3.3.2 Production Phase Assumptions

General material production, processing, use and recycling are taken into account. Ford operations are included. LCC data is based on estimated prices for a selected European market.

The following assembly and material production assumptions have been made:

- Recycled Plastics are assumed to be mainly PP based
- The largest source of LCI data uncertainty is the LCI data for the production of automotive glass (packaging glass data multiplied by 5 was used instead, to approximate the extra materials and processing requirements for the manufacture of automotive glass). However, since the same assumptions are made for all vehicle alternatives in this study, their impact is limited [6]
- LCI data for the production of cellulose and cardboard – natural fiber data used instead
- LCI data for some polymers were unavailable (see chapter 3.5.1 for affected quantities). Average LCI data of all other thermoplastics in [11] have been used to take these polymers into account.

3.3.3 Use Phase Assumptions

The following assumptions have been made:

- 150,000 km, 12 years (functional unit) [21]
- Fuel consumption / emission standard:

Previous Ford Galaxy	1.9 l TDI:	6,5 l diesel/100 km,	Euro 3
New Ford Galaxy	2.0 l TDCi with DPF:	6,5 l diesel/100 km,	Euro 4
New Ford Galaxy	2.0 l gasoline:	8,2 l gasoline/100 km,	Euro 4
New Ford S-MAX	2.0 l TDCi with DPF:	6,4 l diesel/100 km,	Euro 4
New Ford S-MAX	2.0 l gasoline:	8,1 l gasoline/100 km,	Euro 4

- Sulphur content of fuel is assumed to be 50 ppm.
- For A/C, a worst-case assumption is made, assuming that A/C use increases vehicle fuel consumption by 10% over and above the consumption figures listed above. The HFC leakage rate is assumed to be 0.025 kg/year.

Other fluids losses are assumed to be around 5% of initial filling. The leakage rate data is uncertain but is taken here as a worst case assumption and taken at the same rate for all vehicles.

- Fuel prices: €1,229 per liter premium gasoline, €1,099 per liter diesel (variation in sensitivity analysis).
- Insurance cost are estimated based on a country specific set of premiums based on a standard set of individual insurance classes and is indicative only (ratings respective to engineering targets, a 55% deductible, insurance tariff "R" of Ford insurance, without bonus).

All use phase cost are discounted, assuming an interest rate of 8% and 2% inflation. This reflects private consumer interest rates and general European inflation figures.

3.3.4 End-of-Life Phase Assumptions

All vehicles have to fulfill rates of 85% recycling and 95% recovery. These rates have been used for the simplified LCA approach in parallel to product development. For verification, the LIRECAR scenarios for recycling and energy recovery of shredder residues have been used assuming that 50% of the shredder residue goes into recycling and 50% into energy recovery. For End-of-Life vehicles, a substitution methodology is applied to avoid other allocation approaches.

The End-of-Life cost are difficult to estimate:

- From the first owner perspective there is normally a residual value of a vehicle and no end-of-life scenario. A trade-cycle is assumed in this study in which first owners replace their vehicles after three years. The residual value forecast is quite difficult, especially for the Ford S-MAX, as it is a completely new type of vehicle. The forecast is based on the values for Ford Focus/Ford Focus C-MAX, Mondeo and Ford Galaxy, taking into consideration new-vehicle up-lifts (5%), new vehicle type (8% - similar to C-MAX), correction for potential consumer's emotional changes after 3 years (- 5%) and a further correction of minus 2% (no guarantee provided for any of these values).
- From the last owner perspective, the worst case end-of-life cost are zero due to the EU ELV directive (the last owner can dispose of a vehicle free-of-charge).
- From a manufacturer's perspective, the end-of-life cost are currently also zero.
- From a European dismantler and shredding operator's perspective, there are profits based on the high value of scrap. It Market dynamics make it impossible to provide a good estimate of future profits and cost. ELV cost are linked to the large uncertainties as shown in [4]. Therefore, only estimates of future trends and ELV cost can be made.

The following assumptions have been made about future trends from a dismantler/shredding operator's perspective:

- Removal of fluids, central neutralization of pyrotechnical devices, dismantling of heavy metals, catalytic converter, battery, tires and body glass (according to current legislative and regulatory requirements)
- Post-shredder treatment approach
- Reuse profits are not considered - this is a worst case value
- Non-labor related cost are considered for all vehicles (logistics, overhead, etc.)
- All cost are discounted using 8% interest and 2% inflation rates as before

3.3.5 Life Cycle Inventory Result

The simplified LCA does not present the LCI data in a separate step. The calculation is based directly on data such as Life Cycle Impact Assessment and energy data per kg of processed material. For the verification calculation based on [5], LCI data are available at varying degrees of detail (Table 3-5).

Table 3-5: Extract of Life Cycle Inventory result (Verification) for 150,000 km

	Ford Galaxy 2.0L gasoline	**Ford Galaxy 2.0L TDCi with DPF**	**Previous Ford Galaxy 1.9L TDI**	**Ford S-MAX 2.0L gasoline**	**Ford S-MAX 2.0L TDCi with DPF**
Input overview, tons					
Energy resources	15	13	14	15	13
Material resources*	14	16	17	16	14
Production residues in life cycle	0,17	0,17	0,18	0,17	0,17
Output overview, tons					
Emissions to air	72	67	68	70	66
Inorganic air emissions	52	47	48	51	46
Carbon cioxide	43	38	39	42	38
Carbon monoxide	0,17	0,10	0,12	0,17	0,10
Nitrogen oxides (NO_x)	0,05	0,07	0,11	0,046	0,07
Sulphur dioxide	0,03	0,03	0,03	0,03	0,03
Organic emissions to air (group VOC)	0,16	0,14	0,13	0,15	0,13
Particles to air	0,006	0,009	0,013	0,006	0,009
Emissions to fresh water **	0,84	0,80	1,10	0,81	0,78
Production residues**	1,3	1,3	1,5	1,2	1,2
Deposited goods*	15	14	16	15	14

* Only solid materials; roughly 60% of it inert rock;
** Only solid emissions and– for emissions to fresh water only - analytical items as COD.

3.3.6 Life Cycle Costing Inventory

As indicated before, all calculated cost figures are trend-indicators only. They are used to provide a relative overview of cost through the life cycle. These figures may not reflect actual market conditions. Since they are based on the same assumptions for all vehicles (see above), the cost figures allow a relative assessment.

The cost cannot be added to life cycle cost, but a discounting of future cost is necessary to assess whether, for example, higher purchase prices for diesel vehicles might be made up for by future savings in the use phase (see chapter 3.4.3 for discounted figures).

Table 3-6: Inventory of theoretical cost through the product life cycle (trends only, no guarantee)

Theoretical cost along the product life cycle

	Ford Galaxy 2.0L gasoline	Ford Galaxy 2.0L TDCi with DPF	Previous Ford Galaxy 1.9L TDI	Ford S-MAX 2.0L gasoline	Ford S-MAX 2.0L TDCi with DPF
Price €, options*	€ 27,475	€ 29,825	€ 29,700	€ 25,800	€ 28,150
Insurance, tax scheduled maintenance, € year*	€ 1,246	€ 1,687	€ 1,765	€ 1,246	€ 1,669
Fuel, fluids €/year*	€2,091	€1,486	€1,486	€2,065	€1,463
Residual value 3 years (forecast)*	60%	60%	56%	61%	61%
EOL cost (consumer, Ford)*	€ 0	€ 0	€ 0	€ 0	€ 0
Theoretical ELV profits (operators)*	Min -€116	Min -€134	Min -€128	Min -€120	Min -€136

* theoretical value for one selected European market. no guarantee that the cost reflect market conditions.

3.4 Life Cycle Impact Assessment and Directional Life Cycle Costing Result

3.4.1 Life Cycle Impact Assessment Results along the Product Development Process

The impact categories for climate change (indicator: Global Warming Potential, GWP) and air quality (indicator: Photochemical Creation Potential, POCP) have been targeted and tracked as part of the product development process. Based on the changing weights, materials and fuel consumption, varying results have been reported at the different product development milestones. These calculations have been done by Vehicle Integration engineers - non-LCA experts using the previously mentioned spreadsheet files. For verification purposes, a Ford LCA expert using LCA expert software has made calculations for the same vehicles based on the same data as available at the milestone CC (Figure 3-3).
Figure 3-4 shows that the simplified PSI calculations are a 100% match with the expert calculations regarding use phase related impacts and a 98% or better match when looking at the total impacts for the Ford vehicles studied when considering GWP and POCP.

Figure 3-3: GWP and POCP of Ford Galaxy 2.0L TDCi with DPF (left) and S-MAX 2.0 l TDCi with DPF (right) from Kick-off, through the PA, PR and CC milestones, compared to verification by LCA expert tool.

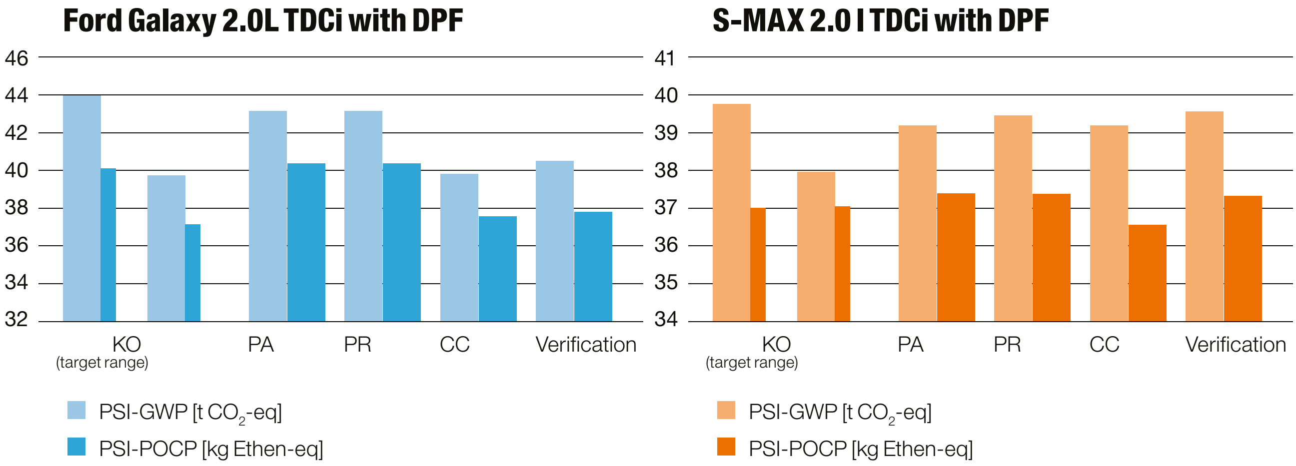
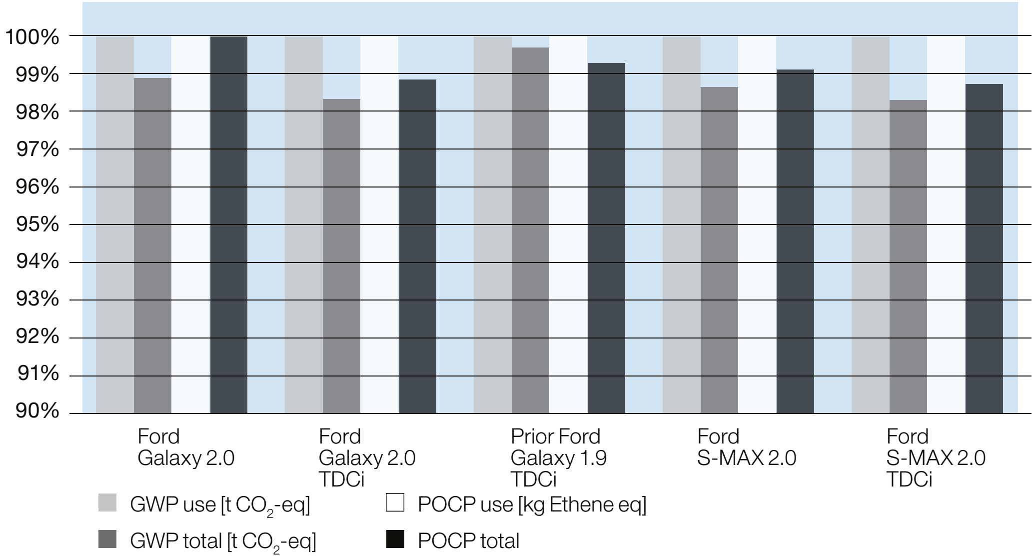


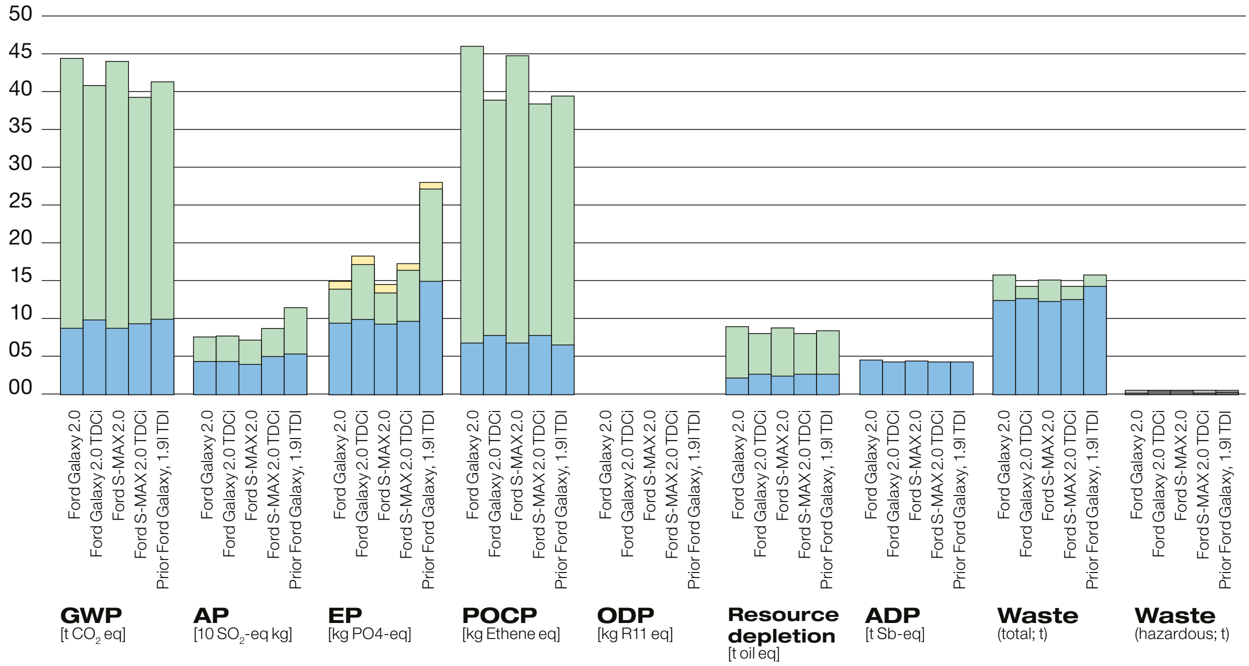
Figure 3-4: Matching between PSI calculation and expert LCA calculation - percentage of PSI values for GWP and POCP of all studied Ford vehicles based on Change Cut-off (CC) status related to verification values.



3.4.2 Other Life Cycle Impact Assessment Results (Verification study results only)

The impact assessment categories mentioned in chapter 3.2.3 are calculated based on the inventory results (chapter 3.3.5) for the studied Ford Galaxy and S-MAX versions (Figure 3-5).

Figure 3-5: Life Cycle Impact Assessment results for the studied Ford vehicles (See acronyms p.32)



3.4.3 Life Cycle Costing Result (Estimated)

Based on the inventory of cost (Table 3-6) and the discounting rules a kind of cost impact assessment is done showing the current value of the various cost through the life cycle (Table 3-7).

Table 3-7: Theoretical Life Cycle Costs (directional, no guarantee)

Theoretical cost along the product life cycle	**Ford Galaxy 2.0L gasoline**	**Ford Galaxy 2.0L TDCi with DPF**	**Previous Ford Galaxy 1.9L TDI**	**Ford S-MAX 2.0L gasoline**	**Ford S-MAX 2.0L TDCi with DPF**
Price €, options*	€ 27,475	€ 29,825	€ 29,700	€ 25,800	€ 28,150
Discounted use phase cost €* (3 years)	€ 8,938	€ 8,498	€ 8,707	€ 8,870	€ 8,389
Residual value after 3 years* (forecast)	60%	60%	56%	61%	61%
Discounted use phase cost €* (12 years)	€ 28,153	€ 26,767	€ 27,427	€ 26,424	€ 27,939
EOL cost (consumer,Ford)*	€ 0	€ 0	€ 0	€ 0	€ 0
Discounted Theoretical ELV profits* (operators)	Min -€ 59	Min -€ 67	Min -€ 65	Min -€ 60	Min -€ 68
Theoretical Cost of Ownership* (3 years)	€ 22,525	€ 23,248	€ 24,396	€ 21,412	€ 22,073
Theoretical LCC* (12 years)	€ 55,569	€ 56,525	€ 57,062	€ 52,164	€ 56,021

* Estimated value for one selected European market, no guarantee that the cost reflect market conditions.

3.5 Interpretation

3.5.1 Data Quality

Data quality will be reviewed predominantly in the following subchapters. Considering the data requirements from chapter 3.2.3, all data sources fulfill these requirements. The data sources themselves do not allow more detailed statistics about data quality indicators. However, for all vehicles significantly more than the required 95% of the materials are reflected in the data. In fact, for all materials at least average data for the material group has been used. For plastics, the data composition was not always clear (i.e. specific type of plastic). In this case, an average of all plastics has been used (mixed thermoplastic). This approximation covers roughly 3% for Galaxy 2l TDCi, 4% for Galaxy 2l I4, 5% for the previous Galaxy, and 2% for the S-MAX variants. In a sensitivity analysis the impact of this approximation has been evaluated, showing a minor impact (clearly below 1% for all impact categories except acidification potential).

Looking at all inputs and outputs of the LCI, 5.5% of them are based on measurements, 16.3 % on calculations, 58.2 % on literature, 16.1 % on estimates, and 3.9 % on unknown methods (partly confidential).

One example comparing the use of measured data (regarding the previous Galaxy model) versus the use of estimated data (regarding the new Galaxy model) is the leakage rate of R134a. The impact of this data has been specifically analyzed using the PSI tool in a sensitivity analysis. The result shows that this data has no significant impact in that a theoretical doubling of the leakage rate changes the life cycle GWP potential by 0.9 to 1 %.

3.5.2 Dominance Analysis

Based on the share of the various life cycle phases (see Figure 3-5), an identification of the environmentally dominating life cycle phases is possible. For the vehicles described, the use phase, including fuel production, accounts for most of the Life Cycle GWP and POCP – gasoline vehicles more than diesel vehicles and previous Galaxy (Euro 3) more than new Galaxy (Euro 4) – this is mainly fuel economy driven. However, the source of the emissions differ slightly. While both sources of emissions are significant, for GWP, the vehicle emissions dominate and for POCP, the fuel production emissions dominate. This is also the reason for the use phase's large share of the overall total resource depletion, which includes crude oil, that is between 70% for diesel and 75% for gasoline powered vehicles. However, the production phase is the dominant life cycle phase for total waste with 81 to 88% - mainly due to metal mining waste. Heavier diesel vehicles come in at the upper end of this range. The production phase also accounts for the greatest (96-97%) abiotic resource depletion potential (ADP) mainly precious metals. For the acidification and eutrophication potentials there is a rough 60:40 split between production (higher; mainly due to metal mining and production including precious metals) and use phase. The one exception to this is – due to the higher emissions of the previous Galaxy (Euro 3 with 0.5 g NOx/km instead of the new Galaxy's 0.25 g NOx/km), the use phase has a 56% share of the acidification potential. The relatively high material production impact is based on high SO_2 emissions in the production of several metals (sulphur in the ore) and the production of some plastics. The share of the end-of-life phase is for all studied impact categories below 5% but it should be noted that the metal recycling reduces the environmental impact of the production (see [6] for typical shares between total and net production. It is not this study's purpose to look at these aspects and impacts).

Table 3-8 provides input for the dominance analysis. It shows the main contributors to the investigated impact categories for the basic scenario. This information shows that a comprehensive check has been made as to whether all relevant emissions and variations are covered by the data sets used.

Table 3-8: Main contributing substance and material flows for the investigated impact categories

	Ford Galaxy 2.0L gasoline	**Ford Galaxy 2.0L TDCi with DPF**	**Previous Ford Galaxy 1.9L TDI**	**Ford S-MAX 2.0L gasoline**	**Ford S-MAX 2.0 l TDCi with DPF**
Acidification potential (AP, CML 2001)					
Nitrogen oxides	54.5%	68.4%	76.5%	54.7%	68.8%
Sulphur dioxide	44.3%	30.6%	22.8%	44.1%	30.3%
Eutrophication potential (EP, CML 2001)					
Nitrogen oxides	52%	63.1%	77.5%	52.5%	63.8%
COD (water)	36.2%	28.5%	29.6%	35.5%	27.8%
Total organic bond carbon	7.0%	5.2%	4.3%	7.1%	5.2%
Global warming potential (GWP 100 years, CML 2001)					
Carbon dioxide	96.9%	96.4%	96.7%	96.9%	96.4%

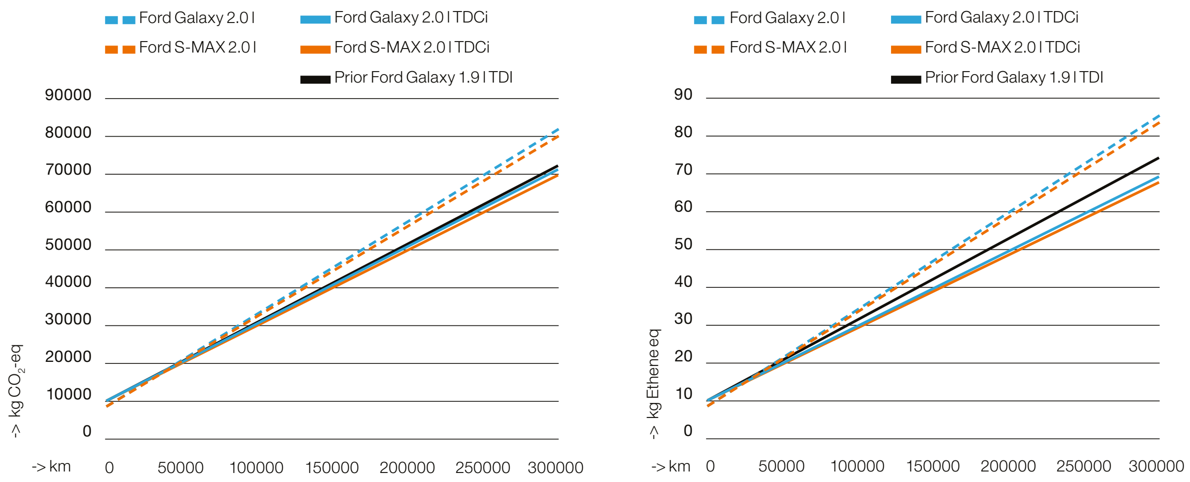
	Ford Galaxy 2.0L gasoline	Ford Galaxy 2.0L TDCi with DPF	Previous Ford Galaxy 1.9L TDI	Ford S-MAX 2.0L gasoline	Ford S-MAX 2.0 l TDCi with DPF
Ozone depletion potential (ODP, CML 2001)					
Halon (1301)	97.8%	96.9%	97.6%	97.8%	97.7%
Photochemical oxidant potential (POCP, CML 2001)					
Carbon monoxide	10.5%	7.1%	8.2%	10.7%	7.2%
NMVOC (unspecified)	81.5%	82.0%	79.1%	81.6%	82.0%
Nitrogen Oxides	2.6%	5.0%	7.7%	2.6%	5.0%
Waste (total)					
Sludge (oil exploration)	4.5%	4.5%	4.1%	4.5%	4.5%
Overburden (mining)	69%	67.6%	71%	69.2%	67.8%
Tailings (ore processing)	24.8%	25.9%	22.5%	24.6%	25.7%

Important Notes:
- Regarding POCP: the methodology suggests impacts for both NOx and VOCs. This is to reflect the ozone creation potential under both common sets of atmospheric conditions that lead to ozone creation: those where NOx is the limiting factor and those where VOCs are the limiting factor.
- For total waste, the amount of mining waste for precious metals (potentially too low) and for talcum (potentially too high) is seen as questionable, that is, the total waste figures for these should be interpreted with some care.
- For Ozone Depletion Potential, the low emissions of Halon can be predominantly traced back to potentially out-dated crude oil production process information about the use of Halon in [11] that should have been updated in the meantime. Due to this potential inaccuracy, ODP is not used for further interpretation.
- Regarding the economics (Table 3-7), the vehicle price represents 54 to 57% of the overall life cycle cost over 12 years for all vehicles. The share of the fuel cost is assumed to be below 50% of all use phase cost for these assumptions.

3.5.3 Monte-Carlo, Break-even and Scenario Analysis

The assumed mileage of the vehicles has been varied in the study. This factor's variation is crucial and it strongly influences those environmental impacts dominated by the use phase. Mileage in particular is a decisive factor for the comparison between vehicles with varying fuel economies (i.e. diesel vs. gasoline). While the production impacts of the diesel vehicles studied is slightly higher than those of the gasoline engines (especially because more metals are needed for a diesel engine, see Table 3-4), the overall environmental performance of the diesels is better when considering the environmental categories where the use phase dominates, GWP and POCP. Here, the reduced impacts during the use phase are more than make up for the additional production impacts (break-even is below 25,000 km for all vehicles – except for the previous Galaxy which needs a few thousand kilometers more). The differences between the gasoline vehicles are insignificant, while between the diesel engines there is a remarkable difference between the POCP of the new Galaxy compared to the previous one due to the higher tailpipe emissions of the older, Euro 3 Galaxy.

Figure 3-6 GWP and POCP of the Ford vehicles studied, considering a range of mileages.



Various Monte-Carlo analyses have been performed. One looked at the impact of changing the data for fuel economy by +/- 10% (due to uncertainties in actual air-conditioning consumption) and refrigerant leakage (new test procedures, etc.) and the fuel price by -10% to + 50%. The standard deviation across all vehicles is displayed in Table 3-9.

Table 3-9: Standard deviations based on Monte-Carlo Analysis looking at changes in use phase assumptions (1500 simulation runs)

Impacted Flow	Standard Deviation
Use phase cost (€)*	12.20%
Abiotic Depletion (ADP)	3.02%
Resource depletion (EUROMAT)	3.82%
Acidification Potential (AP)	1.57%
Eutrophication Potential (EP)	0.97%
Global Warming Potential (GWP 100 years)	3.85%
Photochem. Ozone Creation Potential (POCP)	3.07%
Waste (total)	1.67%
Waste (hazardous EWC)	3.17%
Primary Energy Demand	3.85%

* not discounted, use phase cost only – only covers 50% of the overall LCC. This is the highest standard deviation due to additional uncertainties (quantity and cost of fuels can vary)
All LCIA and LCI standard deviations refer to the full life cycle.

Obviously, the impact of changes affecting the use phase is less important for EP, AP and total waste while other indicators are more strongly affected. The sensitivity of use phase assumptions is highest for the calculated cost since additional uncertainties are covered (alongside varying fuel economy and leakage rates that affect both LCA and LCC, fuel prices also play a role).

Another source of uncertain base data is the material composition of the vehicles (no final data available during the product development, late changes, etc.). Besides changing fuel economy data, this has been one of the reasons for the differences in the results from start (KO) to the end of the development process (CC) – see Figure 3-3. The maximum difference resulting from these changes is up to 8% for GWP and POCP when considering also differences in the material production and painting/assembly data. This can be seen as a good surrogate for a significance criterion. That is, differences below 8% are not seen as significant for GWP and POCP – the same value as analyzed for total waste, but care is necessary due to the abovementioned data uncertainties based on dominance analysis. The respective values for AP, EP and resource depletion are up to 7% while the differences for ADP and hazardous waste are much higher (ADP= 10-15%) due to the very specific linkages to the various types of materials. These thresholds will be used to analyze the significance of differences.

Taking the required minimum threshold of 8% (GWP, POCP, total waste), 7% (AP, EP) and 15% (ADP), the following differences can be considered significant:

- Galaxy 2.0l TDCi is environmentally superior to Galaxy 2.0l in terms of GWP (break-even around 20,000km mileage but “significant break-even” (i.e. min. 8% better) after 82,000 km), POCP (“significant break-even” after 37,000 km) as well as AP and EP (“significant break-even”[2] already at 0 km)
- Galaxy 2.0l TDCi is environmentally superior to the previous Galaxy 1.9l TDI in terms of POCP (break-even 70,000km; “significant break-even” [2] at around 450,000 km), AP and EP (“significant break-even” [2] already at 0 km)
- S-MAX 2.0l TDCi is environmentally superior to S-MAX 2.0l in terms of GWP (break-even around 20,000km mileage but “significant break-even”[2] (i.e. min 8% better) after 82,000 km), POCP (“significant break-even” [2] after 37,000 km) as well as AP and EP (“significant break-even” [2] already at 0 km)

- All new developed vehicles result in less total waste compared to previous Galaxy (“significant break-even” [2] below 100,000 km).

Considering the economic aspects, there are huge uncertainties around end-of-life profits [4], but their overall impact is negligible (below 0.2%) of the total LCC. More significant is the uncertainty for the real insurance cost (highly dependent on personal contracts), real maintenance cost (theoretical values are worst case assumptions), fuel consumption cost (see Table 3-9) and mileage. Economic break-even conditions can be deduced from the following:

- Diesel versions are economically preferable beyond 255,000 km over 12 years for the assumed yearly fuel, insurance and maintenance cost or around 200,000 km with cost at 50% of those assumed in the main scenario.
- The new diesel Galaxy version is economically preferable beyond 250,000 km (S-MAX around 240,000 km) over 12 years for the assumed yearly fuel, insurance and maintenance cost but an interest rate of 4%.
- The new diesel versions are economically preferable beyond 160,000 km over 12 years for the assumed yearly fuel, insurance and maintenance cost but an interest rate of 4% and 50% higher fuel prices than assumed in the main scenario.

The elasticity of results is larger for the LCC calculations than for the LCA calculations (compare [4]) as there is an additional set of assumptions for the LCC calculations – i.e. type of insurance cost, fuel prices and interest rates – that represent additional sources of uncertainty while these aspects have no impact on the LCA result.

[2] “Significant break-even“ refers to that mileage where one vehicle is significantly better than the other vehicle, i.e. in this case the environmental impact potentials are lower by at least 8 % (GWP, POCP) respectively 7 % (AP, EP) – see acronym listing chapter 8.

Figure 3-7. Discounted Life Cycle Cost for a period of 12 years (full, 50% lower insurance/maintenance cost) for the studied Ford vehicles considering a range of mileages.

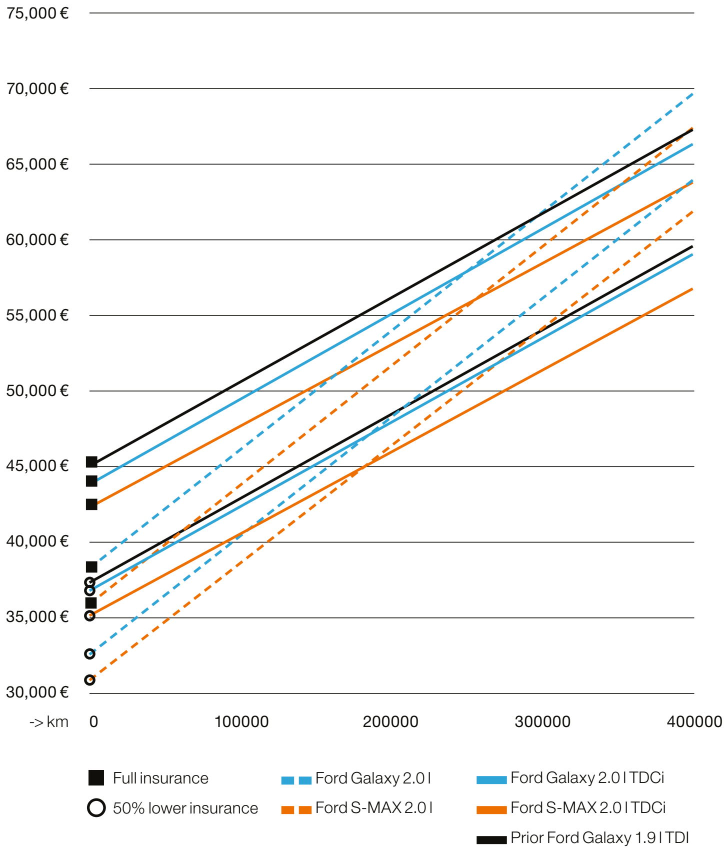
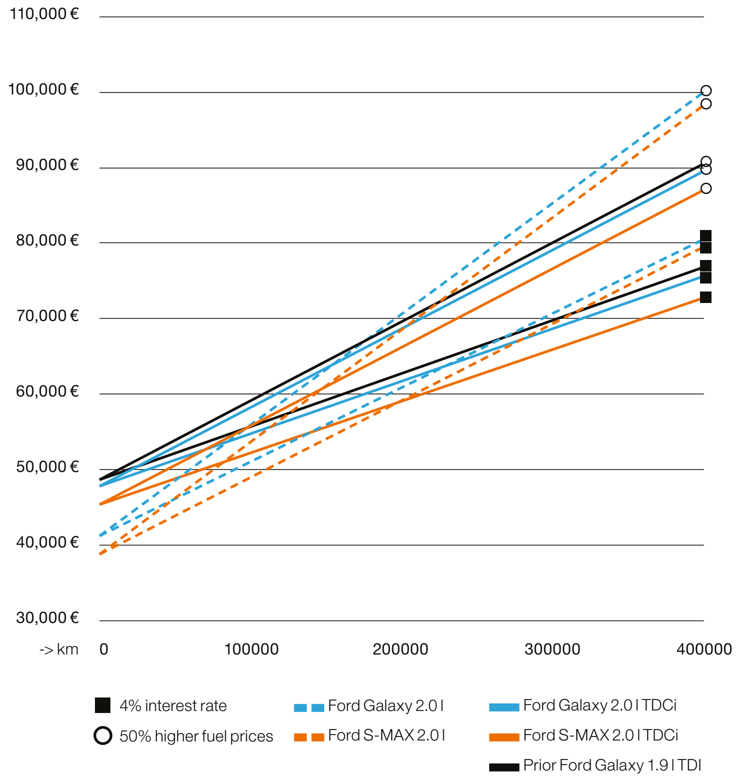


Figure 3-8 Discounted Life Cycle Cost for a period of 12 years (interest rate of 4 instead of 8%, 50% higher fuel prices) for the studied Ford vehicles considering a range of mileages.



3.5.4 Conclusions

Based on the Life Cycle Inventory, Impact Assessment and the sensitivity analysis, the following conclusions can be reached:

- The calculations performed by non-LCA experts in Product Development (using the simplified spreadsheet tool) are in line with those calculated by the LCA expert (using an expert LCA tool). The differences, less than 2%, are insignificant, see Figure 3-4, and the non-expert calculations can be used for PSI in parallel to the product development process.
- Ford Galaxy 2.0l TDCi is environmentally superior to Ford Galaxy 2.0l in terms of GWP (beyond 82,000 km), POCP (beyond 37,000 km) as well as AP and EP (at any mileage).
- Ford Galaxy 2.0l TDCi is environmentally superior to the previous Ford Galaxy 1.9l TDI in terms of POCP (beyond 450,000 km), AP and EP (at any mileage).
- Ford S-MAX 2.0l TDCi is environmentally superior to Ford S-MAX 2.0l in terms of GWP (beyond 82,000 km), POCP (beyond 37,000 km) as well as AP and EP (at any mileage).
- All new developed vehicles result in less total waste compared to the previous Galaxy (mileage beyond 100,000 km).
- Diesel versions are economically preferable beyond 255,000 km over 12 years for the assumed yearly fuel, insurance and maintenance cost and beyond around 200,000 km at 50% of the cost assumed in the main scenario.
- The new diesel Ford Galaxy version is economically preferable beyond 250,000 km (Ford S-MAX around 240,000 km) over 12 years for the assumed yearly fuel, insurance and maintenance cost but an interest rate of 4%
- The new diesel versions are economically preferable beyond 160,000 km over 12 years for the assumed yearly fuel, insurance and maintenance cost but an interest rate of 4% and 50% higher fuel prices than assumed in the main scenario.

4 Ford Galaxy and S-MAX Product Sustainability Index

4.1 Scaling

Traditionally, sustainability indicators are shown in a radar diagram. The scaling of the eight axes has been chosen according to the following principles:

- The higher the number the better.
- The scaling refers to the passenger vehicle range of Ford of Europe without SUVs - Sub-B (Ford Ka) through V (Ford Galaxy). By doing so, all Ford of Europe vehicles can be compared using the same scaling. Some of the different functionalities (mobility capability, safety) are reflected by the different indicators. NB – The varying levels of comfort are not considered in this analysis. That means a lower PSI score does not allow the interpretation of preferences since not all relevant aspects could be considered.
- For the life cycle related indicators, the lowest figure (0%) represents the Ford of Europe vehicle with the highest environmental and cost impacts (worse vehicles by other companies are not considered a suitable benchmark).
- 80% is set at the theoretically best in industry vehicle in the Sub-B to V segment.
- 100% is going beyond the current best-in-industry level – leaving room for improvement towards sustainability.

Table 4-1: Scaling of PSI indicators

Indicator[1]	0% scaling	80% scaling	Vehicles
Life Cycle Global Warming	65.587 kg CO_2-eq	17.500 kg CO_2-eq	Previous Galaxy 2.8l V6 autom. / 2002 vehicle[2]
Life Cycle Air Quality	58.3 kg Ethene-eq	22.9 kg Ethene-eq	Previous Galaxy 2.8l V6 autom. / 2002 vehicle[2]
Sustainable Materials	0%	14.9%	Worst case / best case assumptions[3]
Substance Management	6 points	12,5 points	See below
Drive-by-Noise	82 dB(A)	65 dB(A)	Best / Worst homologated value by KBA
Safety	see below[5]	see below[5]	Several vehicles
Mobility Capability	0.216	0.7	See below
Theoretical Life Cycle Cost[4]	€35,508	€10,984	Previous Galaxy 2.8l V6 automatic / Ka Student

[1] calculated using the same assumptions, calculation rules and tools for all vehicles. Life Cycle data cannot be compared to other studies due to varying sets assumptions.
[2] "Best" performing vehicle sold in Europe in 2002 when the PSI was piloted (no longer on the market)
[3] Worst case assumption: 0 kg natural fibers, 0 kg recycled material
Best case assumption: 15.3 kg natural fibers (best competitor), 25.1 kg actual used non-metallic recycled materials (Ford Mondeo).
[4] 3 years of ownership plus vehicle price (representing the up-stream cost) minus the residual value (representing the down-stream cost aspects). Ford Motor Company does not guarantee that the cost reflect actual market conditions.
[5] Internal, complex safety indicator including EuroNCAP rating.

Substance Management:
For restricted substances – in particular those substances listed in the “Global Automotive Declarable Substance List” (http://www.gadsl.org) - the following methodology and scaling is used:

Table 4-2: Criteria for the PSI indicator “Substance Management” (max 15 points)

Substance Management Criteria	Points
Company related rating (max 10 points)	
Substance Management List exist	0 = no or 1 = yes
Coverage of RSL	1 = limited (e.g. only legal status), 2 = GADSL (www.gadsl.org), or 3 = covers automatically all carcinogenic, other issues e.g. by listing also effect groups
Reinforcement of RSL	0 = none, 1 = only for key components, 2 = IMDS equivalent, or 3 = Reinforcement in case of non-complying suppliers
Performance of substance risk management	0 = no focus, 1 = at best legal compliant, 2 = proactive, or 3 = prepared for new EC chemical policy
Vehicle related rating (max 5 points)	
Smell rating	0 = unpleasant smell, 1 = not unpleasant smell
Clean Compartment Features (adding all features covered in the vehicles)	0 = none, 1 point = pollen filter, 1,5 points = PremAir® (trademark of Engelhard) equivalent, 2 points incoming air completely filtered (activated carbon), 1 point = EcoTex label, 2 point = complete interior third party labeled covering allergenic aspects

The 80% best-in-industry value is defined by Ford Focus and Ford Focus C-MAX, the vehicles with the first third-party certified, allergy-tested interior.

Mobility Capability
Mobility capability is an indicator that will soon undergo further development. The necessary data for an extension are not currently available at all gateways of the vehicle development process. In the interim, the indicator reflects the relationship between:

- The sum of a weighted number of seats and luggage compartment to reflect the capacity to carry passengers and luggage. The weighting factor is 1 for the first and second seat, 0,6 for the third, 0,36 for the fourth, 0,216 for the 5th, 0,1296 for the 6th, 0,07776 for the 7th, 0,046656 for the 8th and 0,027994 for the 9th seat. This factor of 60% for each additional seat beyond the first two seats is reflecting the declining average usage of seats.
- Shadow area (length x width of vehicle including exterior mirrors) to reflect the necessary parking area.
- Multiplied by 1 (none) or 1,2 (mobility service components included that help drivers to by-pass traffic jams), 1,6 (mobility service components that direct drivers to free parking lots and help in intermodality)

The assumption for the 80% value is for a vehicle with a shadow area of 3,75 m^2, 2 seats and a 180 l luggage compartment. The worst case is based on a shadow area of 9,94 m^2, 2 seats and a 140 l luggage compartment.

4.2 Ford Galaxy and S-MAX PSI Results

The resulting PSIs for Ford Galaxy and S-MAX are based on the abovementioned methodology and scaling, the engineering and technical data of the studied vehicles, the Life Cycle study as reviewed by an independent, external LCA expert as well as the TÜV certified, allergy-tested interior of the new Ford Galaxy and S-MAX.

These figures are scaled by the values provided earlier and transferred in a radar diagram to enable a visual assessment of the areas of improvement over the previous Galaxy and the relative performance compared to the best-in-industry levels for all passenger vehicle segments. The new Galaxy and S-MAX show significantly improved performance regarding the use of sustainable materials, restricted substances and safety. Looking at the same engine types, the affordability (Life Cycle Cost) has been also improved based on the assumptions. Thus, indicators from all three dimensions of sustainability have been improved.

Table 4-3: PSI indicator base data of Ford Galaxy and S-MAX

Indicator	**Ford Galaxy 2.0L gasoline**	**Ford Galaxy 2.0L TDCi with DPF**	**Previous Ford Galaxy 1.9L TDI**	**Ford S-MAX 2.0L gasoline**	**Ford S-MAX 2.0L TDCi with DPF**
Life Cycle Global Warming [t CO_2-eq](a)	44 tons	40 tons	41 tons	43 tons	39 tons
Life Cycle Air Quality [kg Ethene-eq](a)	45 kg	37 kg	39 kg	45 kg	37 kg
Sustainable Materials (note: figures may change)	Approx 18 kg non-metallic recyclates and natural fibers		Approx 1 kg non-metallic recyclates and natural fibers	Approx 18 kg non-metallic recyclates and natural fibers	
Substance Management(b)	Substance management, TÜV tested pollen filter efficiency and allergy-tested label		Substance management and pollen filter	Substance management, TÜV tested pollen filter efficiency and allergy-tested label	
Drive-by-Noise	72 dB(A)	71 dB(A)	73 dB(A)	72 dB(A)	71 dB(A)
Safety	Significant improvement (c)		Reference(d)	Significant improvement(c)	
Mobility Capability	10,4 m^2, 7 seats, 435l		9,9 m^2, 7 seats, 330l	10,25 m^2, 5 seats, 1171l	
Theoretical Life Cycle Cost (e)	Approx. € 22,500	Approx. € 23,200	Approx. € 24,400	Approx. €21,400	Approx. €22,100

[a] based on PSI calculations verified by an independently reviewed LCA according to ISO 14040; 1 t = 1000 kg
[b] based on an independent TÜV certification, certification number AZ 137 12, TUVdotCOMID 0000007407
[c] including Euro NCAP savety rating: 5 stars for adult occupant protection, 4 stars for child protection and 2 stars for pedestrian protection
[d] including Euro NCAP savety rating: 3 stars for adult occupant protection, 2 stars for pedestrian protection
[e] 3 years Cost of Ownership including residual value, no guarantee

Ford Product Sustainability Index

Figure 4-1 Ford Product Sustainability Index of Ford Galaxy

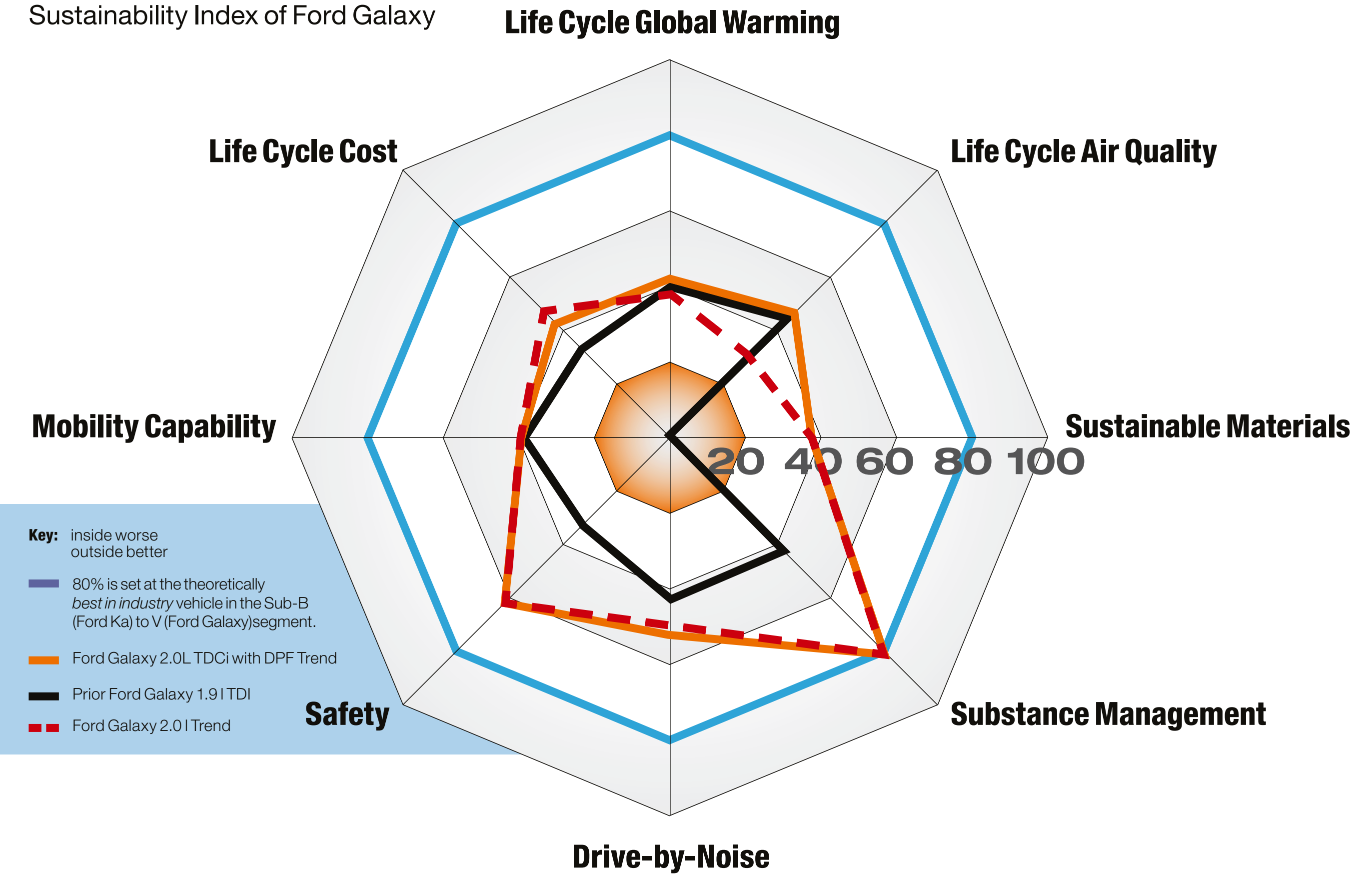
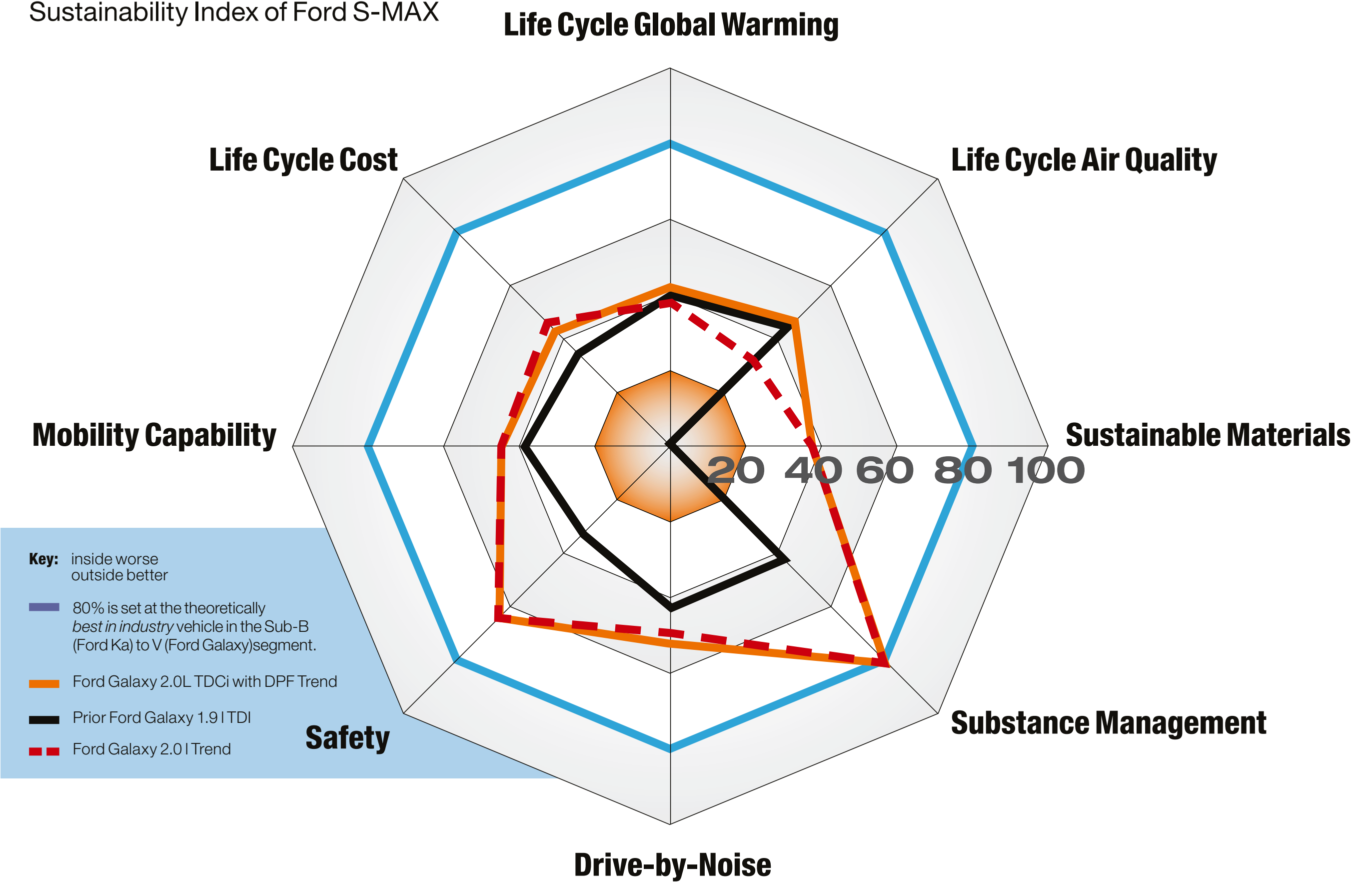


Figure 4-2 Ford Product Sustainability Index of Ford S-MAX



5 References

[1] UN: Report of the World Commission on Environment and Development – Our Common Future (the Brundtland report) 1987 http://www.sdgateway.net/introsd/definitions.htm

[2] William Clay (Bill) Ford, Jr.: speech at the 5th Annual Greenpeace Business Conference in London 5th of October 2000. http://www.crowley-offroad.com/greenpeace__bill_ford.htm

[3] Schmidt, W.-P.; Sullivan, John: Weighting in Life Cycle Assessments in a Global Context. International Journal of Life Cycle Assessment 7 (1), pp 5 - 10 (2002)

[4] Schmidt, W.-P.: Life Cycle Costing as Part of Design for Environment – Environmental Business Cases. In: International Journal of LCA 8 (3), 2003. pp 167-174 DOI:

[5] [5] IKP, PE: GaBi 4 Software-System for Life Cycle Engineering. Copyright, TM. Stuttgart, Echterdingen

[6] Schmidt WP, Dahlqvist E, Finkbeiner M, Krinke S, Lazzari S, Oschmann D, Pichon S, Thiel C (2004): Life Cycle Assessment of Lightweight and End-of-Life Scenarios for Generic Compact Class Passenger Vehicles. Int J LCA 9 (6), pp 405 - 416

[7] Society of Environmental Toxicity And Chemistry (SETAC): Environmental Life Cycle Costing – submitted to SETAC publications as the results of the Life Cycle Costing Working Group of SETAC Europe. 2006

[8] International Material Data System http://www.mdsystem.com

[9] Leiden University Institute of Environmental Sciences (CML): Impact assessment Dec 2001.xls, version 2.5, download: http://www.leidenuniv.nl/cml/lca2/index.html

[10] International Organization for Standardization – ISO (2000): Environmental management – Life cycle assessment – Life cycle impact assessment. European standard EN ISO 14042, Geneva

[11] IKP, PE: GaBi 4 Databases for Life Cycle Engineering. Copyright, TM. Stuttgart, Echterdingen - including up-dates for electronics, textiles, paint, special plastics etc.

[12] European Aluminum Association (2000): Environmental profile report for the European aluminum industry April 2000, EAA, Brussels

[13] International Magnesium Association (2001): “Pidgeon Process of Gold River Magnesium Corporation of Ningxia” Presentation of Mr. Li at the World Magnesium Conference Brussels, May 2001. Document 4 dated 19.08.2001, IMA: Brussels

[14] International Magnesium Association (2001): LCI data Magnesium.xls. Document 6 dated 19.08.2001, IMA: Brussels

[15] European Integrated Pollution Prevention and Control Bureau (2000): Reference Document on Best Available Techniques in the Non Ferrous Metals Industries. Brussels: May 2000

[16] Boustead I (1997): Eco-Profiles of the European plastics industry, APME, PWMI: Brussels

[17] Bundesamt für Umwelt, Wald und Landschaft (1998): Ökoinventare für Verpackungen. Schriftreihe Umwelt Nr.250. BUWAL: Bern

[18] Continental AG (1999): Produkt-Ökobilanz eines PKW-Reifens. Data provided as GaBi 3 data set. Continental AG: Hannover

[19] Öko-Institut: Bilanzierung der Umweltauswirkungen bei der Gewinnung von Platingruppen-Metallen für Pkw-Abgaskatalysatoren, Freiburg 1997

[20] NSW department of primary industries: Prospects for Silicon Carbide Production.

[21] Schmidt, W.-P.; Beyer, H.-M.: Life Cycle Study on a Natural Fiber Reinforced Component. S. 251-258, Proceedings of the Total Life Cycle Conference of SAE in Graz, Dec 1-3 1998

[22] BMW AG, Daimler-Benz AG, Fiat, Ford-Werke AG, Adam Opel AG, Porsche, PSA-Peugeot-Citroën, Renault, Rover Group Ltd, Volkswagen AG, AB Volvo (1998): Life Cycle Analysis – Data and Methodologies Phase 2, EUCAR Project R3. Final Report, EUCAR: Brussels

[23] Fleischer, G (Ed.): Eco-Design - Effiziente Entwicklung nachhaltiger Produkte mit euroMat. Springer: Berlin, Heidelberg, 2000

[24] Schmidt, W.-P.; Duranceau, Claudia; Sullivan, John: Sustainable Materials in Automotive Applications. Proceedings of the 2002 Environmental Sustainability Conference and Exhibition, SAE 2001-01-3762, pp 393 – 398

[25] Quella, F.; Schmidt, W.-P.: Integrating Environmental Aspects into Product Design and Development. The new ISO TR 14062. In: International Journal of LCA 8 (2), 2003

6 Acronyms

A/C	Air-Conditioning System
Air Quality Potential	See POCP
ADP	Abiotic Resource Depletion Potential - Issue of sustainable availability of materials
AP	Acidification Potential - Issue of acid rain leading e.g. to fish population losses in certain lakes
BUWAL	Swiss Environmental Agency
CC	Gateway in product development: Change Cut-off
COD	Chemical Oxygen Demand
CoO	Cost of Ownership
DPF	Diesel Particulate Filter
EuroNCAP	European New Car Assessment Program http://www.euroncap.com/
EFR	European Ferrous Recovery & Recycling Federation
EOL	End-of-Life
EP	Eutrophication Potential - Issue of an excessive addition of nutrients to the environment affecting e.g. biodiversity
Euro 3 / 4	European Emission standards
EWC	European Waste Catalogue
FoE	Ford of Europe
GADSL	Global Automotive Declarable Substance List (http://www.gadsl.org)
GWP	Global Warming Potential (measured as kg CO_2-equivalent emissions) - Issue of climate change
HFC	Hydrofluorocarbon (see R134a below)
IISI	International Iron and Steel Institute
IMA	International Magnesium Association
IMDS	International Management Data System http://www.mdsystem.com
ISO 14040	International Standard about Life Cycle Assessment
KO	Gateway in product development: Kick-off
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LIRECAR	LCA study Light and Recyclable Car [6]
NOx	Nitrogen Oxides
MSI	Ford of Europes's Manufacturing Sustainability Index
ODP	Ozone Depletion Potential - Issue of reducing the stratospheric ozone layer protecting life on earth from harmful UVB sun-light
PA	Gateway in product development Program Approval
PD	Product Development
POCP	Photochemical Creation Potential (Summer Smog; measured as kg Ethene-equivalent emissions covering for example NOx, VOC etc.)
PP	Polypropylene (plastic)
PR	Gateway in product development Program Readiness
PSI	Ford of Euorpe's Product Sustainability Index
R134a	Refrigerant of air-conditioning (1,1,1,2-Tetrafluorethan)
RESI	Responsible Employer Sustainability Index
SC	Gateway in product development: Strategic Confirmation
SETAC	Society of Environmental Toxicology And Chemistry
SiC	Silicon Carbide
SO2	Sulfur Dioxides
VI	Vehicle Integration
VIAQ	Vehicle Interior Air Quality
VOC	Volatile Organic Compounds
WVM	German Association of Metal Industries

7 Appendix

Additional Dominance and Sensitivity Analysis

In addition to the analysis in the main body of this document, an analysis of the contributing processes was undertaken to better understand the life cycle model and the underlying data (Table 9-1). Please note that the percentages reflect the percentage of the process mentioned, not the relative share (due to credits these numbers can differ from those shown in Life Cycle Phase related dominance analysis).

Table 9-1: Main contributing processes to in investigated impact categories

	Ford Galaxy 2.0L gasoline	Ford Galaxy 2.0L TDCi with DPF	Previous Ford Galaxy 1.9L TDI	Ford S-MAX 2.0L gasoline	Ford S-MAX 2.0L TDCi with DPF
Acidification potential (AP, CML 2001)					
Fuel production	51%	31%	21.5%	51.4%	30.9%
Vehicle tailpipe emissions	18.5%	43%	58.7%	18.8%	43.5%
Steel production (sum of all alloys)	12.6%	10.5%	9.8%	12.5%	10.3%
DPF production	0%	10.7%	0%	0%	10.9%
Aluminium prod. (sum of all alloys)	9.5%	8.8%	5.5%	9.6%	8.9%
Copper production (sum of all alloys)	5.8%	5.1%	3.4%	5.5%	4.8%
Ozone depletion potential (ODP, catal., CML 2001)					
Fuel Production	96.9%	97.7%	95.9%	96.9%	96.3%
Global warming potential (GWP 100 years, CML 2001)					
Tailpipe emissions	78.8%	78.8%	78.3%	77.1%	78.9%
Fuel production	12.3%	10.3%	10.2%	13.7%	10.3%
Eutrophication potential (EP,CML 2001)					
Steel production (sum of all alloys)	38.5%	30.5%	31.6%	37.8%	29.8%
Fuel production	33.3%	21.2%	13.3%	33.7%	21.2%
Vehicle tailpipe emissions	15.8%	38.4%	48%	16.2%	39.1%
Photochemical oxidant potential (POCP, CML 2001)					
Fuel production	69%	73.4%	69.9%	69%	73.4%
Vehicle tailpipe emissions	23.3%	17%	22.1%	23.6%	17.2%

	Ford Galaxy 2.0L gasoline	Ford Galaxy 2.0L TDCi with DPF	Previous Ford Galaxy 1.9L TDI	Ford S-MAX 2.0L gasoline	Ford S-MAX 2.0L TDCi with DPF
Abiotic depletion potential (CML 2001) *** without in-/output balancing, i.e. showing in the gross share**					
Catalytic Converter	869%*	907%*	1035%*	879%*	919%*
Recycling of Cat. Converter	(849%)*	(885%)*	(1010%)*	(858%)*	(898%)*
DPF	-	195%*	-	-	189%*
Recycling of DPF	-	(190%)*	-	-	(185%)*
Fuel production	73.1%	67.1%	68.3%	73.1%	66.9%
Total waste					
Steel production (sum of all alloys)	46.0%	52.6%	67.7%	45%	51.8%
Fuel production	44.3%	34.6%	31.7%	44.3%	34.6%
Copper (sum of all alloys)	20.3%	24.8%	21.8%	19%	23.4%
Aluminium	12.6%	16.2%	13.1%	12.6%	16.4%

Where materials are listed as having a significant share of the overall result, it does not mean that these materials have specific issues in these areas. It may in some cases indicate that:

- The weight-related share of these materials is higher than of others.
- In some cases it can be traced to data that might need to be updated, for example, new data for copper are expected to be presented soon by its materials association, for steel there might be an issue with a specific GaBi data set (for the process "Steel billet (X12CrNi17 7)" that is used.) These data uncertainties are acceptable for this study because its purpose is not to identify emissions sources and because the quantities of these materials used are quite similar in all the compared products. However, no conclusions can be drawn related to the material composition of the vehicles.

For aluminum, a 50% secondary share is assumed for casted parts in line with the underlying study [6]. Statistical average data confirm this (WVM statistic – the metal industry association reports a value of 51 % for 2004). However, aluminum castings in automotive applications such as transmission housings, cylinder heads etc. are often linked to higher shares of secondary aluminum (95-99% according to one aluminum supplier). Therefore, the impact of the 50% assumption has been checked (Table 9-3). The impact on the newer models is higher since the cast aluminum content is higher. The impact is in particularly high on acidification and total waste. This means that the break-even points might actually be at shorter mileages than suggested in the main text (increased estimated impacts for new models than for the previous model). However, to err on the side of caution, no change has been made to the break-even figures (general statistics back-up the 50% percentage even if it is too low for the automotive sector).

Table 9-2: Change in result if 100% secondary cast aluminum is assumed

	Ford Galaxy 2.0L gasoline	Ford Galaxy 2.0L TDCi with DPF	Previous Ford Galaxy 1.9L TDI	Ford S-MAX 2.0L gasoline	Ford S-MAX 2.0L TDCi with DPF
Abiotic Depletion [kg Sb-Equiv.]	-0.67%	-0.86%	-0.26%	-0.67%	-0.87%
Resource depletion [kg Crude oil-Equiv.]	-0.81%	-1.14%	-0.42%	-0.83%	-1.17%
Primary Energy Demand [MJ]	-0.81%	-1.81%	-0.53%	-1.28%	-1.84%
Acidification Potential (AP) [kg SO2-Equiv.]	-5.23%	-5.69%	-1.24%	-5.36%	-5.80%
Eutrophication Potential [kg Phosphate-Equiv.]	-1.19%	-1.30%	-0.25%	-1.23%	-1.34%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	-1.42%	-2.02%	-0.62%	-1.44%	-2.05%
Ozone Layer Depletion Potential (steady state) [kg R11-Equiv.]	-0.83%	-1.21%	-0.36%	-0.84%	-1.23%
Photochem. Ozone Creation Potential [kg Ethene-Equiv.]	-1.04%	-1.64%	-0.47%	-1.06%	-1.67%
Waste (hazardous) [kg]	-0.38%	-0.50%	-0.15%	-0.39%	-0.51%
Waste (total) [kg]	-4.88%	-6.71%	-1.80%	-4.95%	-6.81%

8 ISO 14040 External Critical Review of Vehicle Options (full independent report)

8.1 Executive Summary

Based on the documentation provided by Ford, as well as the general methodology employed and part of the data set from a previous study (LIRECAR) for which the chairman of the present review panel was a member of the evaluation, the following statements have been formulated.

Ford has undertaken, within the specifications of ISO 14040, a cradle to grave LCA with an expert panel review a posteriori. The study has been appropriately defined, and reviewed, in accordance to ISO 14040 (ref paragraph 7.3.3). The sources and quality of the data, as well as its interpretation are of a very high level. The development of a reduced list of environmental indicators, as part of Ford's PSI, is valid and appropriate. The conclusions are supported by the data. The use of sensitivity, dominance and Monte Carlo analyses on key elements is well done. According to the reviewers' opinion the LCA-part of the study is consistent with ISO 14040. The two Life Cycle Costing (LCC) studies, which are part of Ford's evaluation, are not covered by ISO 14040ff. This work, for which an international standard is not yet available, can, therefore, be considered as an environmental life cycle costing, from the first user's perspective. This adds valuable information to the comparative assessment of the models investigated. The same is true for the societal aspects covered in this study which aims, within the limits of present-day methodology, to provide a full sustainability assessment.

Prof. David Hunkeler and Prof. Walter Kloepffer
March 21st, 2006

Note by editor: "Prof. David Hunkeler is the chairman of SETAC Europe's Working Group on Life Cycle Costing and Director of AQUA+TECH Specialties SA. Until 2002 he was Professor at the Swiss Federal Institute of Technology Lausanne. David was the lead author on a book on life cycle management and has developed the LCM programs for multinationals in both Europe and North America. He has over 200 publications and several patents as well as being honored for innovation and entrepreneurship. His firm was selected as the top environmental firm in Europe in 2002. Prof Walter Klöpffer is the editor-in-chief of 'The International Journal of Life Cycle Assessment' since 1995. He is professor at the Johannes-Gutenberg-University in Mainz."

8.2 Categorization of the Ford Study and the review process

Ford has undertaken, within the specifications of ISO 14040 (1997), a critical review a posteriori. Since an accompanying review, as suggested by SETAC, is not obligatory according to ISO 14040, the procedure chosen is in accordance with the international standard.

ISO 14040 states that while critical reviews of an LCA are optional, in general, for comparative assertions that are disclosed to the public a critical review shall be conducted. It should be noted that the term "shall" is an extremely strong one in the ISO context and means "must". ISO 14040 specifies that paragraphs 7.3 should be consulted in determining the review options. Paragraphs 7.3.1 and 7.3.2 refer to reviews which will not be used for comparative assertion and are, therefore, not applicable to Ford's LCA.

The majority of ISO 14040 critical reviews, approximately two-thirds, are carried out according to ISO 14040 7.3.3, which involves an expert panel, as is the present case for the Ford LCA. The members of the expert panel must be familiar with the entire documentation provided though it is normal that individual members would focus on certain aspects. This has been followed in the Ford review. Review panels typically comprise two-to-three experts and Ford's specification of two experts is, therefore, within this range. Therefore, Ford's selection of review under 7.3.3 is appropriate.

As a comment it should be noted that 7.3.3, according to ISO 14040 (1997), requires only a panel though does not say anything about the size. Evidently, two is the minimum number for a panel, as opposed to a single expert (7.3.2). ISO FDIS 14040 (2006) prescribes a minimum of three panel members for 7.3.3, though this new standard, which will supersede the present one, is not yet enacted. Therefore, the 1997 standard remains valid and a panel of two is appropriate.

8.3 Compliance of the Ford Study with ISO 14040-43

ISO 14040 asks reviewers to examine if the methods used to conduct the LCA are scientifically valid, if the data used is appropriate in relation to the goal and scope, if the interpretations reasonably reflect the limitations identified and if the report is transparent. The discussion of compliance with ISO 14040 will, therefore, be sub-divided to reflect these points.

8.3.1 Compliance with Standard Goal and Scope

It is relevant to note that the international ISO standard “does not specify requirements on the goals or uses of LCA”. Therefore, a critical review can “neither verify nor validate the goals that are chosen for an LCA, or the uses to which LCA results are put”. Nonetheless, the goal and scope must be part of the original definition and this should be reflected in the report. The reviewers can, therefore, comment that, in the Ford LCA the goal and scope are defined in Section 2.2.1. This section specifies the goal and functional unit for Ford’s “cradle to grave” LCA. The system boundaries of this study are correctly defined from the raw materials extraction down to the end-of-life phase and, thus, define a true cradle-to-grave LCA.

The goal to “support internal product development” as well as examining the life cycle performance and integrating cost with environment is appropriate and reasonable.

The Functional Unit is defined, in the second paragraph, in a completely appropriate manner. The fact that data are, in part, derived from a “complete teardown” of the vehicle is an excellent point for validation and certainly goes beyond the requirements of ISO 14040 and adds significant credibility to the LCA.

8.3.2 Life Cycle Inventory, Data Quality, Data Accessibility

8.3.2.1 Data Quality

Overall the quality of data and its transparency, as well as the extent of references seems appropriate for the study. The data seems, as stated, to meet the requirements for geographical coverage and the selection of databases is appropriate.

The focus on elementary flows, as well as the selection of key emissions, waste and resources is backed up by a detailed study (Ref 6) and is reasonable. Furthermore, the discussion of the scaling of PSI indicators in Table 3-1, though not required by ISO 14040, is excellent.

Section 2.5.1 itemizes, specifically, the sources of data and fraction from literature (58.2%), calculations (16.3%), estimates (16.1%), measurements (5.5 %) and confidential methods (3.9%). This balance is appropriate. The use of mixed thermoplastics as an average is necessary as the unknown plastics remain a significant mass. To ensure that this assumption does not change the results of the LCA, the authors have carried out a sensitivity study assuming the unknown plastic to be various blends, at the request of the reviewers. This indicated that the results of the LCA are insensitive to the plastics composition and that Ford’s assumption was quite reasonable. Given that data were not available for cordierite (catalytic converter) that the review panel requested a sensitivity analysis element. The resulting dominance analysis indicated that the influence of the proxy data used for cordierite is quite low and that these data might represent a worst case assumption when looking at the temperature involved. Therefore, the overall result is not likely to be sensitive to the data related to the catalytic converter. The data presented in the Appendix is, otherwise, appropriate.

There was some discussion between the critical review panel and the commissioner about the quality of those data relevant for the suppliers. These contribute a large fraction of the parts which finally make up the entire car and should – in principle – contribute specific data regarding, for example energy use and emissions. These data are difficult to obtain for reasons of confidentiality and, furthermore, suppliers may change during the production of a car-model. It seems, therefore, reasonable to use average data covering the supplied parts, as was done in this study.

As communicated by Dr. Wulf-Peter Schmidt – Ford Sustainability, Ford’s supply chain management requires that the supplier production sites (as a prerequisite to become a supplier) have to be certified according to ISO 14001 – as are Ford’s production sites world-wide. This ensures that these plants have an environmental management system.

8.3.2.2 Accessibility to Original Data

The accessibility to the original data was not, per se, granted, nor could it be in a review of such limited scope, though all data post-LIRECAR has been provided. However, the Chairman of the review panel asked for supplemental evaluations to evaluate the Ford LCA with similar LCAs he has reviewed and carried out in the immediate past (e.g. Trucks). Given this, it was decided to request from Ford a sensitivity analysis on the loss rate of refrigerant. Ford, and in particular Dr. Schmidt, carried out such a sensitivity analysis, specifically looking at the effect of doubling the refrigerant loss assumption. Furthermore, Prof. David Hunkeler chairman of the review panel was a member of the three-person review of LIRECAR, for which some of the baseline data of the present Ford evaluation were derived. He has, therefore, meticulously evaluated the one hundred plus pages of inventory data provided by the LIRECAR consortium and is convinced that the data, software used to analyze the information and assumptions made are reasonable and consistent with similar LCAs carried out for automobiles or, in general, products for which the use phase dominates.

The references are appropriate.

8.3.3 Life Cycle Impact Assessment (LCIA)

The LCIA, has been carried out in accordance to accepted methods, employing standard data, and using common tools. The overall approach is also acceptable.

8.3.3.1 General Comments on LCIA

LCIA, according to ISO 14042 (2000), consists of several steps, both mandatory and optional:

- Selection of impact categories, category indicators and characterization models (mandatory)
- Assignment of LCI results (classification, mandatory)
- Calculation of category indicator results (characterization, mandatory)
- Calculation of the magnitude of category indicator results with relative to reference information (normalization, optional)
- Grouping (optional)
- Weighting (optional, not allowed for comparative assertions made available to the public)
- Data quality analysis (mandatory for comparative assertions made available to the public)

8.3.3.2 Specific comments on the LCIA

The mandatory steps have been performed is this study, which involves comparative assertions made available to the public. The LCIA is therefore in accordance with the international standard ISO 14042.

It is stated that “weighting is not done” (Section 2.2.3) in regards to LCIA and this is appropriate as it avoids criticism (LCIA weighting is “subjective” in the sense as it cannot be proved according to scientific methods).

8.3.3.3 Appropriateness of Omissions of LCIA impact categories

The initial statement that the study is “excluding elementary flows contributing to environmental impacts where currently no scientific consensus exists for measuring with LCAs” was misleading and could be interpreted negatively against Ford. Following a conference call with Ford it seemed clear that this qualification is intended to note, quite correctly, that data quality is an issue in toxicology. Furthermore, it is a fact that the impact categories “Human toxicity” and “Eco-toxicity”, as proposed in several handbooks on LCA, remain difficult to quantify and there is no consensus regarding the indicators and the characterization models to be used. The correct treatment of these impacts is a current research topic. Ford, therefore, cannot be criticized for omitting these categories at the present time, although cars emit toxic gases and particles. The toxic and eco-toxic effects of volatile organic compounds (VOC) are partly taken into consideration in the impact category “photochemical ozone formation” (summer smog formation) which is included in this study. Furthermore, the (eco-toxic) acidification by emitted acid-forming gases (SO_2, NO_x) is considered. Considering the state of LCIA development, Ford can, in good conscience, write the following:

“This study does not transfer, to impacts, data for which the quality is highly questionable, such as those related to toxicity and landscape”. This phrase should replace the statement that the study is “excluding elementary flows contributing to environmental impacts where currently no scientific consensus exists for measuring with LCAs.”

8.3.4 Interpretation of the LCA Results and Transparency

8.3.4.1 Interpretation

The overall presentation of the results and their interpretation are completely in line with the data collected as well as impacts and cost calculated. As an example, Figure 3.5 communicates key indicators, which are valid, for various vehicle options. The only metric which could be tabulated by Ford in PSI, and is not, is “total waste”. Figure 3.7 illustrates that this metric is relatively high and therefore could be communicated. Clearly, the decision as to what is above a threshold is not absolute, as thresholds are arbitrary. Total was, in the LCA of an automobile, includes a high share of overburden and tailings from mining and ore processing. While in this specific case (Ford Galaxy, Ford S-MAX) there are no significant differences identified between the vehicles regarding “total waste” (sensitivity analysis identified for this case a minimum of 8% difference) it might be different for other cases. Therefore, the question of inclusion of “total waste” in PSI should be analyzed previous to a potential communication of PSI for other vehicles.

In regards to the interpretation, the following comments illustrate Ford’s commitment to ensure the validity of the results they seek to communicate:

- The dominance analysis of Section 2.5.2 is excellent and provides a significant authority for comparative assertions. Crude oil and precious metals, as part of abiotic depletion potential could be in the PSI system though the authors are correct in omitting them as they contribute only approximately 1% of the total environmental impact and this is below any accepted threshold.

- The breakeven analysis in Section 2.5.3 is very good. In particular the identification of tradeoffs between the use phase and production is informative and correctly carried out.
- The calculation, using Monte-Carlo Analysis, of the standard deviation of various use phase assumptions is well carried out and informative. As the use phase cost has, by far, the largest standard deviation, this could be justified in a footnote.
- The fact that the LCIA results were validated using a simplified, spreadsheet-based software with very similar results is an important step foreword in the field and should be commended. The tool should provide a means for Ford to increase the use of LCA within their organization and in design. Without seeing, explicitly the Excel sheet the reviewers cannot comment on it, per se. However, the exclusion of the sheet would in no manner influence the conclusions of the review under ISO 14040.

8.3.4.2 Conclusions and Transparency

The seven conclusions drawn (Section 3.5.3) are completely reasonable and justified. The overall conclusion section (3.5.4) is also quite fine. The fact that the PSI results are presented (in Figure 4-1 and Figure 4-2) in two spider graphs, each for two comparative vehicles, is an excellent communication tool.

8.3.5 Management of the Review Process

Section 7.3.3 of ISO 14040 noted that the commissioner (Ford) has to select an external independent expert to act as the chairperson of the review panel. Ford has, following a tender process, selected David Hunkeler and this corresponds to the norms in the standard. The fact that Ford provided the review panel, and its chair, with a dialog with the LCA-project leader is not, itself, specified in ISO 14040, though is generally recommended to enhance the quality of the review for example by SETAC. Therefore, Ford's participation in the management of the review process has been entirely according to the standard.

ISO 14040 states that the commissioner (Ford) and practitioner must provide access to original data. In all instances of request for additional information or conference calls, Dr. Schmidt has been receptive to provide information. ISO 14040 also states, and it is important to reiterate that "the fact that a critical review has been conducted should in no way imply an endorsement of any comparative assertion that is based on an LCA study".

8.4 COMMENTS ON LIFE CYCLE COSTING (NOT REQUIRED IN ISO 14040)

The life cycle costing is quite diligent with all cost completely appropriately calculated. The depth of inclusion of data across the life cycle is appropriate and the use of discounting possible. The reviewers, who have extensive experience in LCC, believe that the best possible assumptions have been made. Ford can, reasonably, call their LCC an "Environmental Life Cycle Costing" according to the to-be-published deliberations of a SETAC working group. The LCC results presented in Figures 3-10 and 3-11 are totally reasonable as communication tools. Though outside the scope of the present review the LCC studies carried out by Ford seem to be consistent with those being debated and proposed in a SETAC Working Group of the same name and are, therefore, likely to be very close to an eventual Code of Practice.

8.5 COMMENTS ON SOCIAL ASSESSMENT (NOT REQUIRED IN ISO 10404)

The PSI is, in combining environmental, economic and societal information, respecting the Brundtland and SETAC visions of sustainability. It should be noted that the societal and social assessments are both in their infancy and norms have not even been suggested. Therefore, the fact that Ford has included social aspects is sufficient commendation. However, one could in the future consider an emerging axis in societal assessment, that being employment, as a metric. Even if one were to reduce societal assessment to a small set of indicators such as those representing access to essentials, housing, education and health care, all are linked to an individual's employment, or society's ability to employ. Hence, a component, easily measurable for an organization and absolutely justifiable would be product-based employment through the life cycle. In its present state, the societal component can be considered as a nucleus for further development of this "third pillar" of sustainability assessment. It is quite likely that Ford, which have other metrics which address sustainability, have not included life cycle labor within PSI. Overall, the choice of Ford to have several indicators in place of one super-indicator is in line with the thinking of international working groups and is appropriate.

8.6 RECOMMENDATIONS

Overall, the reviewers have found the Ford LCA to be a very well carried out study in accordance with various norms. In light of the positive tone of this reply, the following recommendation is aimed at the long-term evolution and upgrading of the PSI tool.

The generic life cycle inventory data, used within the LCA, should be periodically monitored and validated. This long term evolution should be carried out for data elements clearly above the threshold (so called hot-spots in LCA parlance). While recognizing the difficulty that requesting data from suppliers entails, periodic validation of key materials and, perhaps also components, should be viewed as a means to improve the dialogue with the supply chain, a key element in life cycle management, and not as a bureaucratic exercise.

The PSI tool can be, in good conscience, used as a benchmarking tool for Ford's automobiles. Should, over time, the LCI significantly change, one should re-calculate the existing reference vehicles according to any modified PSI.

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