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Article

Environmental and Financial Evaluation of Passenger Vehicle Technologies in Belgium

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Abstract: Vehicles with alternative drive trains are regarded as a promising substitute for conventional cars, considering the growing concern about oil depletion and the environmental impact of our transportation system. However, “clean” technologies will only be viable when they are cost-efficient. In this paper, the environmental impacts and the financial costs of different vehicle technologies are calculated for an average Belgian driver. Environmentally friendly vehicles are compared with conventional petrol and diesel vehicles. The assessments are done from a life cycle perspective. The effect on human health, resources and ecosystems is considered when calculating the environmental impact. The total cost of ownership (TCO) model includes the purchase price, registration and road taxes, insurance, fuel or electricity cost, maintenance, tires replacement, technical control, battery leasing and battery replacement. In the presented analysis different vehicle technologies and fuels are compared (petrol, diesel, hybrid electric vehicles (HEVs), battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)) on their level of environmental impact and cost per kilometer. The analysis shows a lower environmental impact for electric vehicles. However, electric vehicles have a higher total cost of ownership compared to conventional vehicles, even though the fuel operating costs are significantly lower. The purchase cost of electric vehicles is highly linked to the size of the battery pack, and not to the size of the electric vehicle. This explains the relative high cost for the electric city cars and the comparable cost for the medium and premium cars.

Keywords: clean vehicles; cost-efficiency; environmental impact; total cost of ownership; life cycle thinking

1. Introduction

Today, making a car purchase decision is very complex, especially when different technologies should be evaluated. Next to conventional diesel and petrol vehicles, environmental friendly vehicles, using alternative fuels (LPG, CNG, biofuels) or drive trains (hybrid, battery electric, plug-in hybrid), are entering the market. Electric vehicles can be fuelled by a wide variety of primary energy sources—including gas, coal, oil, biomass, wind, solar and nuclear—reducing oil dependency and enhancing energy security. Electric vehicles are very silent and have zero emissions while driving. Hence, they significantly improve local air quality. They can be made close to CO_2-free, depending on the primary energy source used [1,2]. Zero-emission power-trains go hand-in-hand with the decarbonization of the energy supply [3]. Nevertheless, the transformation of the conventional vehicle market towards an electromobility market is not straightforward. The electric mobility is confronted with several persisting barriers for market penetration, like the high purchase price, the limited range and the lack of charging infrastructure (which creates range anxiety) [4,5]. Because of the early stage of technological development, private investments are still rather limited due to elevated investment risks. Electric propulsion systems require high initial investments in technology development and infrastructure to be able to compete against the technological “lock-in” of current road transport, which is primarily dominated by hydrocarbon fuels.

The aim of this paper is to combine environmental and economic aspects in one assessment in order to find opportunities to enhance the market adoption of cleaner vehicle technologies. Through the development of a total cost of ownership (TCO) model, the cost-efficiency of different vehicle technologies can be compared, market opportunities can be discovered and necessary fiscal support can be identified. The purchase of an environmental friendly car may become a viable economic decision if these cars would provide lower or equal private consumer costs compared to conventional petrol and diesel cars. This research is relevant as literature demonstrates that financial factors such as the sales price and operating costs are decisive purchase factors, while the environmental impact of the car is the least important factor [6,7]. Hence, it is valuable to look at the total cost of different vehicle technologies together with their environmental impact.

A detailed literature survey showed that there are several studies dealing with environmental impacts and total cost of ownership of vehicles separately [8–22]. Throughout the literature, the results are expressed in different units and based on different assumptions. The assumptions (for instance: the goal and scope definition of the study, the temporal and geographical boundaries of the study, the weight and fuel consumption of the vehicles, the lifetime performance of the vehicle and the components and the energy sources to produce the electricity) can differ greatly between various studies, leading to varying results. However, there is a growing need to integrate environmental, economic and social aspects in a sustainability assessment [23]. To have a coherent assessment of the environmental impacts and costs of the vehicles, both the environmental as the financial methodologies should be fully in line with each other and use the same framework. In literature, the life cycle environmental impacts and total cost of ownership are modeled in separate studies with different sets of assumptions and boundary conditions, making it impossible to combine them. This paper provides a coherent framework in which the environmental impacts as well as the total cost of ownership is modeled, enabling a combination of both indicators in the assessment of the selected vehicles.

Table 1 gives an overview of the different vehicles that are selected for the analysis. Three car segments are investigated: the small city cars, the medium sized cars and the luxurious premium cars. All these cars are compared for different vehicle technologies: petrol, diesel, hybrid, battery electric and plug-in hybrid electric.

Table 1. Overview of the selected vehicles.

Segment	Brand	Consumption (L/100km, kWh/100km)	CO_2 g/km	Segment	Brand	Consumption (L /100km, kWh/100km)	CO_2 g/km
City	Citroën C1, P	4.3	99	Medium	Honda Jazz, HEV	4.5	104
City	Peugeot 107, P	4.3	99	Medium	Honda Insight, HEV	4.4	101
City	Toyota Aygo, P	4.3	99	Medium	Toyota Auris, HEV	3.8	89
City	Suzuki Alto, P	4.4	103	Medium	Lexus CT200h, HEV	3.8	87
City	Smart Fortwo, P	4.9	115	Medium	Toyota Prius, HEV	3.9	89
City	Smart Fortwo, D	3.3	86	Medium	Nissan Leaf, BEV	17.3	0
City	Renault Twingo, P	4.5	105	Medium	Renault Fluence, BEV	12	0
City	Renault Twingo, D	3.4	90	Medium	Chevrolet Volt, PHEV	1.2 L and 13kWh	27
City	Mitsubishi iMiev, BEV	13.5	0	Medium	Opel Ampera, PHEV	1.2 L and 13kWh	27
City	Peugeot iOn, BEV	13.5	0	Premium	Audi A6, P	7.7	177
City	Citroën C-Zero, BEV	13.5	0	Premium	Audi A6, D	5.3	139
City	Mia Electric, BEV	10	0	Premium	BMW 535i, P	8.9	209
City	Tazzari Zero, BEV	13.5	0	Premium	BMW 535, D	5.4	142
City	Renault Zoe, BEV	11	0	Premium	Mercedes E250, P	6.6	154
Medium	Citroën C4, P	6.1	140	Premium	Mercedes E250, D	5	130
Medium	Citroën C4, D	4.2	109	Premium	Audi A6, HEV	6.2	145
Medium	Ford Focus, P	4.8	109	Premium	BMW 7-Series, HEV	6.8	158
Medium	Ford Focus, D	4.2	109	Premium	Mercedes E300, HEV (D)	4.3	112
Medium	Renault Fluence, P	6.8	157	Premium	Tesla Model S 40, BEV	18.8	0
Medium	Renault Fluence, D	4.6	120	Premium	Tesla Model S 60, BEV	18.8	0
Medium	VW Golf, P	6	139	Premium	Tesla Model S 85, BEV	18.8	0
Medium	VW Golf, D	3.8	99				

Notes: P = petrol, D = diesel, HEV = hybrid electric vehicle, BEV = battery electric vehicle, PHEV = plug-in hybrid electric vehicle.

2. Environmental Impact

2.1. Methodology

The environmental impact of the vehicle technologies is analyzed through the life cycle assessment (LCA) methodology. The LCA includes the extraction of raw materials, the manufacturing of components, the assembly, the use stage (on a well-to-wheel (WTW) basis), the maintenance and the end-of-life (EoL) treatment, including recycling. The International Standardization Organization (ISO) has published two standards on LCA, namely, the ISO 14040 (ISO 14040:2006) [24] and the ISO 14044 (ISO 14044:2006) [25].

The details of the LCA model are defined in [26]. The underlying LCA is a descriptive comparison of the environmental impact associated with BEVs and conventional vehicles in Belgium. The geographical and temporal scope of the study is the Belgium car market of 2012.

An attributional modeling approach has been chosen. Future, large scale structural consequences are not addressed. The comparison was intended to be disclosed to the public. The environmental impacts are calculated using the Recipe methodology [27], including: climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particle matter formation, terrestrial ecotoxicity, marine ecotoxicity, ionizing radiation, agricultural land occupation, urban land occupation, natural land transformation, water depletion, mineral resource depletion and fossil fuel depletion. A weighted single scoring has been used for the environmental assessment, available in the Recipe methodology. The different impact categories are weighted with respect to relative importance assigned to them by stakeholders. A unique score makes comparison of two vehicles easier. However, a unique score makes the interpretation much more subjective. The LCA study was commissioned and financed by BELSPO (Belgian Science Policy Office). The target audiences were governmental political decision makers, main actors in the automotive sectors and the general public.

2.2. Inventory

The full list of all materials and processes used in the life cycle modelling is provided in the doctoral research [26] report. The average lifetime of a Belgian vehicle in 2010 corresponds to 14.1 years [28] and the annual mileage is 14,856 km [29]. This results in a life time driven distance of 209,470 km, which is the functional unit of the analysis.

The Tank-to-Wheel (TTW) data (CO_2, HC, SO_2, NO_x, CO, PM, CH_4, N_2O emissions (g/km)) are based on type approval emissions considering the NEDC (New European Driving Cycle) values. The type approval emissions of the specific vehicles are available online [30].

The fuel consumption of the vehicles was measured on the NEDC driving cycle. For the Well-to-Tank (WTT) data, the electricity supply mix in Belgium is considered for the year 2011. This contains: hard coal 4%, natural gas 29%, nuclear 57%, hydropower 2% wind 1%, biomass 3%, import France 6%, and export Netherlands 3%. The WTT data for conventional fuels is derived from Ecoinvent and contains also low sulphur diesel and petrol [31].

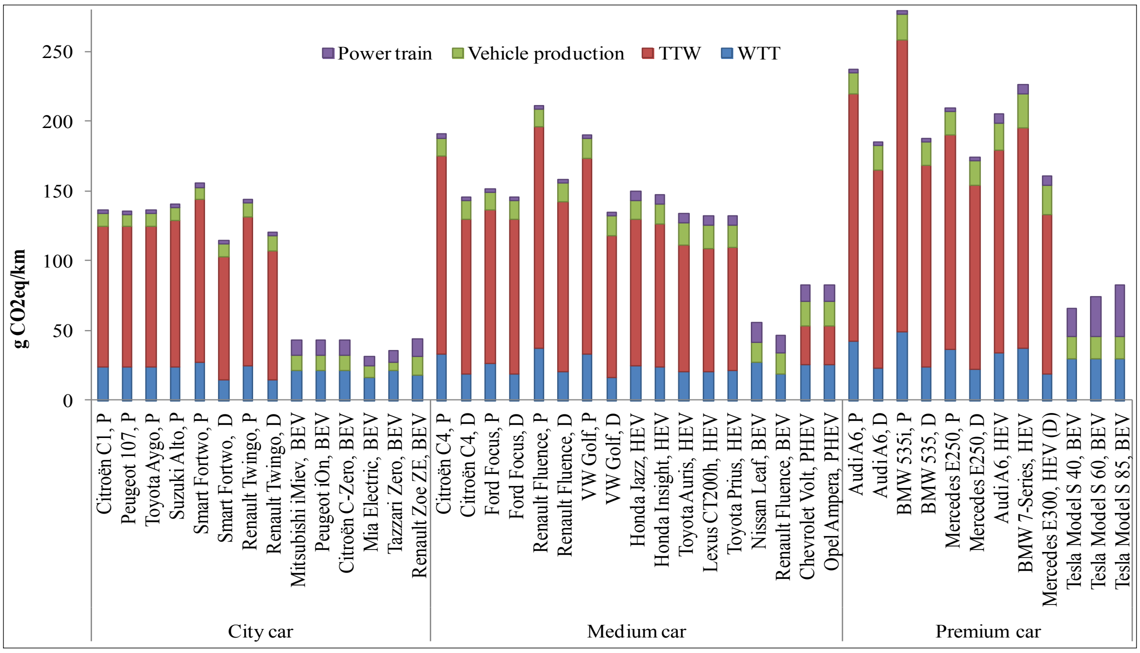
The data for the production of the vehicle is based on the production data of the VW Golf, with respect to the individual weights of the vehicles [32]. Data for parts of specific vehicle technologies, such as the lithium-ion batteries for the electric vehicle, are gathered separately. The Life Cycle Inventory (LCI) of the BEV includes a lithium battery, electric motor, converters, on-board charging equipment as well as public charging infrastructure.

For the conventional vehicles, the model includes a starter, control unit and exhaust treatment. A 2.5 kW electric starter motor with a weight of 3 kg is modeled. Conventional vehicles have a small electric generator in order to produce electricity to charge the lead battery. The electricity in the battery is used to start the car and to power the auxiliaries. A 4.3 kg generator with a power of 1.5 kW is modeled.

2.3. Results

Figure 1 shows the results of the life cycle impact on climate change of the selected vehicle technologies. The effect on climate change is expressed in CO_2 equivalent emissions per driven kilometer. The results show that the WTW stage is dominating the effect on climate change for conventional vehicles. The main part of the greenhouse gases of a conventional vehicle are emitted while driving. Small city vehicles are more fuel-efficient and have a benefit over larger vehicles. Battery electric vehicles have no tailpipe emissions. However, the additional components, such as a battery pack and an electric motor, need to be produced.

Figure 1. Life cycle CO_2 emissions for different vehicle technologies.



However, climate change is not the only environmental impact to consider. ReCiPe harmonizes midpoint and endpoint categories into one single model. Three endpoints exist in ReCiPe: human health (influenced by climate change, ozone depletion, human toxicity, photochemical oxidant, particulate matter formation and ionizing radiation), Ecosystems (influenced by climate change, terrestrial acidification, freshwater eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, agricultural land occupation, urban land occupation and natural land transformation) and resources (influenced by fossil depletion, metal depletion). In Figure 2, the endpoint impact categories are normalized, weighted and summed up in order to have a single score.

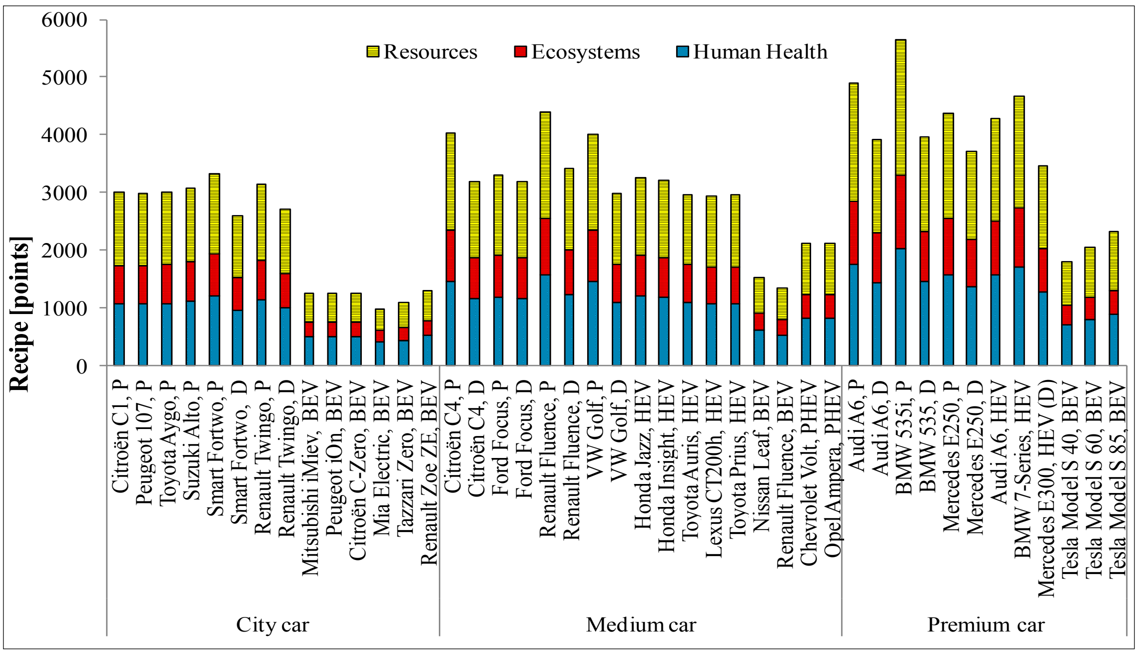
The general trend is that petrol vehicles have the highest overall environmental burden in each car segment. This is due to the relevance of fossil depletion (damage on resource availability) and climate change (human health). Diesel vehicles are more energy efficient and emit fewer greenhouse gasses during usage, which explains the lower environmental impact compared to petrol vehicles. However, it should be mentioned that the examined diesel vehicles are compliant with the most stringent emissions standard (Euro 5). Old diesel vehicles that emit more NO_x and PM would have a higher impact.

The BEVs and the PHEVs have the lowest overall environmental burden. For the BEV, 40% of the total environmental burden is due to the damage on human health, 40% due to the damage on resource availability and 20% due to damage on ecosystem diversity. The damage on human health gained relative importance, compared to conventional vehicles, as the human toxicity potential increased due to the manufacturing of the specific components of the electric vehicle. The differentiation between the various BEVs is explained by the difference in electricity consumption and the battery size.

If two vehicles are used for the same purpose, they can be compared regardless of the difference in size. Unfortunately, many large vehicles are driven in city centers and are used for daily and short distances. This makes a comparison between car segments a fair option. However, it is recommended that the chosen cars and segments are explicitly shown, as it has a large influence on the result.

The car segment highly influences the climate change effect of the particular vehicle and thus the overall environmental impact. Climate change is influenced mostly by the energy consumption of the vehicle. Second, the energy consumption strongly relates to the weight of the vehicle. And there is a strong difference in weight between car segments. A significant reduction is possible if a conventional premium car is replaced by a BEV. However, a large reduction is also possible if the same conventional premium car is downsized to a small city car with the same conventional technology. It should be noted that the hybridization of the drivetrain brings a strong reduction on the climate change impact, without changing the car segmentation. This is important to note, since people are hesitant to change their car segment.

Figure 2. Overview of the life cycle impact of the different selected vehicles.



3. Total Cost of Ownership

3.1. Methodology

A total cost of ownership (TCO) model is developed in order to assess the cost effectiveness of HEVs, PHEVs and BEVs, compared to conventional petrol and diesel vehicles. Consumers will only take eco-friendly cars into consideration when the price surplus is not too high. Of course, other factors influence the consumer's purchase decision: styling, looks, driving sensation, car dealer, influence from friends and family. However, these cannot be included in the TCO analysis.

In this TCO model, the present value of all occurred costs is calculated: purchase cost, registration tax, vehicle road tax, maintenance, tires and technical control cost, insurance cost, battery leasing cost, battery replacement cost and fuel or electricity cost. Some of these parameters, for example battery leasing cost, are only related with a specific vehicle technology. To calculate the present value of future one-time costs, the following equation is used [33]:

$$PV = A_t \times \frac{1}{(1+r)^T} \tag{1}$$

To calculate the present value of future recurring costs, we use [33]:

$$PV = A_0 \times \frac{(1+r)^T - 1}{r\,x\,(1+r)^T} \tag{2}$$

with:

PV = Present value

A_t = Amount of one-time cost at a time t

A_0 = Amount of recurring cost

r = Real discount rate

T = Time (expressed as number of years)

All input parameters are based on existing values for January 2013. We use the same vehicles and vehicle segments as for the environmental impact assessment above. We assume that the average Belgian consumer owns his vehicle for 7 years before selling it and that the average yearly mileage is 15,000 km [34]. We use a real discount rate of 1.18%, which is the 7-year annual nominal Euro area interest rate for governmental bonds for which all issuers have a triple-A rating, dating from 2 January 2013 [35].

The vehicle input parameters are divided into three main groups: the purchase costs (initial purchase price and vehicle registration tax), the fuel operating costs (petrol, diesel or electricity) and the non fuel operating costs (yearly road tax, insurance cost, maintenance and tires costs, costs for the technical control, and possible battery costs).

- The initial purchase price of a vehicle in this TCO analysis includes the VAT (value added tax, 21% in Belgium) but excludes dealer price reductions and promotions. Vehicles depreciate over time, according to the vehicle technology. As BEVs and PHEVs have only recently entered the market, the depreciation rate for these vehicles is still uncertain. For this TCO analysis, we use the following yearly depreciation rates, calculated through exponential regression based on available data from the past 7 years: 0.845 for petrol, 0.827 for diesel, 0.834 for HEVs, 0.720 for BEVs and 0.773 for PHEVs.

- The vehicle registration tax (VRT) has to be paid once, when purchasing the vehicle, and is based on the basis of the CO_2 emission, the EURO norm, the age of the vehicle and the presence of a diesel particulate filter.
- The fuel or electricity prices are based on the average prices in 2012 for petrol (€1.7076/L), diesel (€1.5318/L) [36] and electricity (€0.21/kWh) [37].
- The Belgian yearly road tax is linked to the fiscal horsepower (fiscal hp) of the vehicle, which is in relationship with the cylinder capacity of the engine of the vehicle.
- In this TCO analysis, the omnium insurance (insures vehicle of driver as well as damage done to another vehicle in collision) is taken during the first three years, followed by the civil liability premium (only damage done to another vehicle in collision is insured) for the next years.
- The battery pack of a BEV has to be replaced according to the expected lifetime. Here, we assume a battery lifetime of approximately 6 years, resulting in 90,000 km driven [38]. When this range falls within the car manufacturer's warranty, no costs are included. If not, we consider a battery replacement cost of €400/kWh, which is the expected cost for lithium ion batteries in 6 years [39]. If the battery pack of the BEV is replaced during the investigated 7 years, the residual value of the vehicle is increased linearly based on the replacement value of the battery.
- Some BEVs are sold with a battery leasing contract, in which the manufacturer ensures the quality of the battery.
- Maintenance costs depend on the vehicle technology and the annual mileage. In this analysis, the maintenance prices are specific for every model. Maintenance costs for BEVs are expected to be lower than those of internal combustion engine vehicles (ICEVs), as there are fewer moving components, they face less temperature stress and do not need oil and filter replacements [40]. We assume a maintenance cost for BEVs of 60% of a comparable ICE vehicle.
- Tires are replaced every 40,000 km. We include the cost for the replacement as well as for the balancing of the tires.
- Finally, all cars have to be inspected on the technical control, starting 4 years after purchase.

3.2. Results for TCO

Figures 3–5 present the results of the TCO analysis for the three vehicle segments. The left y-axis shows the total cost of ownership (in €), while the right y-axis shows the cost per kilometer (in €/km). The difference between conventional ICEVs and BEVs for the small city cars segment is clear: small petrol cars range from 0.18–0.23 €/km, small diesel cars range from 0.19–0.21 €/km, BEVs range from 0.30–0.36 €/km. The share of depreciation costs is higher for BEVs (59%) than for petrol (34%) en diesel (44%) cars. On the other hand, the share of fuel and electricity cost is lower for BEVs (8%) than for petrol (38%) en diesel (25%) cars. The results for the medium cars segment are more promising for the analyzed BEVs: the costs per km range from 0.27–0.33 €/km for petrol cars, 0.28–0.31 €/km for diesel cars, 0.27–0.38 €/km for hybrids, 0.39–0.42 €/km for BEVs and 0.45–0.50 €/km for PHEVs. Here, the BEV with a leasing contract (Renault) is financially a more interesting option. In this segment, the share of depreciation between all vehicle technologies is more uniform: 43% for petrol vehicles, 51% for diesel vehicles, 53% for hybrids, 55% for BEVs and 70% for PHEVs. Generally, PHEVs are still an expensive alternative. In the premium car segment, other factors like brand perception, image and looks play a more important role than in the other two vehicle segments. Here, an identical BEV is offered with 3 battery capacities (40 kWh, 60 kWh and 85 kWh). Costs per kilometer range from 0.53–0.67 €/km for petrol cars, 0.52–0.66 €/km for diesel cars, 0.59–0.72 €/km for hybrids and 0.58–0.79 €/km for BEVs. This makes BEVs quite an interesting option from a cost point of view.

Figure 3. Total cost of ownership (TCO) results for small city cars.

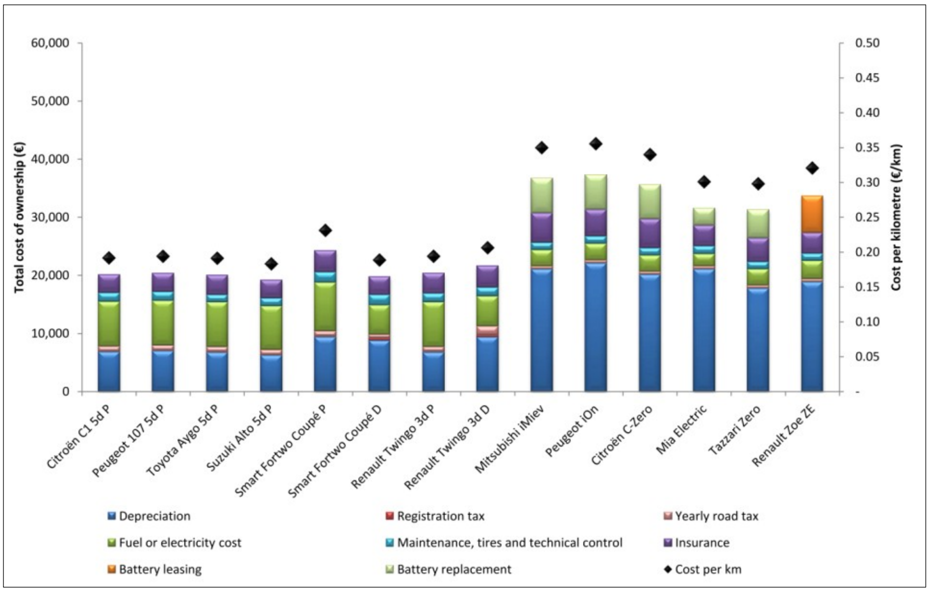


Figure 4. TCO results for medium cars.

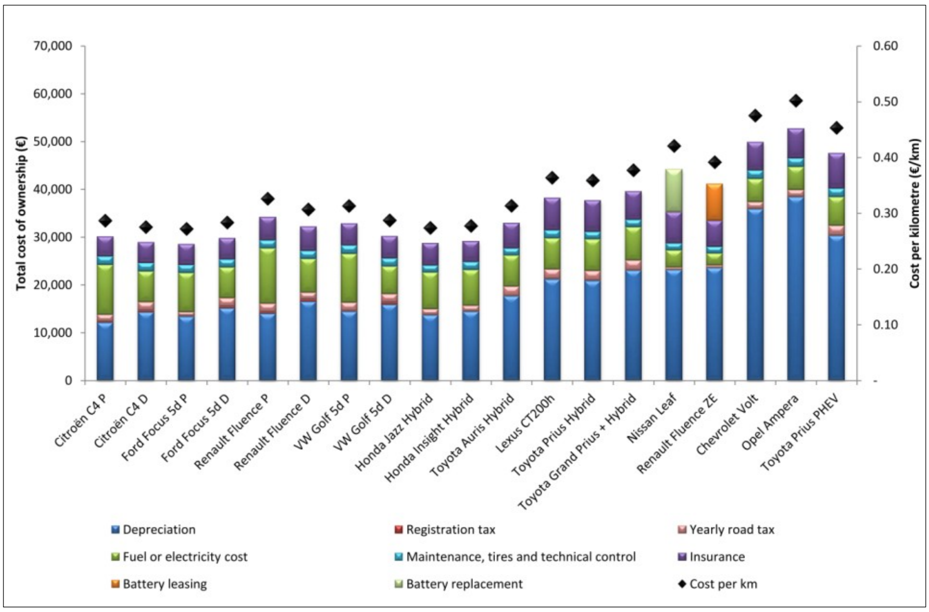
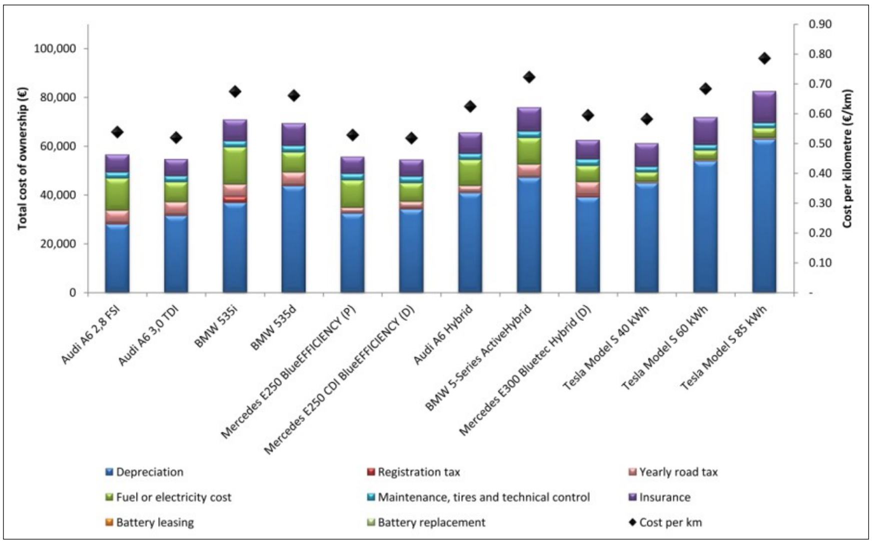


Figure 5. TCO results for premium cars.



4. Economic and Environmental Balance

The balance between the environmental LCA results (in ReCiPe points) and the TCO results (in Euro) are displayed in Figure 6. On the X-axis, the TCO (as in Figures 3–5) is shown, whereas the Y-axis presents the LCA (as in Figure 2). This matrix shows four quadrants.

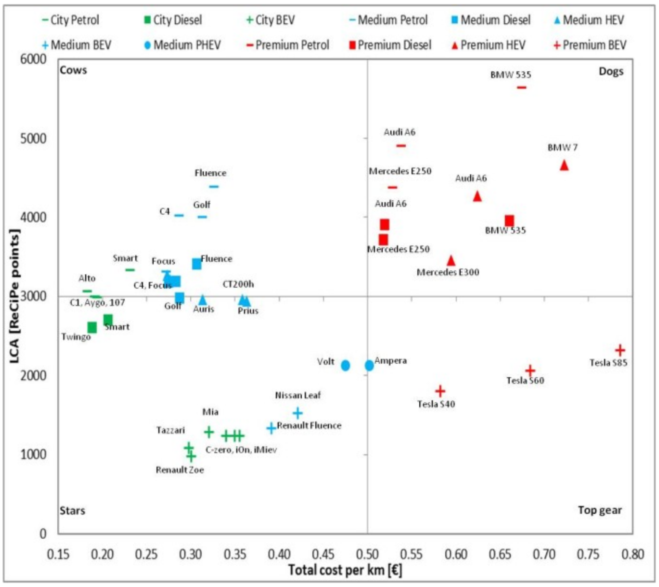
The first quadrant, the lower left, is characterized by cars with a low environmental impact (LCA points < 3000) and a high cost efficiency (<0.50 €/km). As a result, cars in this segment will be able to support the transition towards a more environmental friendly car fleet. These cars are mainly represented by city cars (green) and some medium cars (blue). In order to appropriately assess the LCA-TCO matrix, one needs to compare each car with a comparable car from the same segment. For example, the electric Peugeot iOn has an attractive environmental performance (1240 LCA points), but is more expensive (0.36 €/km) than its Twingo alternative (0.19 €/km and 3137 LCA points for the petrol version, 0.21 €/km and 2702 LCA points for the diesel version). The first quadrant also includes medium cars such as the Nissan Leaf (BEV), Chevrolet Volt (PHEV) and Toyota Prius (HEV).

The second quadrant (upper left) contains cars which are not environmentally friendly (LCA > 3000), but which are cost-efficient (<0.50 €/km). These (conventional) cars could migrate to the first quadrant through hybridization (HEV and PHEV) or through downsizing of the internal combustion engine. However, this would impact the total cost of ownership.

The premium cars are mainly situated in the third quadrant (upper right). Cars in this quadrant typically have a lower market share as they are more exclusive and expensive (>0.50 €/km). Within this study, they are the most polluting vehicles (LCA points > 3000). However, it appears that some progression can be made through hybridization (see for example the Mercedes HEV compared to its petrol and diesel model).

The "top-gear" quadrant (lower right) includes the expensive cars (>0.50 €/km), which are environmental friendly (LCA points < 3000). Normally, premium cars are more luxurious and are heavier, which entails worse fuel efficiency and a higher environmental impact. However, the Opel Ampera (PHEV) and the different versions of the Tesla Model S (BEV) indicate that premium cars can also have a good environmental performance.

Figure 6. Balancing the cost efficiency and environmental friendliness of vehicles.



5. Conclusions: Cost Efficient Clean Vehicles

Comparing the environmental impact of vehicles with alternative propulsion systems is challenging. Not only should tail-pipe emissions and emissions during fuel production be addressed, but so should impacts associated with the production of the vehicle and its components. Furthermore, the different pollutants result in different environmental damages. A dedicated life cycle model is developed and explained in this paper which allows incorporating these different aspects. This paper concludes that electric vehicles are more environmentally friendly on a life cycle basis (including electricity production and the production of the vehicle and its components) compared to the conventional petrol and diesel vehicles. On the other hand, hybrid electric vehicles also have a lower environmental impact, due to the low fuel consumption and emissions.

The main advantage of diesel vehicles is their high energy efficiency. However, their high PM and NO_x emissions make them less environmentally friendly at the moment. Energy efficient vehicles have a lower fuel price, but are sometimes characterized by a higher purchase price.

A total cost of ownership (TCO) analysis has been conducted in order to investigate the financial attractiveness of electric vehicles (battery electric and plug-in hybrid electric) compared to conventional petrol and diesel cars. The cost structure of the TCO is shown in order to illustrate the differences between conventional cars and electric vehicles.

We found that for city cars, the higher purchase costs for BEVs entail a large difference in TCO compared to the conventional cars. Even though the fuel operating costs are significantly lower, they cannot outweigh the high purchase costs. The most interesting electric city cars, from a TCO point of view, are those for which the battery pack is leased instead of sold, and those that offer a vehicle that is smaller than the competition.

Within the medium car segment, the difference between the conventional and the electric vehicles is lower. Some electric vehicles (with and without battery leasing) seem financially comparable to their conventional rivals. This could be because their purchase cost is closer to that of the conventional cars.

In general, the purchase cost of electric vehicles is highly linked to the size of the battery pack, and not to the size of the electric vehicle. This explains the relative high cost for the electric city cars and the comparable cost for the medium and premium cars in the TCO calculation.

The environmental impacts with the economic results. Cars from the first quadrant (low environmental impact (LCA points < 3000) and high cost-effectiveness (<0.50 €/km)) are mainly represented (electric) city cars and environmental friendly versions (BEV and HEV) of medium cars. Cars in this segment will be able to support the transition towards a more environmental friendly fleet. Cars from the second quadrant, defined by a higher environmental impact (LCA points > 3000) but which still are cost-efficient (<0.50 €/km), are mainly petrol and diesel cars. These cars can become stars (quadrant 1) through hybridization (HEV and PHEV), the installation of a PM-filter, or through downsizing of the internal combustion engine. All premium cars are located in quadrant 3 and 4, which are cost-inefficient and which have a respectively high and low environmental impact. The level of environmentally friendliness is related to the amount of electrification of the vehicles: all BEVs are located in quadrant 4.

Conflicts of Interest

The authors declare no conflict of interest.

References and Notes

1. Messagie, M.; Boureima, F.; Matheys, J.; Sergeant, N.; Timmermans, J.-M.; Macharis, C.; van Mierlo, J. Environmental performance of a battery electric vehicle: A descriptive life cycle assessment approach. *World Electr. Veh. J.* **2011**, *4*, 782–786.
2. Van Mierlo, J.; Maggetto, G. Fuel cell or battery: Electric cars are the future. *Fuel Cells* **2007**, *7*, 165–173.
3. Hacker, F.; Harthan, R.; Matthes, F.; Zimmer, W. *Environmental Impacts and Impact on the Electricity Market of a Large Scale Introduction of Electric Cars in Europe—Critical Review of Literature*; ETC/ACC Technical Paper 2009/4; European Topic Centre on Air and Climate Change: Bilthoven, The Netherlands, 2009; pp. 169.
4. Van Mierlo, J.; Maggetto, G.; van de Burgwal, E.; Gense, R. Driving style and traffic measures—influence on vehicle emissions and fuel consumption. *J. Automob. Eng*. **2004**, *218*, 43–50.
5. Lebeau, K.; van Mierlo, J.; Lebeau, P.; Mairesse, O.; Macharis, C. Consumer attitudes towards battery electric vehicles: A large scale survey. *Int. J. Electr. Hybrid Veh.* **2013**, *5*, 28–41.
6. Lebeau, K.; van Mierlo, J.; Lebeau, P.; Mairesse, O.; Macharis, C. The market potential for (plug-in hybrid) electric vehicles in Flanders: A choice-based conjoint analysis. *Trans. Res. D: Trans. Environ.* **2012**, *17*, 592–597.
7. Mairesse, O.; Macharis, C.; Lebeau, K.; Turcksin, L. Understanding the attitude-action gap: Functional integration of environmental aspects in car purchase intentions. *Psicologica* **2011**, *33*, 547–574.
8. Althaus, H. Life-Cycle Assessment of Electric Vehicles. In Proceedings of LowCVP/IMechE Life-Cycle Seminar, One Birdcage Walk, Westminster, London, UK, 14 November 2011.

9. Lane, B. *Life Cycle Assessment of Vehicle Fuels and Technologies*; Final Report London Borough of Camden; Ecolane Transport Consultancy: Bristol, UK, 2006.
10. Helms, H.; Pehn, M.; Lambrecht, U.; Liebich, A. Electric Vehicle and Plug-In Hybrid Energy Efficiency and Life Cycle Emissions. In *Electro and Hybrid Vehicles*, Proceedings of 18th International Symposium Transport and Air Pollution, Dübendorf, Switzerland, 18–19 May 2010; p. 113.
11. Simons, A. *LCA Comparison of Electric Drivetrains in Passenger Cars*; Paul Scherrer Institute: Villigen, Switzerland, 2011.
12. Hawkins, T.R.; Singh, B.; Majeau-Bettez, G.; Stromman, A.H. Comparative environmental life cycle assessment of conventional and electric vehicles. *J. Ind. Ecol.* **2012**, *17*, 53–64.
13. Held, M.; Baumann, M. Assessment of the Environmental Impacts of Electric Vehicle Concepts. In *Towards Life Cycle Sustainability Management*; Finkbeiner, M., Ed.; Springer: Berlin, Germany, 2011; pp. 535–546.
14. Lambrecht, U. Electric Vehicles in a Future Energy System Context. In Proceedings of 43rd LCA Discussion Forum on life Cycle Assessment of Electromobility Answers and Challenges, Zürich, Switzerland, 6 April 2011.
15. Frischknecht, R.; Flury, K. Life cycle assessment of electric mobility: Answers and challenges. *Int. J. Life Cycle Assess.* **2011**, *16*, 691–695.
16. Freire, F. Comparative life-cycle assessment of electric and conventional vehicles in Portugal. In proceedings of 43rd LCA Discussion Forum on life Cycle Assessment of Electromobility Answers and Challenges, Zürich, Switzerland, 6 April 2011.
17. Boureima, F.; Messagie, M.; Sergeant, N.; Matheys, J.; van Mierlo, J.; de Vos, M.; de Caevel, B.; Turcksin, L.; Macharis, C. Environmental assessment of different vehicle technologies and fuels. *Urban Trans.* **2012**, *18*, doi:10.2495/UT120021.
18. Al-Alawi, B.; Bradley, T. Total cost of ownership, payback, and consumer preference modeling of plug-in hybrid electric vehicles. *Appl. Energy* **2012**, *103*, 488–506.
19. Goedecke, M.; Therdthianwong, S.; Gheewala, S. Life cycle cost analysis of alternative vehicles and fuels in Thailand. *Energy Policy* **2007**, *35*, 3236–3246.
20. Lipman, T.; Delucchi, M. A retail and lifecycle cost analysis of hybrid electric vehicles. *Trans. Res. D: Trans. Environ.* **2006**, *11*, 115–132.
21. Werber, M.; Fischer, M.; Schwartz, P. Batteries: Lower cost than gasoline? *Energy Policy* **2009**, *37*, 2465–2468.
22. Windisch, E. The Uptake of Electric Vehicles in the Paris Region: A Financial Analysis of Total Costs of Ownership. In Proceedings of European Transport Conference 2011, Glasgow, Scotland, UK, 2011.
23. Halog, A.; Manik, Y. Advancing integrated systems modelling framework for life cycle sustainability assessment. *Sustainability* **2011**, *3*, 469–499.
24. International Organization for Standardization (ISO). *Environmental Management—Life Cycle Assessment—Principles and Framework*; ISO: Geneva, Switzerland, 2006; ISO 14040:2006.
25. International Organization for Standardization (ISO). *Environmental management—Life cycle assessment—Requirements and Guidelines*; ISO: Geneva, Switzerland, 2006; ISO 14044:2006.

26. Messagie, M. Environmental Performance of Electric Vehicles, A Life Cycle System Approach. Ph.D. Thesis, Vrije Universiteit Brussel, Brussels, Belgium, 2013.
27. Goedkoop, M.; Heijungs, R.; Huijbregts, M.; de Schryver, A.; Struijs, J.; van Zelm, R. *ReCiPe 2008—A Life Cycle Impact Assessment Method Which Comprises Harmonized Category Indicators at the Midpoint and the Endpoint Level*; Report I: Characterisation; Ministerie van VROM Rijnstraat: Den Haag, The Netherlands, 2009.
28. Rapport annuel 2011. Available online: http://www.febelauto.be/nl/jaarverslag2011 (accessed on 17 October 2013).
29. Statistics Belgium. Available online: http://statbel.fgov.be/nl/statistieken/cijfers/verkeer_vervoer/verkeer/voertuigpark/ (accessed on 17 October 2013).
30. Ecoscore. Available online: http://www.ecoscore.be (accessed on 17 October 2013).
31. Jungbluth, N. Erdöl. In *Sachbilanzen von Energiesystemen* (in German); Final report No. 6; Swiss Centre for Life Cycle Inventories: Zürich, Switzerland, 2007.
32. Schweimer, G.W.; Levin, M. Life Cycle Inventory for the Golf A4. Available online: http://www.volkswagenag.com/content/vwcorp/info_center/en/publications/2007/01/Golf_A4__Life_Cycle_Inventory.-bin.acq/qual-BinaryStorageItem.Single.File/golfa4_english.pdf (accessed on 17 November 2013).
33. Mearig, T.; Coffee, N.; Morgan, M. Life Cycle Cost Analysis Handbook. Available online: http://www.wbdg.org/resources/lcca.php (accessed on 17 October 2013).
34. Van Mierlo, J.; Messagie, M.; Boureima, F.; Sergeant, N.; Six, D.; Michiels, H.; Denys, T. *Trans2House: Transition Pathways to Efficient (Electrified) Transport for Households*; Belgian Federal Science Policy Office: Brussels, Belgium, 2012.
35. ECB. Statistical Data Warehouse. Available online: http://sdw.ecb.europa.eu/(accessed on 17 October 2013).
36. Evolutie van de maximumprijzen van brandstoffen in België. Available online: http://www.petrolfed.be/nl/maximumprijzen/samenstelling-huidige-maximumprijzen (accessed on 17 October 2013).
37. Evolutie elektriciteits-en aardgasprijzen (incl. btw) voor huishoudelijke afnemers. Available online: http://www.vreg.be/sites/default/files/uploads/evolutie_elektriciteits-en_aardgasprijzen_incl__btw_voor_huishoudelijke_afnemers_25_oktober_2012.pdf (accessed on 17 October 2013).
38. Van den Bossche, P.; Vergels, F.; van Mierlo, J.; Matheys, J.; van Autenboer, W. SUBAT: An assessment of sustainable battery technology. *J. Power Sour.* **2006**, *162*, 913–919.
39. The China New Energy Vehicles Program—Challenges and Opportunities. Available online: http://documents.worldbank.org/curated/en/2011/04/14082658/china-new-energy-vehicles-program-challenges-opportunities (accessed on 17 October 2013).
40. Van Vliet, O.; Brouwer, A.S.; Kuramochi, T.; van den Broek, M.; Faaij, A. Energy use, cost and CO2 emissions of electric cars. *J. Power Sour.* **2012**, *196*, 2298–2310.