

# Evaluation of eco-efficient car lifecycles

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## ABSTRACT

In order to minimize both economic and ecological resource consumption during car lifecycles, two basic approaches exist. The first approach is to design a car for a longer than usual lifecycle and to use it for up to 20 years rather than the average car lifetime in today's markets. The second approach is to replace a car as early as its successor is available on the market, offering significant technological innovation and an option to benefit from better economical and ecological performance.

The first approach roots back to first studies presented in the 1970s ([1], [2]) and aims at slowing down material cycles. In contrast, the second approach aims at minimizing overall resource consumption taking advantage of accelerated material development cycles and benefits from technological advances such as lightweight designs, hybrid power trains or even hydrogen power trains.

In practice, the most eco-efficient strategy will be an intelligent combination of the two approaches. Looking for example at a 35 years period, where 5 subsequent car models with a production period of 7 years each are offered to the market, at some stages it will be more efficient to keep the previous model longer and at some stages scrapping an old car and using a car of best available technology may offer less environmental impacts than using the old car furthermore.

This paper presents a new evaluation model that offers a lifecycle assessment that combines both ecological and economic considerations and provides an insight into system behaviour and interaction of parameters such as future technological innovations and changes to legal requirements.

## Introduction

A recent Belgian study [3] has shown, that “Optimizing the product life time” of automobiles may lead to lower greenhouse gas emissions. Older publications ([4], [5]) offer similar views, but no real quantitative or qualitative analyses are truly provided. Known studies focusing on passenger cars often consider either only the ecological or the economic aspects of the problem, but fail to link both in an adequate way.

This study aims at developing an evaluation model that identifies passenger car utilization lifetimes which are both ecologically and economically efficient. The model offers an insight into system behaviour and interaction of parameters that impact the vehicle’s usage phase such as future technological innovations and legal requirement changes.

## Strategies for an eco-efficient car use phase

Many lifecycle assessment studies show, that the utilization phase in a car’s lifecycle has the biggest impact on the environment. Therefore, the vehicle’s use phase offers the highest potential to save both economic and environmental resource consumption. The extent of ecological and economic burden a car generates depends primarily on vehicle class type, age, technological state, and individual driving behaviour.

Figure 1 shows a qualitative representation of how vehicle utilization phases during a given observation period differ with respect to economic and environmental resource consumption. The three basic cases depicted in the diagram are explained in the subsequent sections.

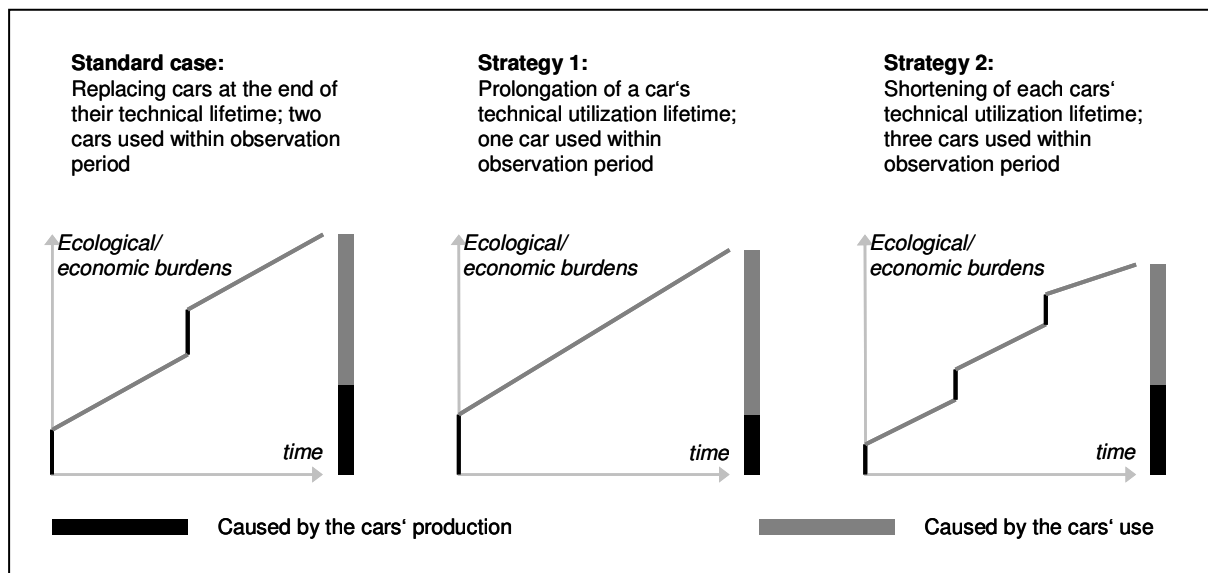


Figure 1: Schematic comparison of the three basic cases for an eco-efficient car use phase.

### Standard case: Replacing cars at the end of their technical utilization lifetime

The standard case, depicted in figure 1, is defined by operating cars throughout their entire technical utilization phase and replacing them with a new car only after this phase is completed. The replacement car is again used until its technical utilization lifetime is achieved.

### Strategy 1: Prolongation of a car’s technical utilization lifetime

This approach requires an extension of each car’s technical lifetime to cover the entire observation period. This can be done by investing more resources in producing car components which are designed to last the entire observation period. Strategy 1 shown in figure 1 shows increased production-related burdens per car as a result of these longer lifecycle requirements. These higher initial costs are compensated by the fact that no second car needs to be produced to fulfil the utilization lifetime. For example, expensive lightweight material may be profitable with regards to the longer use phase in this particular case. The application of these high-quality materials result in reductions in overall weight and vehicle fuel consumption, which then lead to lower economic and environmental burdens within the vehicle’s utilization phase. Strategy 1 targets to take advantage of any potential technological advances available during the initial production phase.

### **Strategy 2: Shortening of each cars' technical utilization lifetime**

Strategy 2 focuses on the potential reduction of the car's use phase economic and ecological resource consumption. This strategy proposes that a substitution before the end of a car's technical lifetime may be beneficial, especially when replacement cars incorporate innovative technological improvements.

In strategy 2, each car is replaced by its immediate successor as soon as the latter is available on the market, offering significant technological improvements to the entire car sequence. By shortening each car's utilization phase, the sequential production of a second and a third car is necessary to provide mobility within the considered period. This results in both overall ecological and economic burdens due to increases in the number of vehicles produced and their respective resource consumption. This increase is compensated by diminished consumption during the utilization phase as each succeeding car contains innovative technologies which offer utilization advantages concerning weight and fuel consumption. Moreover production efforts invested in developing each single car may decrease due to the elimination of design requirements aiming at extending the vehicle's technical lifetime.

Both strategy 1 and 2 represent the extreme limits of a multitude of opportunities. In practice, the most eco-efficient strategy will be an intelligent combination of the two approaches.

### **New approach for identification of eco-efficient car use phase**

In past research studies, several product lifetime optimization analyses have been carried out. Most authors have devoted themselves to a product lifetime optimization from an ecological perspective ([8], [9], [10], [11]). Only a few studies have combined both the ecological and economic aspects of the problem, but results in these studies were aggregated on a very broad level ([6], [7]).

The differing results of these studies show that lifetime optimization of products, cars in particular, depend on the assumptions and system boundaries used in their respective evaluation models. A product's lifetime is influenced by many factors. Thus a "lifetime optimization" is known to encounter conflicting goals. The vehicle utilization lifetime cannot meet every competing goal but can be at best somewhat efficient. It is therefore more important to focus on the interactions within the system of individual car utilization lifetimes and automobile substitution opportunities throughout a fixed reference period.

The combination of both ecological and economic aspects in a vehicle's lifecycle assessment is absolutely necessary. There are no advantages to be gained from ecological efficient cars if they are not purchased and used by consumers. The consumer acceptance of eco-efficient cars depends mainly on costs, which can be adapted to a common evaluation model where a data base can be developed to enable quantitative comparison of environmental results.

In contrast to previous studies, this new approach for identification of an eco-efficient car utilization phase bases on an evaluation model that considers different technologies and hence is open to innovation steps. The model allows varying the length of the cars' usage phase in yearly intervals. In addition, the model permits working with a single car specimen as opposed to a car fleet as is normal convention in most other models. This allows for a concrete definition of each car while considering its availability on the market, specific key technologies and variable use periods.

### **Description of the system considered**

To implement all assumptions made above, the study cannot be based on a macro-economic analysis of the automotive market. As an exemplary extract, a system composed of different sequences of used car models should be examined. A sequence is defined as the successive use of cars within a given observation period. A sequence can consist of one or more cars depending on the technical lifetime of each car in the sequence and the length of the observation period. Different car sequences result by varying the length of each cars' utilization phase. To build a car sequence, succeeding specimens belonging to a specific car production series were adapted to the model. This study bases on succeeding former and future models of the BMW 5 series. The advantage of this approach is that the cars are comparable in relevant parameters such as size, weight, configuration and engine power or fuel consumption. Thus transparency in the model is guaranteed not only between the different car specimens but also within the car sequences. In order to deduce the car sequences, it is necessary to first define the observation period then the maximum lifetime and at last the period in which cars are available on the market.

**The new evaluation model**

Since the car sequences selected are configured by technological differing vehicles, it is necessary to define their particular order and the explicit length of their use phase. Three key parameters have to be established: the observation period, the technical lifetime of each car in a sequence, and the number of years a car is available on the market.

Within this study the period from 1995 until 2030 is of interest. That means that car sequences need to cover a period of 35 years.

The second important parameter is that of the car’s technical utilization lifetime, which means the maximum length of the usage phase. In this model, the maximum utilization lifetime for each car is assumed to be a consecutive 15 year period.

Accordingly, in the modelled 35 year scenario, mobility cannot be provided by just one car but rather multiple cars, since the observation period exceeds that of a single car’s technical utilization lifetime. Consequently, there is more than one possible car sequence.

The number of car sequences as well as the interior structure of the car sequences is limited by a third parameter, the availability of cars. Since only the succeeding vehicles of one series build a car sequence, their period of availability must be equated to the period in which cars are produced and available on the market. Within this evaluation model an availability of 7 years is assumed for each vehicle. The relationship between observation period, maximum lifetime and market period of used cars is showed in figure 2.

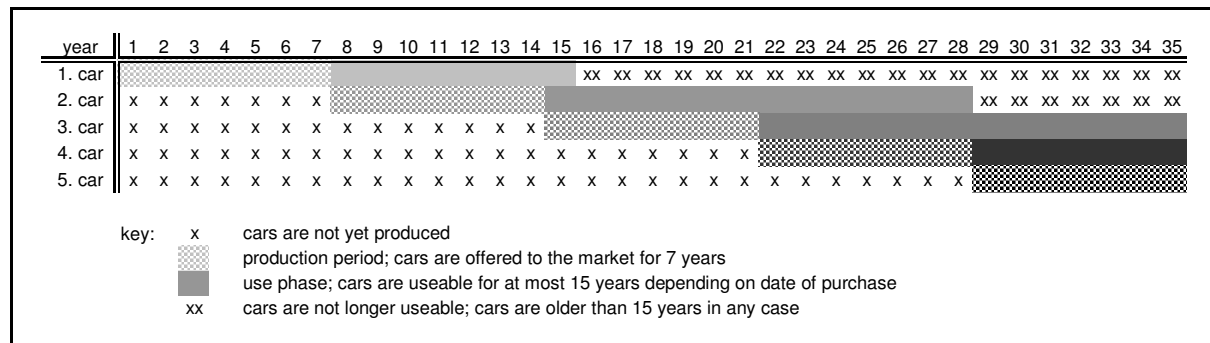


Figure 2: Availability of five subsequent cars within a 35 year observation period depending on production period and utilization lifetime.

The car sequences are derived from an algorithm that transfers the information about the sequences to numerical series regarding the given parameters. Looking at the specified 35 year period, 5 subsequent car models with a production period of 7 years are offered to the market, resulting in exactly 3,379 possible car sequences. These are analysed regarding both their ecological and economic performance. The comparison of results will allow an understanding of relationships between the length of a vehicle’s utilization phase and other related parameters such as innovative technologies and the reduction of fuel consumption rates.

**Methods of analysis**

To assess the car sequences from an ecological point of view, the whole lifecycle of each car is evaluated using a Life Cycle Assessment (LCA). These case studies are being geared towards international standards, such as ISO 14040 and ISO 14044, and evaluate the cars’ environmental performance in regards to the impact it has on the categories of energy demand, global warming potential, photochemical creation potential and acidification potential. The individual results for each car are aggregated to a total result for each car sequence.

As required above, the economic assessment of each car sequence has to meet the environmental assessment method and data basis. For this reason Bubeck [12] developed a special Life Cycle Costing (LCC) method for vehicles that goes well together with LCA. This LCC method considers all cost and proceeds over a car’s entire lifecycle, including the production, utilization, and recycling phases. This tool determines the lifecycle costs of each individual car. The lifecycle costs of each car in a sequence can then be aggregated to determine a car sequence’s total cost.

The combined implementation of LCA and LCC provides an opportunity to configure the evaluation model that describes the modelled system and allows for comparable quantitative results.

It is expected that the total results can be divided in clusters of car sequences that are extremely eco-efficient and those, which are not. It will be interesting to analyse, which patterns and mechanisms cause the eco-efficiency and which conclusions can be made concerning the cars' utilization lifetimes. Furthermore the results provide the opportunity to determine interactions between ecological and economic aspects.

### **Conclusion**

The new approach presented in this paper builds upon existing studies the identification of an eco-efficient car's utilization phase through the derived evaluation model. The model's basic principle is to perform a combined ecological and economic lifecycle analysis that uses an identical method and database in its calculation. The analysis of a cars' lifetime must be based on a model that allows defining individual car sequences, because the eco-efficient lifetime of a vehicle depends very much on the type and age of the preceding and succeeding models. The examination of a car fleet using averaged data fails to provide the necessary transparency to breakdown results to single cases. This new approach also offers an insight into the interaction between system parameters that can be applied to other scenarios.

Currently the project still is in its data collection phase. As soon as sufficient LCA and LCC data is available a first evaluation will be possible.

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