Comparison of Energy Consumption and Green-House-Gas emissions of different mobility scenarios with Optiresource®

The “Well-to-Wheel” Optimizer used at DaimlerChrysler

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Abstract

A software tool (Optiresource®) for the analysis and visualization of car-related energy chains and energy scenarios (in terms of energy consumption, greenhouse gas emissions and fossil fuel content) has been developed. It has two operating modes (query and scenario) which allow either the comparison of energy consumption and green-house-gas (GHG) emissions of different energy chains or to calculate the total energy consumption and GHG-emissions of chosen scenarios. The scenario mode helps to understand the effects of the introduction of new fuels and drive trains on total energy use and GHG-emissions. The results depend on the available data basis, especially concerning vehicle fleet composition, drive patterns and driven distance per year and vehicle. Though simplifications concerning these parameters are necessary, the software is suitable to show general effects. We have used Optiresource® in a first approach in a simplified scenario to compare e different options for future transport, like biodiesel, ethanol, hybridization and hydrogen fuel cell vehicles . It can be seen that there are significant differences in reduction of energy consumption and GHG-emissions. Assuming the same share of replacement for every of the investigated options (20% of all cars are replaced by the investigated alternative) shows that hydrogen used in fuel cells leads to the largest reduction effects compared to a base scenario, whereas introduction of hybrids has a significantly lower effect.

Keywords: Alternative Fuels, Alternative Drive Trains, Well-to-Wheel Analysis, Energy consumption, Green-house-gas emissions

1. Introduction

Security of fuel supply, air quality and climate change are the main reasons for the need of the introduction of alternative fuels and alternative drive trains for transport applications, especially road transport. A considerable number of options and solution is currently being developed, some are already on the road. Due to the variety of different fuel and drive train options it is not easy to asses the effects of those solutions on total energy consumption and the environment. Several studies concerning the energy consumption and green-house-gas (GHG) emissions of different transport options have been carried out and published. As the matter is very complex, only experts are able to interpret the results of such studies.

Furthermore, results showing the benefit of a particular solution in terms of fuel consumption and GHG-emissions for a single car do not show the effect of the introduction of the technology in total. In order to enhance the understanding of such effects, DaimlerChrysler decided to develop a software tool for the visualization of single energy chains for road transport applications and build up of scenarios for mobility. The software uses data for energy consumption and GHG-emissions from WTW-studies which already have been carried out. In the first version, most data were taken from the EUCAR/CONCAWE/JRC-WTW-study [1]. As this study did not cover all possible options, data for some drive train options have been created by the Ludwig Bölkow System Technology GmbH and integrated in Optiresource®. The software can either be used to compare single energy chains in the query mode or to investigate the impact of new fuel and drive train options on total energy consumption and GHG-emissions. More Information about Optiresource® can be found on **http://www.optiresource.org**. Furthermore a public version of the Optirsource® query mode is located on the DaimlerChrysler website under **http://www.daimlerchrysler.com** [3]

2. Software description and data sources

The base philosophy of the Optiresource®-Car software is to use existing data implemented in a purpose-made database, and several specific input/output bi-lingual (English and German) interfaces, according the kind of user. The database plus the user interface constitute the WtW system.The data used for the computations were taken from the "Well-to-Wheel Analysis of Future Automotive Fuels and Powertrains in the European Context" [1], Version 2a (December 2005) realized by EUCAR and CONCAWE in cooperation with the European Joint Research Center. Pathways which have not yet been covered in this study have been calculated by LBST using the E3 database. All data from the study and these of the additional chains were incorporated in the database of the visualization software. This database contains the data defining the different energy paths from WtT and TtW in terms of energy efficiency, greenhouse gas emissions or any other available parameter. The users do a query to the database and they get the results in term of visualization of the absolute or relative values of the efficiency, CO2 emission, etc. of each energy path. The way the query is done and the way the results are displayed depend on the kind of users, but anyway they work on the same data.The data base stores and elaborates the data, the user interface manages how the query are done and how the results are displayed.

2.1.Specifications

Optiresource® has the following hardware and software requirements:

- PC with Windows 2000/XP and a CD-ROM reader;
- The library of the Microsoft .Net Framework must be installed on the hard disk;
- The execution must be done from the CD-ROM, neither installation on the hard disk nor writing operation on the hard-disk are allowed; the libraries of the .Net Framework or a link for the downloading from the MS web site are included in the CD-ROM

2.2. ;System architecture

The system has 2 main sub-systems, the processor unit and the user interface, both based on a purpose made software. The system can be set up for different languages and will have two working modalities
- Query mode
- Scenario mode

In the "query" mode the user can compare different pathways according primary energy use and green-house-gas emissions. The result is displayed as energy or GHG-emissions per pathway, but the overall influence of the deployment of the respective pathway on total energy consumption and GHG-emissions of a region or a state cannot be evaluated. For this purpose, the the "scenario" mode has been developed. In this mode users can do assumptions about the energy mix, the vehicle fleet, the technical improvements etc. and see the impact on total energy consumption and GHG-emissions.

2.3. Query mode

The user chooses the quantities they like to see (energy, GHG or both in the first version), the time period to which these quantities refer (now, 2010 or both for the first version) and the energy chains. To select the energy chains, the user can select one or more primary energies and/or one or more processes, one or more fuels and/or one or more powertrains. It is possible to select all the chains with one single command. The selection can be done in a random way (the sequence of the choices is free). The system automatically pre-selects all the possible choices, according the selections made in the previous step. At the end of the query, the results are displayed in a bar diagram. The system is already designed to include the choice of various geographical contexts.

The query is completed defining:

- the quantity or quantities to be displayed as results, divided in quantities related to the technology (e.g. MJ/km, l/km/miles, etc.) or related to political/social aspects (e.g. g CO_2/km, effects on the human health, effects on the ecosystem etc.);
- how to display the results, i.e. if as absolute values or relative values (%).

During the definition of the query, the results are displayed in the same window as a graphic. The users can change one or more criteria, looking immediately the effects. The results can be printed and can be exported as a text file for an importation into a spreadsheet (e.g. Excel). The option to visualize the WtT and TtW is implemented too. The query level described above is the most complete and it can be assumed that it is devoted to the professional users. For other users, like children, motorshow visitors, WEB users, etc. a different interface with a simpler query mechanism is implemented

2.4. Scenario mode

In this modality the user defines the energy mix, the composition of the vehicle fleet (type, km/year driven, and quantities) the technical improvements of a certain geographical area. As an alternative, pre-set scenarios can be up-loaded and modified. The results show what happens in that area in terms of quantities related to the technology (e.g. MJ/km, l/km/miles, etc.) and/or related to political/social aspects (e.g. g $C0_2$/km, effects on the human health, effects on the ecosystem etc.) or any other available quantity in comparison with the present situation of that area.

3. Description of investigated scenarios

3.1. Basic Scenario and Reality Check Scenario

Building scenarios for future road transport first needs a basic scenario in order to make reality checks and then compare results of the future scenarios with the basis. Detailed data for the composition of vehicle fleets concerning car types and drive trains on the road in different regions of the world are not always available. Theoretically it is possible to build a base scenario with a detailed differentiation in car categories (e.g. small cars, medium size cars, large size cars, etc.), also considering the share of gasoline and diesel engines for each category. For the existing vehicle technology all necessary technical data as fuel consumption and GHG-emissions are also available. However, when building future scenarios, those data would be needed for every new drive train technology. As either only a limited number of cars (e.g. fuel cell vehicles) or only a limited choice of types (e.g. hybrid vehicles) have been produced so far, it is not possible to generate the necessary data (fuel consumption and CO_2-emissions) for those drive train technologies for every car type. For this reason it has been decided to simplify all scenarios. Another simplification is to assume the same yearly mileage for every drive train, knowing that in reality diesel cars mostly have a higher mileage than gasoline cars. The base scenario consists of 50 million compact class cars, driving all 12,000 km per year. Furthermore the driving pattern was also simplified: it has been assumed that the cars are always driven in the New European Drive Cycle. The share of diesel engines in the base scenario is 23%, the share of gasoline engines is 77%. All other drive trains are disregarded in the base scenario. Table 1 displays the parameters chosen for the base scenario.

For reality check we have also used Optiresource® to obtain the respective calculated energy consumption and GHG emissions for all passenger cars in Germany. The numbers used for this scenario were taken from a publication of the DIW [2] and are shown in table 2.

Table 1: Parameter list for Base Scenario

Car type	**Mileage/car**	**Number of cars**	**Driving Pattern**	**Drive Train**	**Fuel**
Compact class	12,000	38.5 Mio (77%)	NEDC	Otto engine (Port injection)	Gasoline from crude oil
Compact class	12,000	11.5 Mio (23%)	NEDC	Diesel engine (Direct Injection with particle filter)	Diesel from crude oil

Table 2: Parameter list for Reality Check Scenario

Car type	**Mileage/car**	**Number of cars**	**Driving Pattern**	**Drive Train**	**Fuel**
Compact class	10,900	36.0 Mio (79%)	NEDC	Otto engine (Port injection)	Gasoline from crude oil
Compact class	19,500	9.6 Mio (21%)	NEDC	Diesel engine (Direct Injection)	Diesel from crude oil

3.2. Alternative Scenarios

Currently a number of different options for future mobility are in the discussion, some of those being already on the road to some extent, some others being still in the development phase. We have investigated scenarios for four different future scenarios. In every case we have replaced 20% of the cars of the base scenario with the investigated fuel/drive-train option. The options which have been investigated are: 1) 20% of all cars fueled with biofuels, 2)20% of all cars replaced by hybrid electric vehicles fueled with conventional fuels, 3) 20% of all cars replaced by fuel cell vehicles fueled with hydrogen from wind energy and 4) 20% of all cars replaced by electric vehicles with lithium-ion battery for urban use. The detailed parameters are shown in tables 3 to 6.

Table 3: Parameter list for the Biodiesel Scenario

Car type	**Mileage/car**	**Number of cars**	**Driving Pattern**	**Drive Train**	**Fuel**
Compact class	12,000	33.5 Mio (67%)	NEDC	Otto engine (Port injection)	Gasoline from crude oil
Compact class	12,000	6.5 Mio (13%)	NEDC	Diesel engine (Direct Injection with particle filter)	Diesel from crude oil
Compact class	12,000	10.0 Mio (20%)	NEDC	Diesel engine (Direct Injection with particle filter)	Biodiesel from rapeseed

Table 4: Parameter list for the Hybrid Electric Vehicle Scenario

Car type	**Mileage/car**	**Number of cars**	**Driving Pattern**	**Drive Train**	**Fuel**
Compact class	12,000	33.5 Mio (67%)	NEDC	Otto engine (Port injection)	Gasoline from crude oil
Compact class	12,000	6.5 Mio (13%)	NEDC	Diesel engine (Direct Injection with particle filter)	Diesel from crude oil
Compact class	12,000	5.0 Mio (10%)	NEDC	Parallel Hybrid with Otto engine	Gasoline from crude oil
Compact class	12,000	5.0 Mio (10%)	NEDC	Parallel hybrid with Diesel engine	Diesel from crude oil

Table 5: Parameter list for the Fuel Cell Vehicle Scenario

Car type	**Mileage/car**	**Number of cars**	**Driving Pattern**	**Drive Train**	**Fuel**
Compact class	12,000	33.5 Mio (67%)	NEDC	Otto engine (Port injection)	Gasoline from crude oil
Compact class	12,000	6.5 Mio (13%)	NEDC	Diesel engine (Direct Injection with particle filter)	Diesel from crude oil
Compact class	12,000	10.0 Mio (20%)	NEDC	Hybridized Fuel Cell Drive Train	Hydrogen from Wind energy (by electrolysis)

Table 6: Parameter list for the Battery Electric Vehicle

Car type	Mileage/car	Number of cars	Driving Pattern	Drive Train	Fuel
Compact class	12,000	33.5 Mio (67%)	NEDC	Otto engine (Port injection)	Gasoline from crude oil
Compact class	12,000	6.5 Mio (13%)	NEDC	Diesel engine (Direct Injection with particle filter)	Diesel from crude oil
Compact class	12,000	10.0 Mio (20%)	NEDC	Li-Ion Battery and Electric Motor	Electricity from Wind energy

4. Results

4.1. Energy Use and GHG Emissions for Reality Check Scenario

As already explained in the description of the basic scenario, we have used a simplified scenario. As simplification always causes uncertainties, we have checked the accuracy of the model results by comparison with real data for passenger cars in Germany in the year 2005. Table 7 shows the data obtained with Optiresource® as well as the published data.

Table 7: Comparison of Optiresource® results with data for Germany

	Total energy consumption for passenger cars tank-to-wheel (TTW) (MJ)	Energy consumption per 100 km TTW (MJ/100km)	Total GHG emissions from passenger cars TTW (tons)	GHG emissions per km TTW (g_{CO2eg}/km)
Data for German passenger cars in 2005	1.48×10^{12}	255	110×10^{6}	189
Results from Optiresource® for simplified scenario for Germany 2005	1.22×10^{12}	210	92×10^{6}	158

The comparison shows that both TTW energy consumption and TTW-GHG emissions of the Optiresource® scenario and real data differ in the range of 15%. Considering the simplification of the inputs for the scenario, using only one car type, deviation is rather small. The fact that the Optiresource® results are lower than real data can be explained with the different ages of the vehicles. In Optiresource® the data for the 2002 compact class reference vehicle were used, whereas the cars being actually on the road show a broad distribution of ages and are mostly equipped with older engines with somehow higher fuel consumption and CO_2-emissions. Other main reasons are the variety of vehicle types on the road and the real driving patterns which also differ from the NEDC. Taking all this into account, the results obtained with Optiresource® give a fairly good correlation with reality.

4.2. Comparison of the base scenario with alternative scenarios

Figure 1 shows the total energy consumption and GHG emissions for the whole fleet of 50 Mio passenger cars for the five investigated scenarios. Due to the simplification the results do not represent the exact effect in the real world but they show general trends and impacts for the different technology options. As the number of cars in the fleet and the driven mileage per car in the base scenario are different from the reality check scenario the total energy and GHG also differ. For the base scenario, the total energy used for a number of 50 Mio passenger cars is 1.28 x 10^{12} MJ Well-to-Wheel (WTW), according GHG_{WTW} is 97.4 Mio tons CO_{2eq} Introduction of 20% of HEVs leads to reduction of GHG emissions and energy use as well, however the degree of reduction is not very high. Fueling 20% of the fleet with biodiesel leads to a significantly higher reduction of GHG-emissions, but also to an increase of total energy use for passenger cars. Introduction of 20% FCVs leads to a significant reduction of GHG-emissions as well to a significant reduction of energy use. 20% BEVs show a similar effect on GHG-emissions as the FCV case and lead even lower energy use than FCVs. However, it has to be considered that BEVs do not have the same driving range as the other investigated vehicles and also need a long recharging time, thus being a solution mainly for use in urban areas, whereas all other options provide the full requirements of a passenger car for general use.

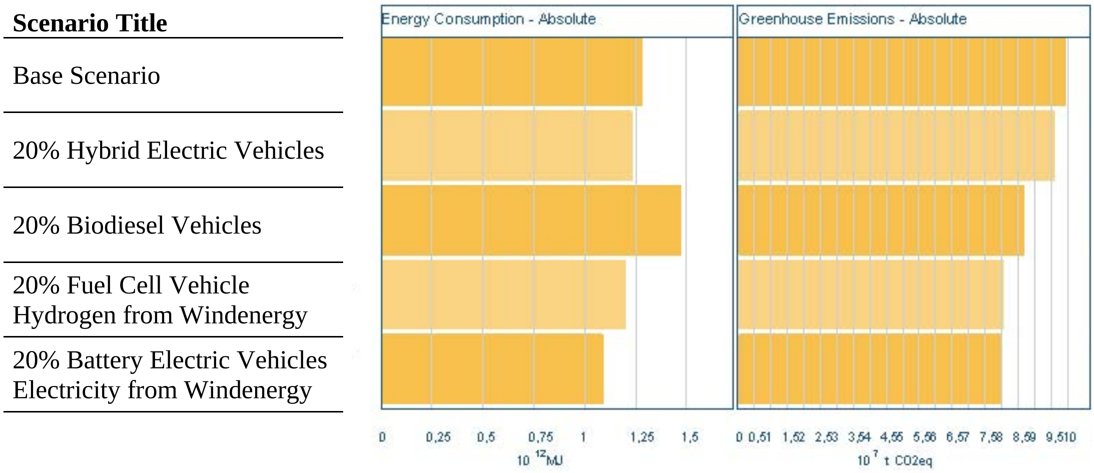

Figure 1: Energy consumption and GHG-emissions for the five scenarios

5. Conclusions

It has been shown that the scenario mode of Optiresource® is a powerful tool for the evaluation of different scenarios for future transport solution. Principally it is possible to represent a comprehensive mix of drive train technologies and fuels as well as car types. However, the necessary input data are not always available and thus the first investigated scenarios are simplified ones. Nevertheless, the results of Optiresource® show a very good correlation with real data. Comparison of five scenarios clearly shows that there are significant differences in the effect of the various technologies on energy consumption and GHG-emissions.

6. References

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7. Authors

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Acknowledgement:

The authors would like to acknowledge the very valuable contributions for the development of the Optiresource® software and calculation of scenarios from Prof. Bernd Höhlein and Mr. Martin Vallon.