Project Achievements / Results

"Testing and demonstration of new technologies in daily operation in transport (waste collection)"

Introduction

The overall aim of the project Care-North was to develop a comprehensive, strategic and practical approach for the urban and regional transport to deal with climate change and declining oil supplies.

This part of the project deals with the collection of municipal solid waste which is a process that consumed a lot of energy caused by the permanent stop and go from bin to bin during waste collection.

Caused by inefficient use of the big engines installed in conventional trucks, the fuel consumption of waste collection vehicles during waste collection is much higher than during the journeys from and to the waste treatment facility.

To address this issue most producers of waste collection trucks have developed solutions like collection vehicles with fully electric collection unit or vehicles with electronic auxiliary engines feed from batteries that are charged during deceleration the vehicle.

The effect of the use of these new techniques on different factors like fuel consumption, wear of breaks and on the economics of waste collection had to be evaluated scientifically. For this, a diesel-electric waste collection vehicle was used for a demonstration employment in the city of Bremen by using it for the collection of municipal solid waste on several collection tours.

Approach

The evaluation of the diesel-electric hybrid vehicle was done by comparing the performance of the hybrid vehicle with a conventional vehicle of the same type. This comparison was done by collecting data during daily work and on a specific designed test track.

The vehicles

Faun, a company specialized on the production of waste collection and street cleaning vehicles, built the waste collection vehicles used during the project.

For the evaluation of the diesel electric hybrid waste collection vehicle, the two vehicles are compared in their performance during daily work in respect of fuel consumption and involved CO_2-emissions.

The used vehicles were both so called rotary drum vehicles where the waste is collected and compacted in a rotating drum. The drum and all other components that are necessary for the waste collection, for example the appliance for tipping the bins, are mounted on a conventional truck frame, that was build by Mercedes Benz. Both collection vehicles have comparable engines with 240 kW for the hybrid and 210 kW for the conventional vehicle.

The dimensions of the drum are the same on both vehicles. Also the total maximum weight of both vehicles is identical with 26t. The main difference between the two vehicles is the drivetrain used during waste collection and the vehicle load capacity.

While the conventional vehicle uses the big truck engine during waste collection, that runs far away from its ideal operation point, the hybrid vehicle switches to its diesel-electric drivetrain, that consists of an electric drive-motor, a small 2.0 litre diesel engine as electricity generator and high-power capacitors (SuperCaps) as energy storage. These drivetrain was especially designed for the requirements during waste collection. Through that, the small diesel engine could be run in its optimal operation point. The optimized operation and the smaller size of the engine lead to fuel savings. The additional parts have a total weight of around 1.5 t. That means, that the hybrid vehicle has lower vehicle load capacity than the conventional vehicle.

Picture 1: Faun ROTOPRESS DUALPOWER during test drive on the test track

The field test

For testing the diesel-electric collection vehicle under real-life conditions, 20 waste collection tours were selected from a pool of collection tours in Bremen. These 20 collection tours were than covered several times by both collection vehicles in a 14 day cycle. The collection tours are spread over the whole area of the city of Bremen. The diversity of these tours was the main aspect during the selection process. To cover as much different collection scenarios as possible, it was necessary to assemble a cross-section from all possible structures of collection tours. Tours with high population density as well as tours in peripheral regions, where the building and population density is more urban.

Data loggers were installed in both vehicles for data collection. These loggers record all relevant parameters, like driving speed, used fuel, drive distance or engine revolution. The collected data were then processed and evaluated in respect of fuel consumption, separated for the actual collection process and the journeys between treatment plant and collection area.

Figure 1 shows exemplarily a graphical analysis of the waste collection with the main parameters recorded during daily work. These graphics were mainly used to get an overview on the progress during waste collection, to find out where special events like a stopover at the treatment plant happened.

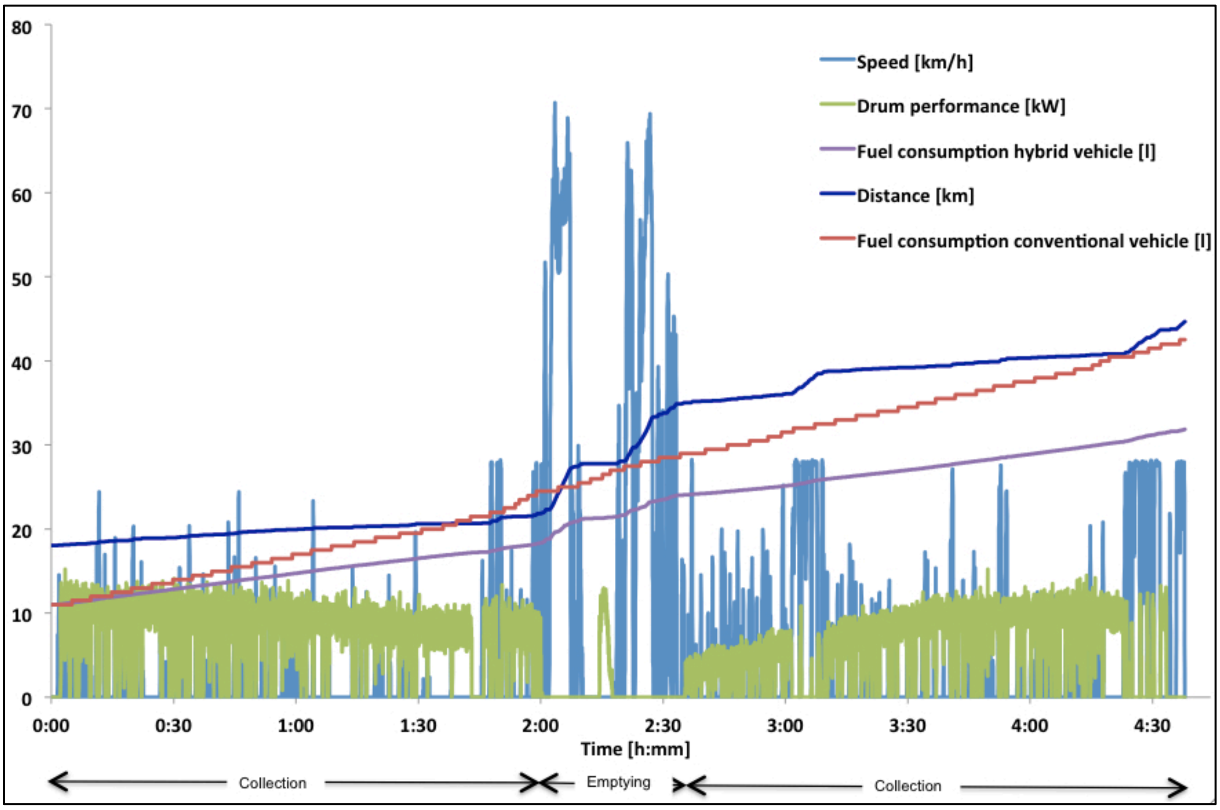

Figure 1: Example of a visual evaluation of the collected data for one collection tour

Test track

For a more detailed analysis of the coherences between key parameters related to the collection areas and the fuel consumption of the vehicles, a test track was designed. It was designed to test the vehicles under controlled conditions with just one parameter affecting the fuel consumption. The factor, that seems to have the biggest affect on the fuel consumption of the two vehicles during waste collection, is the number of bins per distance, which can also be expressed as the average distance between the bins.

To determine the affect of the distance between the bins on the actual fuel consumption, the test track was driven by both vehicles, simulating a real waste collection process, with bins on the side of the track, that have to be tipped. The distance between the bins were changed between the tests, starting with 10 m going over 20 and 50 m up to 100 m. The overall driving distance per test was increased in each case, the more distance between the bins was adjusted. That was necessary because a minimum time per test was needed to get sufficient data for evaluation and the time per round decreases with increasing distance between the bins.

In addition to the simulated collection the fuel consumption for tipping bins was ascertained by tipping bins for 10 minutes on each vehicle. The fuel consumption per tipped bin and per minute could be ascertained on that way.

Carbon footprint

The carbon footprint of a product or a service describes the balance of emitted gases that are relevant to the climate change for the whole lifetime of the product, from the manufacturing of the needed basic materials to the production of the product itself, the use and the disposal of the product.

For the determination of the emissions during the production of the vehicle, datasets from a database especially made for the creation of carbon footprints called EcoInvent 2.0 were used. The Swiss Centre for Life Cycle Inventories created this database. It contains datasets for a large range of products and activities, from energy production over building activities to transport of material and people and also for several disposal processes.

One example for a used dataset is the production of a waste collection vehicle with a total weight of 21 t. The vehicles used for this test have a total weight of 26 t. For the adaption of the dataset to the higher weight of the used vehicles the emissions are multiplied with the factor 1.24. This correlates with the ratio of the weights of 21 t and 26 t.

Because both vehicles have the same base, the emissions caused by the production are calculated with the dataset for the conventional waste collection vehicle. The additional emissions for the production of the hybrid vehicle cause by the additional parts like the SuperCaps or the electric driving motor are also calculated with datasets from the EcoInvent database multiplied with the weight of these parts.

The use phase is calculated with the results of the field test (fuel consumption) and the parameters shown in Table 1.

Table 1: Parameters for the calculation of the use phase for carbon footprint

	Hybrid vehicle	Conventional vehicle
Lifetime (Years)	8	8
Working days per Year	280	280
Km per working day	70	70
Used fuel per 100 km in L	59,7	83
CO_2-eq for use of 1 L Diesel	2,63	2,63
CO_2-Emissions for produktion of 1 L Diesel	0,63	0,63

Results

The results of all tests conducted in this project have shown, that significant savings can be generated by the use of a diesel-electric hybrid waste collection vehicle. But there are big differences between the savings from the different collection tours caused by the tour characteristics. All these results and effects are described in the following section.

Fuel savings and CO_2-Impact

The conducted tests have shown, that savings in fuel consumption (and with that also in greenhouse gas emissions) can be achieved through the use of the diesel-electric hybrid vehicle. The savings are mainly achieved during the actual process of waste collection. During the journeys from and to the collection area the hybrid and the conventional vehicle have nearly the same fuel consumption.

The averaged savings achieved during actual collection in the field test were 38.9 % (fuel consumption per 100 km collection stretch). For the parameter of consumed fuel per collected Mg of waste the savings are nearly the same with 37.6 %. Tanking the whole collection tour into consideration the savings decreases to 28.1 %. The different shares of transfer journeys and collection compared to the total stretch cause this as well as the different fuel consumptions for collection and transfer journeys.

Tanking a more detailed look into the results by looking at single collection tours, it came out, that the savings vary much from tour to tour. The maximum saving was 62 %, the minimum 8 %. The parameter with the biggest affect on the savings was the bin density. The highest savings were found in tours with a high number of bins and a short collection stretch what means a high bin density. That leads to the result that using the hybrid vehicle for collection tours in populous area results in higher savings. In more rural areas the bin density decreases. This results in decreased possible savings.

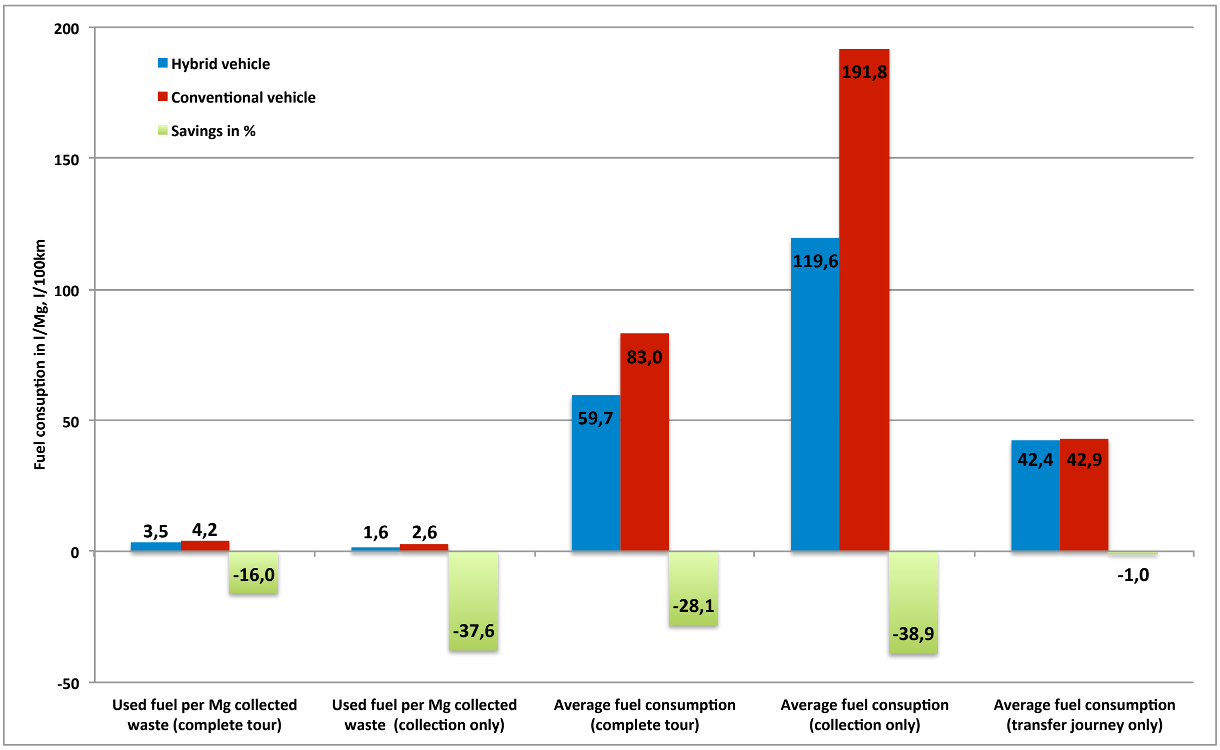

Figure 2: Average consumed fuel of the two vehicles for the 20 collection tours and achieved savings

Not only the relative parameters like fuel consumption per 100 km have to be taken into account for an overall evaluation of the performance of the hybrid vehicle. Also the absolute values as used fuel per tour in litre have to be considered during the evaluation. This is necessary, because the relative parameters do not take into account, that the driven distances during the collection trips are different for the two vehicles. That means, that the more driven km for the hybrid vehicle, caused by the reduced load capacity, are not considered in the calculated fuel consumptions. That is different with the average absolute consumption for the 20 collection tours.

A look on the values in Table 2 shows, that the absolute savings in fuel consumption of the hybrid vehicle during actual collection correlates with the relative savings. With 38.9 % the savings are nearly identical. However the fuel consumption of the hybrid vehicle for transfer journeys is higher than the consumption of the conventional vehicle. In average over the 20 collection tours included in this study, the hybrid vehicle uses about 20 % more fuel per tour for the trips to the treatment facility and back to the collection area. This is mainly caused by the reduced vehicle load capacity. The load capacity is reduced through the installation of the additional parts with a total weight of around 1.5 t. Caused by that, the hybrid vehicle is mostly not able to drive the whole collection tour without a stopover at the treatment plant. During the 20 tours included in the evaluation, the conventional vehicle managed to do 9 tours without a stopover, the hybrid vehicle did only 3. This weak point leads to a reduction of the overall savings of the hybrid vehicle during a collection tour to 15.8 %. Or spoken in litre, the 4.36 L more used fuel per tour for transfer journeys reduces the overall saving of 12.81 L during the collection to 8.39 L.

Table 2: Average fuel consumption over 20 collection tours

	Average cosumed fuel per tour (Whole Tour)	Average consumed fuel per tour (transfer journeys)	Average consumed fuel per tour (collection only)
Hybrid vehicle	44,68L	24,54L	20,09L
Conventional vehicle	53,08L	20,18L	32,90L
Diffenrence total	8,39L	4,36L	12,81L
Savings by using hybrid vehicle in %	15,81	-21,63	38,94

The result of the tests on the test track substantiate the results of the field test in respect of fuel savings during collection, and the changes while increasing and decreasing the distance between the bins.

The maximum fuel consumption was found on the smallest distance (10m) with 354 l/100km for the conventional and 198 l/100km for the hybrid vehicle. While increasing the distance between the single bins, the relative fuel consumption of both vehicles decreases to 118 l/100km for the conventional and 93 l/100km for the hybrid vehicle (see Figure 3). This result corresponds with the results from the field test, where the highest fuel consumption was found on tours with a high bin density.

Comparing the results of the test in respect of fuel saving it shows that the possible savings decrease with decreasing fuel consumption. It came out, that the savings with a distance of 10m between the bins is around 40 %. With a distance of 20 m the savings were only around

36 %. With a distance of 50m the savings decreased to around 23 % coming to 21 % with a distance of 100 m.

Combining the results of the field test and the results from the test track it can be stated, that it is possible to achieve up to 40 % savings in fuel by using the diesel-electric hybrid vehicle for the collection of municipal solid waste. It also came out, that the savings depend strongly on the structure of the collection area. The evaluation of the 20 tours in detail shows, that the fuel consumption is not only affected by the bin density. Many other factors directly related to the collection area have an effect on the consumption, but it is impossible to determine the exact magnitude of their effect. But it can be stated as fact, that their effect is lower than the effect of the bin density. The other factor that has a big effect on the fuel savings is the distance of the collection area to the treatment plant and the vehicle depot. By increasing the distance between collection area and treatment plant, the share of the actual collection on the totally driven distance decreases. That leads to a higher share of stretch with no savings, what lowers the overall relative saving.

Summarising all collected information, the best conditions for the employment of the diesel-electric hybrid vehicle are areas with high bin density and short distance to the vehicle depot and the waste treatment plant. This factor combination can mostly be found in cities, where the density of people and with that the density of waste bins is very high. The distance to the treatment plant is normally not related to a special type of collection area. Depending on the location of the plant, the best collection areas in respect of bin density could be further away, if the plant is located outside the city.

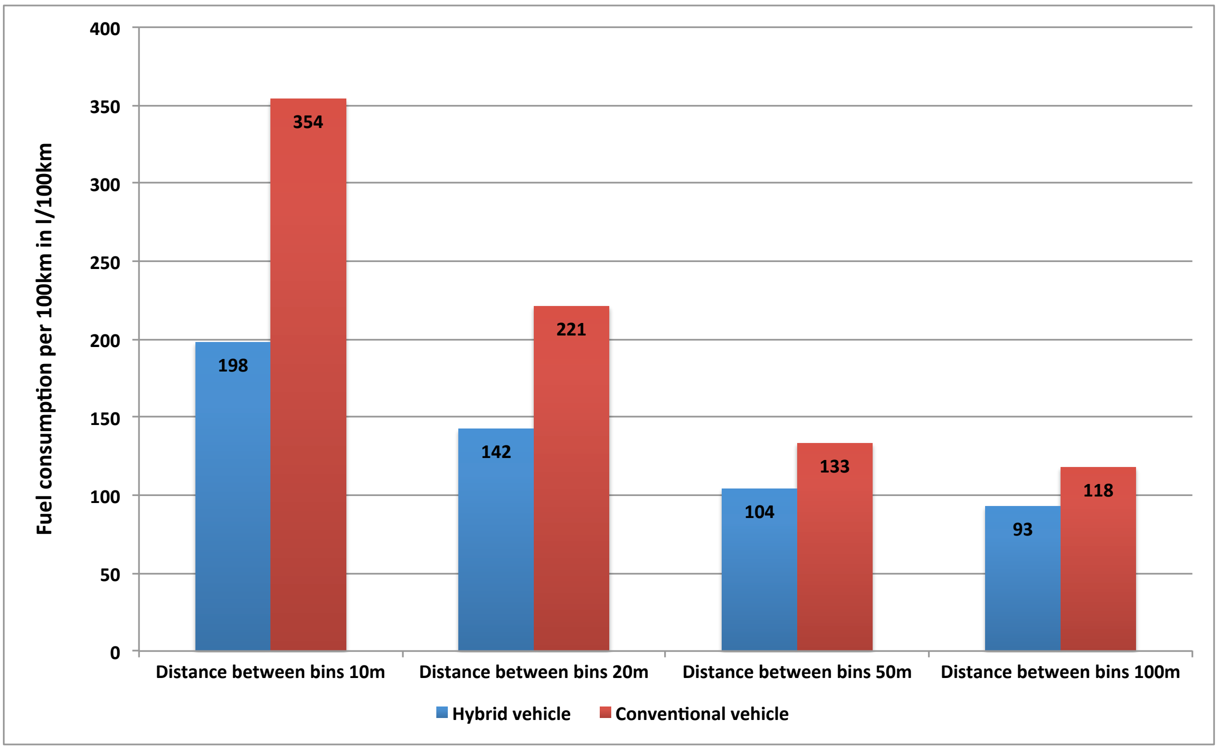

Figure 3: Consumed fuel of the two vehicles during test track driving for the different distances between the bins

The fuel savings that are determined in this section can easily be transferred into possible CO_2-savings. For the combustion of 1 litre diesel 2.63 kg CO_2 are emitted. 8.39 litres is the average total fuel saving per tour. This results in a saving of 22.07 kg CO_2-emissions per day or per tour. Multiplied with 280 working days per year total savings of 6.43 Mg CO_2 per year can be achieved. This amount is equal to the amount of CO_2-emissons that are emitted by cars with diesel engine during a driving distance of around 40,000 km[1].

Other impacts

Besides the saving of fuel during the use of the hybrid vehicle there are other impacts that have to be investigated.

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[1] Average of admitted cars in Germany in 2010; Calculation base: CO2-emissions from a 2010 admitted car: 152g CO2/km

First to mention are the possible savings in maintenance costs and materials. One example for that could be the hydraulic system most conventional waste collection trucks are equipped with. This has to be maintained, and the hydraulic fluid has to be changed at stated intervals. Also the tubes filled with the fluid have to be changed. The hybrid vehicle does not have a hydraulic system that has to be maintained. All functions that are realised with hydraulic engines on a conventional vehicle are working with low-maintenance electric motors. Another example are brakes. The hybrid vehicle does not use the conventional truck brakes during waste collection. The electric drive motor that acts as a brake and electricity generator during deceleration decelerates the vehicle. Through that, the brakes are not used that much what probably leads to a longer life of the brakes and a longer interval between brake changes.

For a comprehensive evaluation of the stated effects on the overall life costs and the carbon footprint of the vehicle it is necessary to analyse the maintenance processes of the two vehicles over a period where both got the main services for brakes and the hydraulic system. This was not possible during the project period. During the period of testing, neither the hybrid nor the conventional vehicle got a service on the brakes or the hydraulic system.

This means in effect, that a clear statement to the impacts of the hybrid vehicle on maintenance costs and used material is not possible.

Another advantage of the deployment of the hybrid vehicle is the lower noise emissions generated during operation. Caused by the use of more silent electro motors the noise emissions are around 3 dB lower than noise emissions from a conventional collection vehicle.

Carbon Footprint

In difference to the calculation of the fuel savings and the involved CO_2-savings, the carbon footprint takes all emission accruing during the lifetime of the vehicle into account. From the construction of the vehicle to the disposal when the lifetime is over, all emissions are accounted, and the overall CO_2-load or saving is calculated.

This means, that a product, that generates a lot of savings during the use phase but causes a lot of emissions during production must not be better in its overall CO_2-balance than a normal product with average emissions during construction and use.

The result of the comparison of the carbon footprint of the two vehicles is shown in Figure 4. The contributions of the three phases of the carbon footprint to the overall emissions are illustrated. First to see is that the disposal of the vehicles after eight years of usage has nearly no impact on the overall carbon footprint. With a share less than 0.5 %, the contribution of this phase is negligible.

The situation is different for the construction and the use phase. The use phase has with 78.4 % for the hybrid and 90.1 % for the conventional vehicle the biggest share on the total lifetime emissions. The difference of nearly 12 % is caused by the increased demand of components and materials for the realisation of the diesel-electric drivetrain and the attached higher emissions for the construction of the vehicle.

Locking into the absolute emissions for the production of two vehicles, it comes out, that the emissions of the hybrid vehicle are twice as big as the emissions caused by the construction of the conventional vehicle.

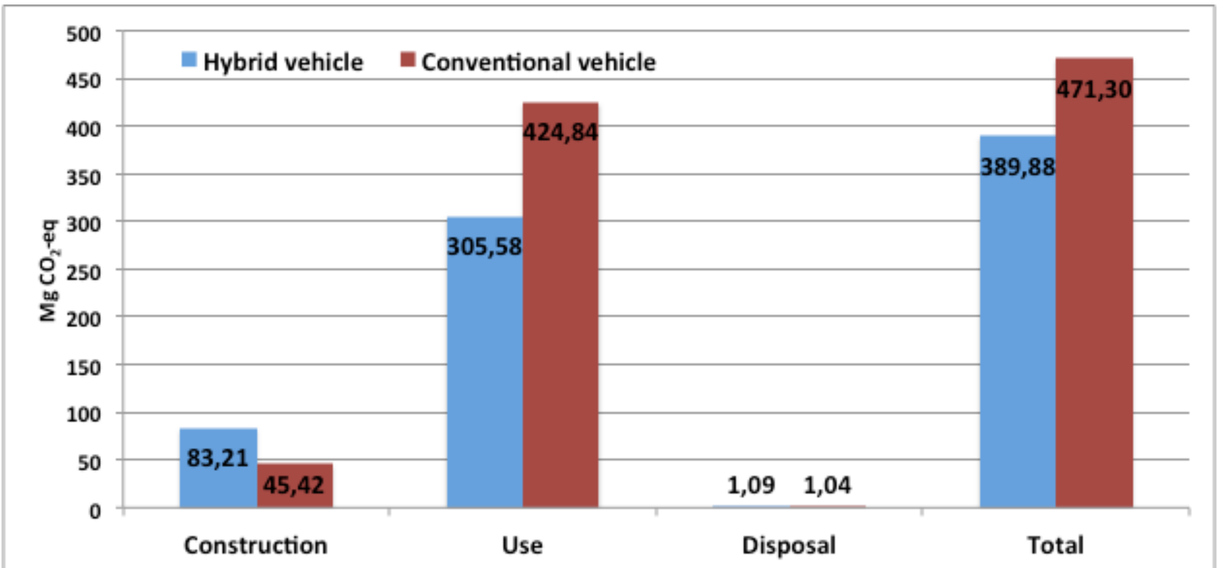

Figure 4: Share of the three life-cycle phases to the total emissions

The comparison of the overall carbon footprint of the two vehicles shows that the hybrid vehicle has a positive balance overall. The more emissions produced during the production of the hybrid vehicle can be regained through the savings achieved in operation during the eight years of use. After three years of operation the more caused emissions during the production are regained through the saved emissions from daily operation.

Evaluation

The Results have shown that the use of alternative drivetrain technologies in the field of waste collection has good prospects to become more and more established in daily operation. The possible savings are with nearly 40 % higher than expected. But these savings can only be achieved with optimized collection tours that regard the strengths and weaknesses of the hybrid vehicle.

The strengths of the diesel-electric hybrid collection vehicle are collection areas with high population density and a high number of waste bins on a short collection stretch. That means that city regions should become the main operation sites because the needed characteristics can be found there. Using the diesel-electric vehicle in more rural collection areas will also lead to savings, but the achievable savings are not as high as in a more urban collection areas.

The weak point of the hybrid vehicle is the reduced vehicle load capacity, compared to a conventional collection vehicle. As stated before, the load capacity is reduced by 1.5 t caused by the additional parts of the diesel-electric drivetrain. The solution to face this weak point is to use the vehicle in collection tours with more than 12 Mg waste, where the conventional vehicle also has to make a stopover at the treatment plant or in collection tours with not more than 10 Mg waste, where both vehicles can do the collection without a stopover.

This leads to the conclusion that an efficient use of hybrid vehicles is only possible in combination with an optimisation of the collection tours. Only by planning the tours especially for the diesel-electric vehicle or any other collection vehicle with an alternative drivetrain it is possible to benefit from the full advantage of these new technologies.

The findings from the tests have shown that the use of the diesel-electric hybrid vehicle is ecological advantageous. But for an extensive use of this new technology an ecologic advantage is not enough. Without an economic added value it will not be easy to establish this new technology on the market.

A calculation of the payoff period has shown, that the costs for the diesel-electric hybrid vehicle compared to a conventional collection vehicle are that high, that the investment for theses additional costs will not be amortized during the operation life of the vehicles. With the actual average saving of around 8.5 litre diesel per day, additional costs of about 50,000 € could be rediscounted. With optimized collection tours and possible savings of 12.5 litres diesel per day, the rediscountable additional investment would be around 60,000 €, which is not even half of the actual additional investment for a Faun Rotopress vehicle.

Perspective

As stated before the optimization of collection tours is essential for a further development of hybrid collection vehicles. Without addressing the special attributes of the hybrid collection vehicle it is not possible to turn the complete benefits to account and the maximum savings cannot be achieved.

For a further development of alternative drivetrain technologies in the field of waste collection and especially for the development of the diesel-electric vehicle from Faun the framework conditions have to be changed towards an extensive use of alternative drivetrain technologies. Currently it is not economically useful to invest in a diesel-electric hybrid collection vehicle. The additional costs compared to a conventional collection vehicle are too high. In addition the fuel savings are not high enough to regain the additional investment during the lifetime of the vehicle. To face that economical barrier other inducements have to be created. One example could be an explicit requirement of collection vehicles with alternative drivetrain technologies in bidding conditions for collection contracts.

Another possible way for the creation of inducement for an extensive use of alternative drivetrain technologies could be the permission for vehicles that do not use the big truck engine during waste collection outside of the normal collection times. The collection of waste early in the morning or late in the evening would cause in less traffic and with that in less additional stops for evading other road user.