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Evaluation of a multipurpose hybrid vehicle concept

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Abstract

The HOST project developed concept and prototype for an innovative low polluting modular transport mean suitable for the urban transport of people and goods. Main HOST commercial innovation is to use one vehicle for four different transport service in the 24 hours thus lowering the extra-cost of having a low polluting vehicle. HOST has been dimensioned to supply four different urban transport services: nocturne collective taxi, daytime car sharing, daytime freight collection and distribution and nocturne garbage collection. The user acceptance, energy and environmental and financial evaluation are reported in this paper.

The user acceptance evaluation showed that HOST characteristics (transshipment capabilities, enhanced maneuverability and environmental concern) are interesting, but issues as the technological complexity and lack of infrastructures have to be resolved.

The powertrain, a hybrid series, has considerably lower emissions levels than conventional vehicles while consumption is comparable for all the services but car-sharing in which HOST consumes more due to its higher weight.

The financial evaluation shows that at the moment, to build the HOST powertrain, about 165 000 € are needed and a complete vehicle with also the cabin could cost about 290 000 €. To be financially competitive, the global cost of HOST should be between 220 000 and 230 000 €, 60 000€ less than the cost of the prototype.

Keywords: hybrid series, financial evaluation, emissions, HOST vehicle.

1 Introduction

Today's European cities face many problems, and transport is one of the most relevant if not the most relevant. Mobility in cities gives problems of congestion, energy consumption, pollutant emissions, loss of green belts, occupancy of public spaces, and last but not least of health and safety.

Although passenger transport is always perceived to be the main cause of mobility related problems recent studies proved that freight transport impact is not negligible; from 30 to 40% of energy consumed for transport in cities is due to freight [1] and these percentages grow when certain pollutant, such as PM (Particulate Matters), are considered.

Any of the attempts made so far, for research or demonstration purposes, to have a cleaner mobility, based on low polluting vehicles, have been successful in demonstrating that cleaner vehicles are technically feasible but have failed to start a real market for non-polluting vehicles. Low impact busses (hybrid, electric, hydrogen, or gas) have been tested in many research projects proving to be much less polluting than conventional ones [2], but are not commonly adopted, if not for niche applications, by city public transport companies because they are more expensive and problematic [3].
To lower the impact of mobility on the cities, cleaner vehicles are not enough: an integrated passenger and freight strategy must be adopted. Cleaner vehicles must be specifically designed for the purpose and prove to be better than conventional ones under any aspects, including costs.
To lower such costs and to start up the Low Polluting Vehicle (LPV) market the versatility of LPVs has to be enhanced.
To this aim the European Commission funded, under the Strategic Objectives Clean urban transportation systems for transport of persons and goods and Freight transportation system development towards door-to-door, the project HOST (Human Oriented Sustainable Transport mean), Figure 1.

Figure 1 HOST Vehicle at Bologna Motor-Show 2008

The HOST project developed concept and prototype for an innovative low polluting modular transport mean suitable for the urban transport of people and goods.
To achieve its general goal the HOST consortium addressed a wide subset of aims:

- to subvert the vehicle design process and instead of designing the vehicle on the basis of the available technology it started from the real user needs;
- to design a multipurpose vehicle which can be used for several tasks h24 reducing de facto the investment costs for an environmental friendly vehicle;
- to develop a modular power train with interchangeable power generation units so to minimize the impacts of the vehicle circulation according to the task it is supplying;
- to design a modular chassis capable to change length according to the capacity (in terms of volumes of freights or number of passengers) it has to have for the task it is supplying;
- to design different vehicle cabins which can be easily and automatically switched for passenger and freight transport;
- to integrate in the vehicle chassis an advanced horizontal transshipment device capable to transfer pallets of freights as well as facilitate the cabin interchange.

Fulfilling all these objectives lead to the construction of a vehicle which could supply financially freight and passenger services in cities and allow, if adopted in combination with some accompanying measures, the city mobility to become more sustainable.
In this work the final evaluations of the concept and the vehicle are performed; three main evaluations have been completed: user acceptance evaluation, energy and environmental evaluation and financial evaluation.
User acceptance evaluation methodology and results are reported in section 2; potential users and decision makers where interviewed in Rome and Stockholm to judge HOST characteristics under the user point of view.
Section 3 reports methodology and results of HOST energy and environmental impact in comparison with the impact of conventional vehicles supplying the same services.
The Financial evaluation is in section 4; it is divided in 3 parts: the first analyzes the costs needed to release the HOST power-train, the second reports the kilometrical costs of all the services (nocturne collective taxi, car-sharing, garbage collection, freight transport) made with conventional vehicles and last but not least the HOST and conventional scenarios are compared.
Finally the conclusions of the evaluation process are reported.

2. User acceptance Evaluation

The indicators to measure the user acceptance are:

- Usefulness;
- Ease of use;
- Perception of safety;
- Perceived level of comfort.

The usefulness indicator quantifies how much HOST vehicle characteristics can help users to satisfy their needs and requests.
The ease of use indicator measures how easy the user feels using the HOST vehicle would be in supplying the different services.
The perception of safety measures how a user feels safe in the use of the HOST vehicle.
The perceived level of comfort measures how comfortable the HOST vehicle is for its users.
To measure these indicators, a demonstration of the use of the HOST prototype was required.
Since the HOST prototype could not be transported in due time to the different sites and “tried” by the local stakeholders, the indicators to measure, as well as the method to measure them, were readdressed.
The method chosen was to organize workshops in which the concept was presented, by means of the concept-and-styling-video produced as interim project result; and the prototype presented through the videotaped at the Bologna Motor Show by the national Italian TV news when it showed its maneuvering capabilities.
The invited people were then asked to discuss the concept and then to fill in a questionnaire mostly to measure the usefulness of the vehicle, of its enhanced maneuverability and of the applicability of the new mobility concepts. The workshops, as well as the questionnaires, were slightly different in Italy and Sweden to reflect the local habitudes.
Several questions were asked both in Stockholm and Rome and here results are compared.
In both Rome and Stockholm most people think it is HOST vehicle can be used to supply more than one service. In both cities however 20% or more of the interviewees are openly against this possibility.
In order to promote vehicles like HOST, knowing that not all agree with such concept, it could be possible to introduce it in a voluntary way: if anyone wants to adopt such concept can do it, while who does not agree can continue with the conventional technologies.
The reasons of the skeptics are different for each city: the complexity of the system is the main reason in Stockholm: its weight, the difficulty to manage it etc.; in Rome instead the infrastructure is the main problem. There is cultural difference between the two cities: in Rome big changes as a deep modification in infrastructures are seen as impossible more than technological limits, the opposite happens in Stockholm.

Table 1 Consumption and emissions of HOST the engine switched on

	Host measured consumption and emissions	
	Specific fuel consumption and emissions g/kWh	***Hourly consumption and emissions g/h***
Consumption	320	2 137 (2.51 l/h)
CO_2	949	6 633
NO_x	1.96	13.71
CO	0.087	101.61
HC	0.045	0.313

Integrating transshipment capabilities in the vehicle is generally favorable seen; however in Rome about 20% of the interviewees believe the usefulness is linked to the presence of accompanying measures and incentives.
Enhanced maneuverability, the possibility to translate and rotate is positively seen wherever, but while in Stockholm there is more than a quarter of the interviewees that has little or no interest in such features, in Rome they are seen as the most desired feature of all. Such result may be due to the many problems in parking and the many small streets of Rome where these capabilities might be very useful.
In both cities, environmental concern is high and therefore any measure which might contribute to urban sustainability is well seen, however none of the operators fell the extra cost due to sustainability should fall upon the category.

3. HOST energy-environmental impact

To calculate the energy and the environmental impact of HOST, a set of experimental tests have been done at the JRC of ISPRA; the engine specifications, chosen from the experimental tests made on [4] with the following characteristics:

- 850 cc, (the Smart engine);
- Runs at 1800 rpm and with 16 kW of power.

The tests, made at constant rpm show the following levels of consumption and emissions (**Errore. L'origine riferimento non è stata trovata.**).
The methodology used in this section to evaluate the energy-environmental impact of HOST is the following.

- The engine power requirement, for the driving cycles plus auxiliaries, for each service are known from [4] and reported in Table 2.
- The power requirement is dependent on the average speed of the missions, the weight and the auxiliaries onboard, so the hardest service is freight because of higher weight and, for some service, of the cooling system for refrigerated cargoes. The lightest is garbage due to the very low average speed.
- With such data the engine supplies more power than request for 3 of the 4services. For example for the car-sharing service the engine can be switched off for 37.5% of the time. The only service which requires the engine always on is freight.

HOST makes daily all the services for 6 hours each and during the year the hours of work for each service are 2184.
The kilometers made each year for every service are:

- taxi:30000;
- car-sharing: 30000;
- freight: 40000;
- garbage: 21000.

For three services out of four, all but car-sharing, it is assumed that the 6 hours per day of each service are entirely used by the vehicle moving. Such assumption is not plausible for car-sharing. The percentage of time the vehicle is in use in this service is calculated as a product of the measured average speed car-sharing cars when in motion and overall on the day. The effective hours of daily use for HOST in car sharing are then 4.18 over the 6. To calculate consumption and emissions of the HOST vehicles in the different services the hourly consumption and emissions of the engine are multiplied by the percentage of time the vehicle is switched on and by the percentage of time the vehicle is in motion. Consumption and emissions levels calculated for the HOST vehicle are in Table 3.
The consumption is not particularly good, but a series Hybrid is not the optimum strategy to minimize the consumption and CO2 production; however these values are close to those measurable for conventional vehicles. Also NOx seems to be high but real driving cycles require higher power values than those supplied during type approval procedure; however in the following section the results of an experimental campaign with a conventional diesel vehicle is reported and the emissions values of NOx are much higher.

HC and CO are very low due to the fact that HOST has a diesel engine that does not produce high levels of carbon monoxide and hydrocarbons.

Table 2 Host power requirement for the four services

	Host power requirement			
	Avg. power (kW)	***Aux. Power (kW)***	***Tot Power (kW)***	***Time with engine on (%)***
Car-Sharing	8	3	10	62.5
Taxi	9	4	13	81.0
Garbage	6	1	7	44.0
Freight	12	4	16	100

Table 3 Consumption and emissions levels of HOST

	Host consumption and emissions for the different services				
	Fuel Cons km/)	***CO_2 g/km***	***CO g/km***	***NO_x g/km***	***HC g/km***
Car-Sharing	12.6	210	0.02	0.43	0.01
Taxi	5.5	391	0.04	0.81	0.02
Garbage	8.7	303	0.03	0.62	0.01
Freight	7.3	362	0.03	0.75	0.01

To give a more accurate reference to consumption and emissions of car-sharing vehicles than the homologation data; road tests have been made on a Citroen C3 HDi 75 cv which is the kind of car often used in car-sharing services. The results of the on the road data collection campaign are reported in Table 4. Comparing the data in Table 4 with the first row of Table 3 it is clear that HOST would consume and emit much less than a conventional Diesel city car to supply the same service.
As for HOST measurements, the CO and HC for diesel vehicles are not a problem in terms of emissions produced, while NOx are more than 6 times higher the Euro IV limit although still less than the 20 times of the conventional diesel car tested.

Table 4 Measured emissions levels of a conventional diesel car in urban environment

Citroen C3 Hdi 75 cv				
Fuel Cons km/l	***CO_2 g/km***	***CO g/km***	***NO_x g/km***	***HC g/km***
11.3	251	0.18	1.63	0.004

Figure 2 is a chart taken from a previous CTL publication [5]; it reports the measured consumption and environmental impact of a freight delivery vehicle in Rome. Specifically it compares the urban and interurban emission and consumption levels.

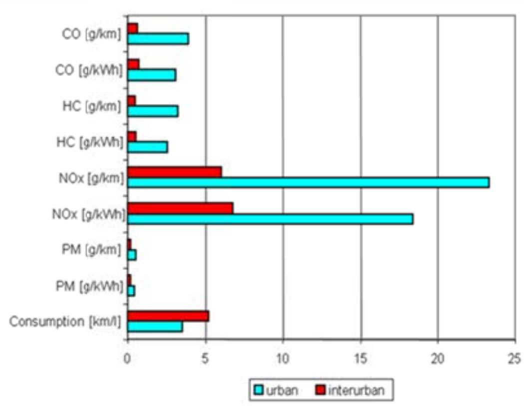

Figure 2 Environmental impact of freight distribution in Rome [5]

Comparing the data in Figure 2 with those in the last row of Table 3 it clearly emerges how Host would lower emission and consumption in cities under the good performances the conventional vehicles do out of the cities. NOx in particular decreases from the measured 23 g/km of a conventional delivery truck in Rome to 0.75 g/km.

4 Financial Evaluations

This section is divided in 3 sub-sections: the first analyzes the costs needed to build the HOST power-train, the second reports the kilometrical costs of all the services (nocturne collective taxi, car-sharing, garbage collection, freight transport) made with conventional vehicles and the last section compares the costs of two scenarios: the present situation with the conventional vehicles what we could call the HOST scenario.

4.1 The HOST cost

The summary of the cost of all the components is reported below.
The chassis, produced by Stile Bertone, made in aluminum, is much similar to a sport car chassis rather than a freight vehicle's chassis. The costs, 15000 € is due to the fact that it is unique prototype and it could be reduced.
The choice to use the wheel motors for traction is made to allow to HOST to rotate on itself, to translate transversally and to give it a higher capacity to move than conventional vehicles. The cost of them is 52000 € plus some part of the power controller section, 2500 €. Also the costs of the suspension system designed specifically for this purpose have to be added (25000 €).

Table 5 Costs of conventional vehicles used as a first approximation to estimate the costs of Host's cabins

Cabin costs for the different services	Cost €
Car-Sharing	15000
Collective Taxi	30000
Garbage	30000
Freight	50000

In practice the superior capability of steering costs more or less 80000 €, the 50% of HOST powertrain costs; if this characteristic is not fundamental for some applications the price can be reduced of a not negligible amount.
The battery pack, with a maximum power of 24 kW of power and of 1.4 kWh of energy stored has a cost of 10000 €, the ultracapacitors, coupled to the batteries to increase peek power, cost about as much. The total cost of the energy storage is then 20 000 € plus auxiliaries (power controllers etc.). With mass productions of this prototype the costs of this section can be significantly reduced.
The onboard power generation, made with an internal combustion engine and an electrical generator, together cost 10500 € plus power controller (2500 €).
The total cost of HOST prototype is about 165000 €, but it is the cost for one vehicle; if it is produced in series, from at least 10 to more than a 100, the cost of the powertrain could probably be reduced to 20% of the actual cost. 30000 € could be a reasonable cost for a series production of this kind of powertrain.
All the costs reported above, are referred only to the powertrain not to the cabins and transshipment. As first approximation, each cabin could cost as a complete conventional vehicle used today to supply the same service (**Errore. L'origine riferimento non è stata trovata.**).
All included the total hypothetical cost of one vehicle is then 290000 €.

4.2 Service costs with conventional vehicles

Calculating the costs of supplying the services with conventional vehicles is useful to set a benchmark against which the HOST scenario could measure itself. Such cost calculation takes into account all vehicle related costs; which are:

- purchase cost;
- insurance costs (an averaged value is used to take account for the costs per year of insurance);
- fuel consumption (measured for all services with conventional Diesel vehicles and cost of Diesel fuel has been set to 1.1 € per liter);
- maintenance (10% of the purchase price has been used as yearly maintenance cost);
- driver's cost (the price for each hour of driver work is set to 20 €/hour).

To take into account the deference between investments happening at the beginning and costs sustained operating the service a discount rate of 4% as been used.

4.2.1 Car Sharing

Following the user needs analysis a car-sharing vehicle is a city car with a an engine displacement between 1000 and 1500 cc, with specific power of about 5 kW/q and a length between 3.5 and 4 m. A typical vehicle could be a Renault Clio 1.5 dCi, a diesel vehicle that can be used to represent such service.

It is a Euro IV vehicle of 1461 cm3 of displacement, 50 kW of maximum power at 4000 rpm and 120 g/km of CO2 during the type approval procedure.

To perform a financial evaluation of the car-sharing service made from this vehicle the following data are considered:

- it is used for 40000 km/year;
- the purchase price is about 15000 €;
- the insurance is about 1500 €/year;
- the consumption is 11.3 km/l as measured for the Citroen C3
- being car sharing the sole service not requiring drivers no driver costs have been considered.

With the above hypotheses the vehicle costs about 0.23 €/km or 7054 €/year. Such figure is stable changing car brand or model it just slightly increases with the vehicle size; bigger cars can reach up to 0.35 €/km (this is the case for a Fiat Multipla).

4.2.2 Nocturne Collective Taxi

The vehicle used to calculate the costs per km for the nocturne collective taxi, a light duty vehicle.

A Fiat Ducato Panorama with the following characteristics was chosen.

- 2.2 dm3 engine displacement, 100 cv maximum power, diesel fueled, Euro IV;
- 9 passengers, maximum weight 3000 kg (drivable with "B" driving license, the same as cars);
- length 5450 mm;
- width 2050 mm.

To calculate the vehicle costs for running a nocturne collective taxi service the following data are used.

- The vehicle is used during nights from 20 to 2 a.m. (6 hours /day).
- It is used for 30000 km/year.
- The purchase price is about 30000 €.
- The insurance is about 1800 €/year.
- The driver's cost is 20 €/hour.

The costs per km of this vehicle for nocturne collective taxi is about 1.90 €/km. The largest portion of such cost is the driver who costs more than 1.4 €/km while all the others together are about 0.50 €/km.

4.2.3 Garbage Collection

To calculate the costs per km of the door-to-door garbage collection service, the data collected in Rome during the HOST user needs analysis are used. This service is supplied with Iveco Daily light duty vehicles equipped with caissons to collect garbage.

The Iveco Daily used for this service has the following characteristics:

- 2.3 dm3 engine displacement, 100 kW maximum power, diesel fueled, Euro IV;
- maximum weight 3500 kg (drivable with "B" driving license, the same as cars);
- wheelbase 3000 mm.

To calculate the costs per km of the door-to-door garbage collection service the following data are used.

- The vehicle works 12 hours for 5 days (Monday to Friday) and 6 hours on Saturday.
- It is used for 21000 km/year.
- The purchase price, comprehensive of the tool to collect the garbage, is about 50000 €.
- The insurance is about 1800 €/year.
- The driver's cost is 20 €/hour.

The first thing to say about this service is that the vehicle run at very low speed and, even if the service is active more hours daily than the others, the mileage of the vehicles is very low.

The depreciation term for example is 0.35 €/km, higher than the same term for collective taxi that is 0.14, but the big difference is the cost of the driver: 3.26 €/km. The total kilometric cost of this service is then about 4 €/km.

4.2.4 Freight distribution

Freight delivery service is the one to be thoroughly changed to have Host vehicles adopted. Host has not been designed to run out of the urban environment while today the delivery platforms from which trucks leave for their delivery rounds are out of the city. The Host scenario would therefore imply one more passage; the freight should leave the outer urban area with a shuttle train and being transshipped on Host vehicles in a rail terminal inside the city. The implementation of such scenario is complex not just because of costs but because an agreement between several operators, as well as the appropriate infrastructures need to be found. Only the intervention of the authorities, putting in place regulations which practically oblige private actors to re-organize their delivery services, could foster such model. Leaving the evaluation of this complex scenario to other studies here the interest is focused on comparing vehicle costs. It is therefore assumed such new freight delivery scenario to be in place either with conventional or Host vehicles. Vehicles gross weight in this new scenario would be 60 q to allow a load of 40 q or more. The Iveco EuroCargo 60E14, with 60 q of maximum weight at full load and 140 cv of maximum power has been chosen as the conventional vehicle to compare Host cost's with.
To evaluate the costs of the freight distribution service, a table from [6] was used.
This table reports all the costs for freight transport for an Iveco EuroCargo 60E14 varying the annual mileage. The only term to specify to read this table is the km per year made by this service and the only modification done is to neglect the fees for highways because the vehicle is used in urban environment.
For the service analyzed on average each vehicle run 40 000 km/year and then the vehicle cost is 1.446 €/km.

4.3 Cross comparison and financial evaluation

Estimating the cost of Host vehicles, assuming they will be produced in small series, is not a simple task. Clearly the cost of the prototype reported in the first subsection of this section is too high to compare it with vehicle produced in series.
In this subsection, using the same relations for the financial evaluation of the 4 services made with conventional vehicles, a cost per km curve is built varying the purchase cost. This allows finding the breakeven cost under which using Host for the four services would cost less than using four different conventional vehicles.

Table 6 Global costs of all the services per km and per year

Conventional vehicle cost	Cost per kilometer, kilometrage and cost per year		
	Cost per kilometer (€/km)	*Yearly kilometrage (km/year)*	*Cost per year (€/year)*
Car-Sharing	0.23	30 000	6 976
Collective Taxi	1.90	30 000	57 046
Garbage	3.98	21 000	83 641
Freight	1.45	40 000	57 840
Total	1.70	121 000	205 503

In the present analysis the costs of the cabins are included on the purchase cost, but all the other additional costs (to change the cabin etc.) are not considered. Moreover, also some of the benefits of adopting such technology are not considered in this work, and also some of them should be showed to advantage in the perspective of a eco-compatible transport; at the moment a vehicle with lower emissions levels has no advantages in financial terms, and also the fact that HOST does not park is an advantage in that sense.
The total kilometric cost of all the services supplied with conventional vehicles calculated in the previous subsection is summed up in Table 6.
The total cost, supplying the four services is 1.698 €/km and the kilometers made by the four vehicles all together are 121 000 each year.

- To calculate the total kilometrical cost of HOST, the following hypotheses were used.
- HOST is able to make all the services made today with the conventional vehicles; in practice one HOST make the job of 4 vehicles. It is able then to make the sum of all the kilometers made: 121000 km/year.
- HOST is in use 24 hours a day; 6 hours for every service.
- The consumption of HOST, different from service to service is calculated in the section 3 and here reported:
    - Garbage collection - 7.4 km/l
    - Freight distribution - 6.2 km/l
    - Nocturne collective taxi - 5.73 km/l;

- Car sharing - 12.14 km/l.

With these hypotheses, together with those made in the previous chapter, the only unknown is the purchase cost; it is possible to build a graph of the kilometrical cost varying the purchase cost (Figure 3).

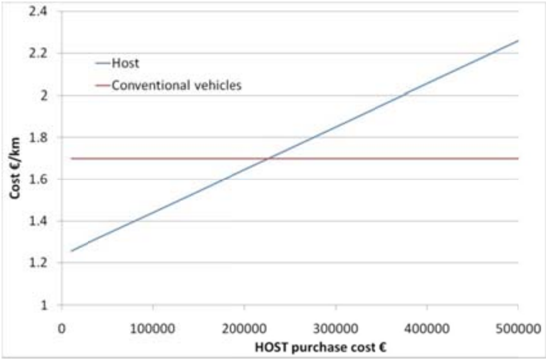

Figure 3 Influence of the purchase cost on the Costs per km

As shown in Figure 3 the kilometrical cost increase linearly with the purchase cost and for a value about 220000-230000 € the cost is the same for the services made with conventional vehicles. This value is the price under which HOST is financially competitive.

To have a large market HOST might need some legislation to advantage electrical and hybrid vehicles in cities which might then induce a new approach to freight distribution.

5. Conclusions

The HOST project developed concept and prototype for an innovative low polluting modular transport mean suitable for the urban transport of people and goods. Main HOST commercial innovation is to use one vehicle for four different transport service in the 24 hours thus lowering the extra-cost of having a low polluting vehicle. HOST has been dimensioned to supply four different urban transport services: nocturne collective taxi, daytime car sharing, daytime freight collection and distribution and nocturne garbage collection. The user acceptance, energy and environmental and financial evaluation are reported in this paper.

User acceptance evaluation was made by means of workshops in Stockholm and in Rome where potential users and authorities were presented with videos of concept and prototype and asked their opinion on such an innovative concept and vehicle.

Energy and Environmental evaluation has been made calculating the energy and environmental impact of HOST and comparing it with conventional vehicles running the same services.

Financial evaluation has been made calculating the cost of HOST and the costs of the conventional vehicles used to supply the same services and comparing them finding the breakeven cost for HOST that would allow HOST to be financially viable.

The user acceptance evaluation measured how the stakeholders see a vehicle like HOST as interesting, but some issues have to be resolved: in Stockholm the skeptics see the vehicle too technologically complex and are afraid this might cause problems, while in Rome the main skepticism are due to lack infrastructures.

However transshipment capabilities (in both cities), enhanced maneuverability (much more for Rome) and low-environmental impact are well seen and can be the real added value.

The results of energy and environmental evaluation shows that HOST is really environmental friendly and its best advantages can be obtained supplying freight services (garbage collections and freight distribution) where the vehicle higher weight is mitigated by the load weight.

The powertrain, a hybrid series, show the best advantages in terms of emissions and for all the services the results are considerably lower than conventional vehicles. HOST has consumption comparable with conventional vehicles for all the services but car-sharing; in car-sharing service HOST consumes more fuel than a conventional city car.

The financial evaluation shows that at the moment, to build the HOST powertrain, about 165000 € are needed; the costs of the cabins are not known and in first approximation can be equal to the cost of the entire conventional vehicle running the same services: about 30000 € for collective taxi, 30000 € for freight distribution, 50000 € garbage collection, 15000 € for car-sharing.

These are the costs of a unique prototype and thus far it is not possible to have more realistic costs for the HOST vehicle when it will be produced on large scale. However, rather than comparing HOST costs to the 4 conventional vehicles, the global cost of all the services supplied by conventional vehicles were calculated and the cost for one HOST which would make the overall kilometrical cost equal to the present cost is between 220000 and 230000 €, 60000€ less than the cost of the prototype and cabins which means it should be possible to build Host at a financially viable price.

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