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Total cost of ownership, social lifecycle cost and energy consumption of various automotive technologies in Italy

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ABSTRACT

This paper estimates the total cost of ownership, social lifecycle cost and energy consumption of 66 cars with different fuel/powertrains available in Italy in 2013. The aim is to provide the various private and public decision makers with information that could allow them to better understand the current market penetration of the various automotive technologies and to predict the future one. It is found that the car operated by conventional fuels (gasoline, diesel) is currently the least expensive as far as the total costs of ownership are concerned. The bi-fuel liquefied petroleum gas (LPG) and the bi-fuel compressed natural gas (CNG) internal combustion engine vehicles are in the same price range. Both the battery electric vehicles (BEVs) and, especially, the hybrid ICEVs are more expensive. On the contrary, the social lifecycle costs of the BEVs are the lowest, thanks not only to their zero air pollutants' emissions in the use phase but also to their reduced noise emissions. The amount of the social costs relative to the total cost of ownership, estimated using recent European parameters, represents at the most 6% of the total cost. Consequently, even if the external costs were internalized, the alternative fuel vehicles would not become convenient for the final consumer from a monetary point of view. Considering the energy consumption, with the 2011 Italian energy production mix, the BEVs and the diesel hybrid are the most energy efficient cars. Focusing on 7 specific models, and simulating realistic scenarios, it is found that the relative ranking of the BEVs in terms of total costs improves moderately when the traveled distance increases, subsidies are introduced and battery price drops. However, the BEVs become convenient only when the annual distance traveled is at least 20,000 km, a value much higher than the current Italian average and posing serious issues in terms of vehicles' range. Only a joint reduction of the battery price to €240/kWh from initial estimated cost of €412/kWh and the introduction of a subsidy would make the BEVs competitive with the current average Italian annual distance traveled.

1. Introduction

The movement of people and goods is crucial for economic and social development. Yet, it consumes considerable amounts of energy and generates various environmental impacts including global and local polluting emissions. As vehicle ownership is forecasted to increase dramatically worldwide, in order to achieve a better balance between the pros and cons of transportation, governments enact incentives and regulations to develop new vehicles and foster the use of cleaner fuels. The automotive industry reacts developing many vehicles' engine/fuel options (compressed natural gas; liquefied petroleum gas; hybrid; range extender; full electric; hydrogen, fuel cell, etc.). Within a given infrastructural and regulatory framework, the consumer ultimately decides which vehicle to buy and use on the basis of his/her preferences for a number of attributes, including purchase and operating costs, energy consumption and environmental impact.

Both governments and consumers are influenced in their decision-making process also by the existing scientific evidence. However, the scientists who estimate the costs of different vehicles and their energy and environmental efficiency are faced with a difficult task since there are many uncertainties due to lack of data, uncertain data sources and high variability in measurements in the areas of the energy, environmental and economic evaluation.

A further difficulty is the lack of a unique and easy-to-communicate indicator because of the existence of many

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Acronyms

BEVs	battery electric vehicles
CH_4	methane
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
E85	ethanol
EVs	electric vehicles
FC	fuel-cell vehicles
FC-HEV	fuel-cell hybrid electric vehicles
FC-PHEV	fuel-cell plug-in hybrid electric vehicles
GHG	greenhouse gas emissions
GWP	global warming potential
HEVs	hybrid electric vehicles
ICEVs	internal combustion engine vehicles
Leased BEV	BEV with battery leasing
Li-ion	lithium-ion batteries
LPG	liquefied petroleum gas
Ni-MH	nickel–metal hydride batteries
NMVOC	non-methane volatile organic compounds
NO_x	nitrogen oxide
PHEVs	plug-in hybrid electric vehicles
$PM_{2.5}$	particulate matter (2.5 μm diameter)
PM_{10}	particulate matter (10 μm diameter)
PV	present value
SO_x	sulfur oxide
SO_2	sulfur dioxide
TtW	tank-to-wheels
WtT	well-to-tank
WtW	well-to-wheels
VOCs	volatile organic compounds

heterogenous components: economic costs expressed in monetary terms; energy consumption expressed in energy units; environmental impacts expressed in g/km for the various air pollutants; and noise expressed in decibel. This paper chooses to compare the alternative cars in terms of total cost of ownership (TCO), social lifecycle cost (SLC) and energy consumption.

The costs of a car are inevitably time- and location-specific. The cost of buying, running and maintaining a car continuously changes over time and varies by location. The vehicles' purchasing costs, insurance costs, fuel costs, taxes and subsidies are country-specific due to different market structures, firms' strategies or purchasing power. The energy content and the energy impact depend on the energy mix of the country. The impact of air pollutants depends on the characteristics of the locations where they are released. Furthermore, technological innovation develops very rapidly so that an indicator estimated with today's parameters, based on historical data, might not be valid tomorrow.

Notwithstanding this variability and uncertainty, decisions need to be taken by policy makers, car manufacturers and consumers on the basis of existing knowledge.

Focusing on Italy, this paper contributes to the current knowledge by providing an estimate with up-to-date parameters of the TCOs, social costs and energy consumption of 66 car models. In order to obtain this result, the lifecycle energy consumption and environmental emissions are calculated and a monetary assessment of the external costs is provided making use the monetary values more appropriate to the Italian situation. The estimates are made taking into account urban and intercity trips. Finally, a sensitivity analysis is performed in order to evaluate how the results depend on the model's parameters.

The estimates on TCO, SLC and energy consumption provided in the paper could be useful to the public and private (firms and consumers) decision makers to make more informed decisions and to the analyst to understand the present and future market penetration of the various automotive technologies in Italy. To the best of our knowledge, no estimates for Italy have been so far provided.

The paper reviews the literature in Section 2. Section 3 presents the model used to estimate the private and social costs of alternative technologies is. In Section 4, the results obtained for 66 models available in Italy are discussed. In Section 5, 7 specific, more homogenous car models are compared and in Section 6 a sensitivity analysis for the 7 models is performed, focusing focus on the impact of varying the annual kilometers driven, introducing a subsidy for less polluting cars, and reducing the battery price. In Section 7 conclusions are drowned.

2. Literature review

Although there is an abundant literature on the comparison among different vehicles technologies in terms of private and social costs, energy use and environmental impacts. For a variety of reasons, few consensus results have emerged.

2.1. Environmental and energy assessments

A survey by Hawkins, Gausen, and Strømman (2012) and Hawkins, Singh, Majeau-Bettez, and Strømman (2012) reviewed 55 studies from peer-reviewed and gray literature containing environmental and energy assessments. Their focus is on the comparison between internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and electric vehicles (EVs). Their conclusion is that very few full lifecycle inventory studies exist. They find that more studies include the lifecycle inventory of fuels and electricity than the lifecycle inventory of the vehicle itself. The Global Warming Potential (GWP) is the most frequently reported result followed by acidification (SO_2, NO_x), smog (CH_4, NMVOC, NO_x), and toxicity impacts.

Various factors can explain this lack of knowledge and consensus.

A crucial factor is that HEVs, PHEVS and EVs are still a relatively new technology with a scarce penetration compared to ICEVs. As a consequence, some features are yet not well-documented. For instance, with regards to batteries: a) the battery chemistry and size are not fully-established yet; the Li-ion and a Ni-MH batteries are most widely used, with different materials availability for battery production; b) the battery lifetime is still unknown,[1] the end of life impact of the battery (down-cycling, reuse, and recycling) is not yet sufficiently researched; c) battery management systems, electronic controls, and temperature control systems are still under research and improvement.

Moreover, the battery and electricity supply chain is very complex. Many, and very diverse, electricity production possibilities and mixes are available, the interaction with the infrastructure is yet to be understood with regards to both the infrastructure used to transmit and distribute electric energy and the infrastructure for

[1] It varies in the range of 150,000–300,000 km and the expected lifetime for Li-ion batteries appears to have more than doubled in the last 10 years (Zackrisson, Avellán, & Orlenius, 2010).

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