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Modelling road transport technologies in future scenarios: Theoretical comparison and application of Well-to-Wheels and Input-Output analyses

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HIGHLIGHTS

- Input-Output analysis is proposed to perform LCA of future automotive technologies.
- Input-Output analysis and Well-to-Wheels methods are theoretically compared.
- Penetration of fuel cell vehicles in Germany in 2050 has modelled and analyzed.
- Results of Input-Output analysis are significantly different compared to Well-to-Wheels.

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ABSTRACT

According to IEA projections, the penetration of electric vehicles in the world transportation sector is expected to increase in the next decades to comply with the future GHG emissions policy targets. The change in transport technology mix will cause a change the environmental and economic impacts of the transportation sector, switching it from flows to funds, that is, from the production and use of the fuel to the production of the fuel pathway and powertrain infrastructures. Therefore, due to their comprehensiveness, the use of Life Cycle Assessment models will be increasingly important with respect to Well-to-Wheels ones in assessing the impact of future transport technologies.

In this paper, the Hybrid Input-Output analysis is proposed as the appropriate framework to assess the impact due to a change in transport technology mix from a LCA perspective. First, LCA and WTW approaches are theoretically compared. Secondly, the LCA model is applied for the analysis of the economic and environmental impact caused by the prospected penetration of Fuel Cell Electric Vehicles (FCEV) based on Proton Exchange Membrane Fuel Cell (PEMFC) for Germany in 2050. In addition to the production of the vehicles, the LCA model includes the infrastructures for hydrogen production and distribution and the prospected change in the national electricity production mix.

Significant discrepancies have been found by comparing results of LCA with the ones obtained by well-established WTW models already available in the literature. It is found that the impact caused by infrastructures and production of vehicles could significantly offset the expected reduction in CO_2 emissions and primary non-renewable energy consumptions.

1. Introduction

Among all the human productive activities, the energy-related activities represent by far the largest source of pollutants and greenhouse gases (GHG) emissions. In particular, CO_2 emissions from energy-related sectors account for the largest share of global anthropogenic GHG emissions [1]. According to IEA data, fossil sources still accounted for 82% of the global TPES in 2015, playing a key role in the upward trend of CO_2 emissions [2]. Among other sectors, production of energy utilities (electricity and heat) and transport activities account respectively for the 42% and the 24% of the total CO_2 emissions. Despite the growth of renewable energy deployed in developed countries, the share of fossil energy sources in the world electricity and heat supply has slightly changed over the past four decades, and it is dominated by coal and natural gas (Fig. 1, right side). On the other hand, considering the world emissions by sector (Fig. 1, left side), it can be inferred that the transport sector has the highest share of world oil consumptions (49.7% in 2015); moreover, the road transport sector accounted for three

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Nomenclature

Subscripts

A	technical coefficients matrix, M€/M€
b	exogenous transactions coefficients vector, Mtoe/M€ or Mton/M€
B	exogenous transaction matrix, Mtoe or Mton
C	cutoff matrix, M€/M€
f	final demand vector, M€
L	Leontief inverse matrix, M€/M€
m	imports coefficients vector, M€/M€
v	value added coefficients vector, M€/M€
V	value added matrix, M€
x	total production vector, M€
CB	Consumption Based
D	Downstream
PB	Production Based
S	detailed system
U	Upstream
0	baseline economy
1	defined scenario

Acronyms

ANL	Argonne National Laboratory
BEV	Battery Electric Vehicle
CB	Consumption Based
DOE	Department Of Energy
ELCD	European Life Cycle Database
EPA	Environmental Protection Agency
ETP	Energy Technology Perspective
FC	Fuel Cell
FCEV	Fuel Cell Electric Vehicles
GHG	Greenhouse gases
GM	General Motors
GREET	Greenhouse gases Regulated Emissions and Energy use in Transportation
H2ME	Hydrogen Mobility for Europe
ICE	Internal Combustion Engine
IEA	International Energy Agency
IOA	Input-Output Analysis
ISIC	International Standard Industrial Classification
JRC	Joint Research Centre
LC	Life Cycle
LCA	Life Cycle Assessment
MIOT	Monetary Input-Output Table
MRIO	Multi-Regional Input-Output
NEEDS	New Energy Externalities Developments for Sustainability
NEDC	New European Driving Cycle
NEI	National Emissions Inventory
NG	Natural Gas
PB	Production Based
PEMFC	Proton Exchange Membrane Fuel Cell
PHEV	Plug-in Hybrids Electric Vehicle
SRIO	Single-Region Input-Output
TPES	Total Primary Energy Supply
TTW	Tank-to-Wheels
WTT	Well-to-Tank
WTW	Well-to-Wheels
2DS	2 °C Degrees Scenario

quarters of world transport GHG emissions [3].

According to the IEA future Sustainable Development scenario, to complain with the world long term emission reduction commitments defined by the COP21 Paris agreements, emissions mitigation actions must be undertaken by all the participant countries and by acting in both energy production and transport sectors. According to IEA scenarios, the adoption of electric transportation modes may play a crucial role in achieving the 2 °C target and for reducing oil dependency: among others, Fuel Cells Electric Vehicles (FCEV) appears as the most promising systems for future generation vehicles with the potential of competing with Internal Combustion Engines vehicles (ICE) [4]. Indeed, while electric vehicles based on batteries (BEV) are economically competitive for small travel distances and small vehicles, FCEV performances, driving range and refueling time are expected to be competitive with ICE [5,6]. Among the various type of fuel cells, the Proton Exchange Membrane Fuel Cells (PEMFC) fueled by hydrogen seems to be the most suitable technology for road transport applications, due their high power density, quick start-up time and rapid response to load change. Recently, the so-called *hydrogen economy* has received particular attention in literature, since hydrogen characteristics makes it an ideal candidate for a future sustainable energy system using renewable energy as primary source and hydrogen and electricity as energy carriers for a variety of purposes [7]. Despite such positive aspects, there are technical and economic barriers to overcome before FCEV will achieve significant shares:

- First, the cost of them is still not competitive with those of ICE: total cost of FCEV are dominated by materials, stemming from the special polymer required and the platinum-based catalyst layer [8].
- Secondly, PEMFCs adopt platinum as catalyst, which is a rare and precious metal characterized by an energy intensive and expensive production process, and literature argues that it may have a non-negligible environmental impact in terms of GHG emissions [9].
- Finally, the development of hydrogen generation and distribution

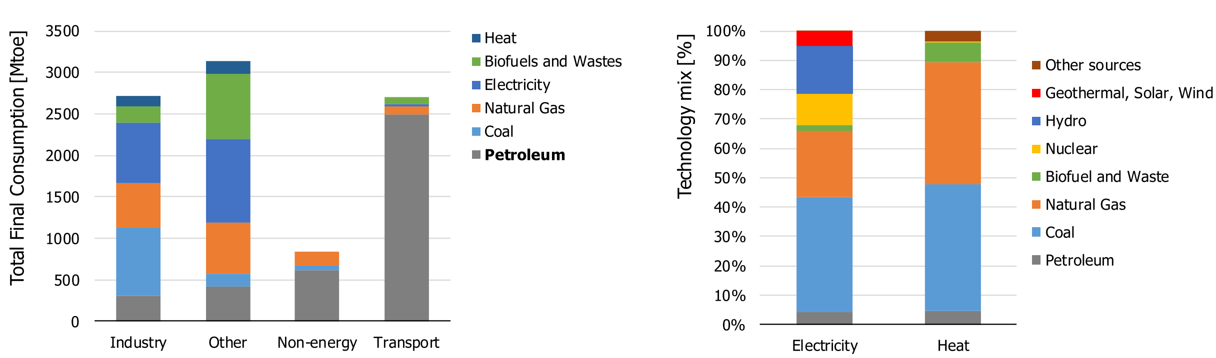

Fig. 1. World Total Final Consumption (TFC, left side) and technology mix for electricity and heat production, year 2015 [2].