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Building an optimal hydrogen transportation system for mobility, focus on minimizing the cost of transportation via truck

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Abstract

The approach developed aims to identify the methodology that will be used to deliver the minimum cost for hydrogen infrastructure deployment using a mono-objective linear optimisation. It focuses on minimizing both capital and operation costs of the hydrogen transportation based on transportation via truck which represents the main focus of this paper and a cost-minimal pipeline system in the case of France and Germany.

The paper explains the mathematical model describing the link between the hydrogen production via electrolysers and the distribution for mobility needs. The main parameters and the assumed scenario framework are explained. Subsequently, the transportation of hydrogen via truck using different states of aggregation is analysed, as well as the transformation and storage of hydrogen. This is used finally to build a linear programming aiming to minimize the sum of costs of hydrogen transportation between the different nodes and transformation/storage within the nodes.

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Keywords: Hydrogen, infrastructure, transportation, storage, compression, liquefaction, cost optimisation

1. Introduction

One of the big challenges of the future of our energy systems is to find a balance between the increasing demand on energy, the limited conventional resources and the necessity to lower the carbon emissions. This challenge is

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particularly apparent in the transportation sector. In the one hand, this sector shows a high energy demand, in the case of the European Union (EU), it needed 32% of the final energy demand in 2014 [1]. On the other hand, the expected further increase of transportation intensifies the dependency on conventional fuel accompanied by more carbon emissions as well. In fact, the transportation sector has been the only one with increasing emissions by 22% in the EU [1] during the last 25 years. To change these trends, the EU pushes towards decarbonising the transportation sector by fixing the threshold of oil dependency in transportation in 2050 to 70% less compared to 2008 [2].

The use of low carbon hydrogen in Fuel Cell Electric Vehicles (FCEV) is one of the promising alternatives to conventional fuels. Still, the main barrier restraining its deployment is the need to install and define an adequate infrastructure. Under this problematic, this study aims to provide an approach to identify the minimum cost for hydrogen infrastructure deployment using a mono-objective linear optimisation.

The optimization of a possible future hydrogen infrastructure has been the subject of research in different studies. However, most of the existing analyses focuses on one way of hydrogen transportation, either via trucks or pipeline system [3],[4]. In cases, in which all transportation modes were taken into account, the geographical representation was omitted by restraining the study to a decomposition into grids [5] or the geographical visualization was limited to one region [6], [7] or one country [8], [9].

This paper presents the methodology allowing to build an optimum transportation network via trucks at different states of aggregation (pressure, aggregate condition etc.), including as well transformation (liquefaction, compression) and storage. This represents a primary study that will be completed by a second transport option via an endogenously optimized pipeline network. The approach will be applied for France and Germany to highlight the different European energy strategies, but also to investigate a potential collaboration in developing hydrogen infrastructure like the Scandinavian common strategy [10].

The overall methodology is presented in the first part introducing the different notations. Then the four model components are presented which includes demand estimation, hydrogen production, conversion of hydrogen for transportation and storage modes. The model calculation is then presented as a mixed-integer linear program by defining the objective function and the constrains associated with. Finally, a conclusion is conducted to show how this optimal road transportation will be associated to a pipeline network in order to present results for France and Germany.

Nomenclature

$\times_i$,$\times_j$	nodes location
$\times^S$,$\times^{S'}$	Hydrogen state of aggregation
$\times_y$	year
$\times_0$,$\times_f$	initial and final condition
L	driving distance
$T_{l/u}$	Loading and unloading time
m_{H2}	truck capacity
n_{rt}	annual number of truck round trips
n_T	annual number of trucks
S_a	average truck speed
n_d	number of truck drivers
F_p	fuel price
TC_{cab}	truck cab cost
CRF_{Cab}	cab capital recovery factor
TC_{und}	truck undercarriage cost
TC_{H2}	tube cost
CRF_{Traile}	undercarriage and tube CRF
TC_d	driver wage
TCC	truck capital cost
St	Stored flow
Q	flow transported
P	flow produced
p	hydrogen installed capacity
d_{max}	Maximum demand flow
d_{min}	Minimum demand flow
CRF	capital recovery factor
CF	capacity factor
c_T	cost of liquefaction or compression work
CC_c	capital cost of compression
CC_L	capital cost of liquefaction
CC_S	capital cost of storage
TCC	transportation capital cost
TOC	transportation operation cost
FCC	facility capital cost
FOC	facility operation cost
SCC	storage capital cost
OM_t	transportation operations and maintenance
OM_f	facility $O\&M$ operations and maintenance
OM_s	storage $O\&M$ operations and maintenance