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Sustainable transport by use of alternative marine and aviation fuels—A well-to-tank analysis to assess interactions with Singapore's energy system

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ABSTRACT

Sustainable economic development and renewable energy carriers are challenges facing hub cities that will influence their future role in trade and transport. The objective of this paper is to discuss the interactions between alternative transport fuels for international applications and Singapore's energy system as a central hub of global transport.

The process chains for the supply of conventional fuels, liquefied natural gas, biofuels, and liquid hydrogen in Singapore are analysed by applying a well-to-tank analysis, following which the energy demand and the associated greenhouse gas emissions are calculated. A sensitivity analysis is performed to assess the individual impacts of various processes.

A comparison of process chains for the supply of fuels for marine and aviation purposes shows that conventional energy carriers and liquefied natural gas achieve higher energy efficiencies than biofuels and liquid hydrogen. Alternative fuels reduce greenhouse gas emissions by varying degrees depending on the fuel type. An analysis of interactions with Singapore's energy system identifies emerging opportunities and challenges for the city-state's economic system associated with future development of international transport. Although alternative fuels offer the possibility of diversifying Singapore's energy supply, creating new business opportunities, and increasing Singapore's impact on fighting climate change, limited resource potentials and higher energy prices set new challenges to secure Singapore's role as an international trade and transport hub.

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Contents

1. Introduction . . . 854
2. Material and methodology . . . 855
   2.1. Review of related literature . . . 855
      2.1.1. Basic and general literature . . . 856
      2.1.2. Literature with a focus on marine transport . . . 856
      2.1.3. Literature with a focus on aviation technologies . . . 857
   2.2. Definition of methodology . . . 857
   2.3. Scenarios . . . 859
   2.4. Inputs and data . . . 859
      2.4.1. Conventional fuels . . . 859
      2.4.2. Liquefied natural gas . . . 861
      2.4.3. Biofuels . . . 861
      2.4.4. Liquid hydrogen . . . 862
      2.4.5. Economic data . . . 863

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3. Results . . . 863
3.1. Assessment of individual pathways . . . 864
3.1.1. Conventional fuels . . . 864
3.1.2. Liquefied natural gas . . . 864
3.1.3. Biofuels . . . 864
3.1.4. Liquid hydrogen . . . 864
3.2. Sensitivity analysis . . . 865
3.2.1. Conventional fuels . . . 865
3.2.2. Liquefied natural gas . . . 865
3.2.3. Biofuels . . . 866
3.2.4. Liquid hydrogen . . . 866
3.3. Comparison of pathways . . . 866
3.3.1. Cumulative energy demand . . . 866
3.3.2. GHG emissions . . . 866
3.3.3. Costs . . . 867
3.4. Comparison of pathways with related literature . . . 867
4. Discussion . . . 868
4.1. Energy use in Singapore . . . 868
4.2. Availability of alternative bunker fuels and import dependency . . . 868
4.3. Interactions of alternative bunker supply with the national economy . . . 869
4.4. Effects on GHG emissions of international transport . . . 869
5. Conclusion . . . 869
Acknowledgements . . . 870
Appendix A. Supporting information . . . 870
References . . . 870

1. Introduction

This paper aims to determine future opportunities and challenges for Singapore that might arise out of interactions between its unique energy system and the supply of sustainable fuels for international transport.

Climate change, pollution, and resource dependencies are raising awareness towards the need for a more sustainable global economy. Development of unconventional energy resources, such as tight oil and shale gas, and the increasing economic efficiency of renewable energy sources have had a strong impact on energy supply of developed countries and have led to decarbonisation of economic activity. Environmental regulations will shape the future development of energy production in many countries. However, while alternative fuels and drive trains are being implemented for road transport in order to achieve a more sustainable transport system, maritime transport and aviation lag behind.

Current trends in global transport show that environmental and economic drivers might cause shifts in the type of fuel used for international transport. In marine transport, emission control areas limit emissions and set new environmental standards [1]. With low gas prices and higher petroleum prices, liquefied natural gas (LNG) is becoming an interesting alternative to the fossil fuels generally used for maritime transport (e.g. fuel oil) from an economic point of view. Ship engine manufacturers have started producing dual-fuel gas engines to allow the use of both natural gas and conventional fuels [2–4]. Ship owners see LNG-fuelled engines as a promising option for mitigating emissions [5]. Biogenic fuels and hydrogen are other possible substitutes to conventional fuels that have been discussed in scientific articles [6–9].

Singapore is a crucial spot in the introduction of alternative fuels for international transport on a global scale. Over 42 million tonnes of the world's fuel supply for shipping is bunkered in the port of Singapore [10], and 30% of world trade is shipped through the Strait of Malacca [11]. Situated at this key position, the city-state of Singapore is more than just a large and highly developed city. Its population has grown rapidly to around 5.5 million people in 2014 [10], and it is the world's most important bunkering port [5], a leading container port [1], one of the largest exporting refinery centres [12], South Asia's leading financial centre [13], and a major airport hub [14]. These specialisations make Singapore a typical hub city. Most of its energy demand is determined by the above mentioned specialisations. The use of fuels for international aviation and marine shipping exceed demand for domestic primary energy use [15]. In order to create a sustainable energy supply for Singapore, not only domestic but also international energy use has to be taken into account. Singapore's energy system is highly dependent on technological and market developments with respect to fuels used for international transport. However, because of its role as one of the most important transport hubs, decisions taken in Singapore could have significant impact on the sustainability of international transport. These interactions make Singapore a key country in the future development of international transport.

Various life cycle assessments (LCA) have been carried out for the automotive sector. The Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context [6] and Argonne's GREET life cycle analysis [16] studied the effects of alternative fuels for passenger vehicles. In recent years, further studies have been done to investigate the environmental impact of alternative marine fuels [7,8,17–19] and alternative aviation fuels [20–23]. These studies, however, were based on data from Europe or the US.

Singapore and its surrounding region, which are situated in the centre of international trade flows, offer different framework conditions in terms of energy availability, renewable energy potential, and political constraints. As a hub for international transport, Singapore's energy system offers unique interactions with fuel supply for ships and aircraft and is therefore of high importance for the sustainable development of the world economy.

In Section 2, a methodology is developed on the basis of a detailed literature review to discuss process chains for the supply of bunker fuels for ships and aircraft in Singapore. Conclusive input data are derived from literature sources, and an overview of the selected scenarios is given. Conventional and alternative process chains for the supply of fuels for international transport demand are assessed in Section 3. Typical energetic factors, GHG emission factors, and costs are derived for each fuel type. Indicators derived from related literature are compared. Section 4

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