Towards sustainable biofuels production for aviation and maritime: summary

This doctoral thesis explores the key role of sustainable agro-energy value chains in the advancement of more sustainable and regenerative agricultural practices. With a specific focus on critical factors such as crop rotation, soil carbon sequestration, decentralized production, and the mitigation of indirect land-use change (ILUC) effects, the research project is embedded within the EU Horizon 2020 project *"Biofuels production at low ILUC risk for European sustainable bioeconomy"* (BIKE). This project is aimed to providing evidence, measuring, and widely disseminating the market potential of low ILUC risk value chains for biomass, biofuels, and bioliquids in Europe, aligning with the implementation of RED II. This initiative provides robust evidence and measurements to validate the feasibility of low ILUC risk value chains in the European bioeconomy.

The thesis introduces a comprehensive framework for sustainable biomethane production in Europe, with a specific focus on Italy, and its conversion into sustainable biofuels. Under the light of existing policy targets and regulatory instruments (e.g. Guarantees of Origin for biomethane), the research explores an innovative and sustainable agro-energy chain – biomethane as energy vector for downstream conversion, also characterized by a significant potential to promote more sustainable and regenerative agricultural practices. This biomethane-based value chain under consideration is designed to produce Sustainable Aviation Fuels (SAF) and methanol for maritime, both of which play a key role in the decarbonization of these hard-to-abate sectors.

The work explores the possibility of integrating:

- A decentralized *biogasrefinery* that produces biomethane and Guarantees of Origin;
- Injecting this biomethane into the natural gas (NG) grid;
- Collecting an equivalent amount of natural gas through Guarantees of Origin in a centralized refinery, thus effectively utilizing biomethane for the production of Sustainable Aviation Fuels (SAF) and maritime fuels.

This approach combines the advantages of the decentralized biomass conversion in small farms with the centralized biomethane conversion in large-scale industrial refineries, either through existing or new plants.

The proposed value chain leverages advanced technologies characterized by high Technology Readiness Levels (TRL). These technologies stand as cornerstones of the envisioned production process, promising efficiency and effectiveness. The adoption of the Biogasdoneright (BDR)

model, recognized as one of the most sustainable advanced biofuel pathways, further strengthens the sustainable nature of the proposed approach. The proposed value chain also gives the unique opportunity to exploit the EU existing gas infrastructure to rump-up the uptake of the advanced biofuels.

Within this concept, biomethane is utilized in three key Gas-to-Liquid (GTL) technologies: Fischer-Tropsch (FT) synthesis, Methanol (MeOH) synthesis, and Gas Fermentation and Alcohol-to-Jet (ATJ) conversion. These give rise to three distinct routes to be analysed in this thesis, i.e. (i) GTL-FT, (ii) GTL-MeOH route, and (iii) GTL-F_ATJ, respectively.

A computer-aided process simulation model and data collected from a thorough literature review of industrial references have been used to estimate the energy performances. The model provides insights into process yields and energy balances of these biofuel production routes, enabling a data-driven approach to biofuels production modelling. Moreover, preliminary insights into expected investment costs are given.

In the European context, based on the estimated availability of 38 bcm of biomethane at 2030, the GTL-FT route may address 4-9% of kerosene-based jet fuel EU demand, with variable outcomes based on employed technologies; meanwhile, the GTL-F_ATJ route exhibits a 11% potential coverage. For maritime fuels, the GTL-MeOH route could cover from 25 to 56% of the demand, contingent on technology. Alternatively, at 2050, with an estimated biomethane potential of 91 bcm, the GTL-FT route could potentially meet 9-19% of the EU demand for kerosene-based jet fuel: in contrast, the GTL-F_ATJ route shows a potential of 25%. Concerning maritime fuels, the GTL-MeOH potential could range from 48 to 105% coverage.

In Italy, based on the estimated availability of biomethane of 5.6 bcm by 2030, the potential of the GTL-FT route spans 7-14% of jet fuel demand, while GTL-F_ATJ may meet 18%. As for maritime fuels, GTL-MeOH could meet demand ranging from 69% to 152%. On the other hand, at 2050, given an estimated biomethane availability of 8.2 bcm, the GTL-FT route has the potential to meet 8-17% of the demand for kerosene-based jet fuel, while the GTL-F_ATJ route demonstrates a potential coverage of 22%. Regarding maritime fuels, the GTL-MeOH route could span from 91 to an impressive 198% coverage.

However, these processes also yield other very valuable co-products, including naphtha, diesel, waxes, hydrogen, and gasoline: therefore, a fair evaluation should consider these co-products when comparing with the other routes, beyond considering only jet and maritime components, and decide on the different pathways based on sector priorities to meet the set climate targets.

Ultimately, the thesis evaluates the investment costs associated with the implementation of these sustainable agro-energy systems, thereby enhancing our comprehensive understanding of their

feasibility and economic viability. It is important to note that these costs are specifically related to the GTL plant (Gas-to-Liquids) part of the refinery. They do not encompass the upstream segment of the value chain, such as the biogas plants, the costs associated with upgrading for grid injection, or the costs of grid connection. While these aspects are certainly interesting and worth studying, our focus is limited to the GTL plant. The investments are estimated, on average, to be 791,970 USD/tonne/day (GTL-FT), 130,275 USD/tonne/day (GTL-MeOH), and 669,740 USD/tonne/day (GTL-F_ATJ), depending on plant scale.