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Wind energy and carbon dioxide utilisation as an alternative business model for energy producers: A case study in Spain

I. González-Aparicio*, Z. Kapetaki, E. Tzimas

European Commission, Joint Research Centre, Energy, Transport and Climate Directorate, Westerduinweg 3, 1755 LE Petten, The Netherlands

HIGHLIGHTS

- The methanol plant is scaled down to compete with power market.
- High wind speed features are the optimum conditions for producing methanol.
- Wind producer gets 33% higher profit integrating methanol production in bidding strategy.

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ABSTRACT

Renewable energy sources for electricity and more efficient processes are needed to decrease greenhouse gas emission rates, in line with the Paris agreement adopted in 2015. Carbon dioxide utilization is emerging as a complementary technology to carbon dioxide capture and storage for reducing greenhouse gas emissions, and as a promising source of competitive advantage for European industry. Current carbon dioxide utilisation technologies are at different stages of maturity, with some being ready to implement immediately. Others are still under research or at a pilot or demonstration phase, requiring further development to reach commercial maturity. Thus, the profitability of such processes under current market conditions is still under evaluation. This study explores the conditions required for an environmentally and economically feasible methanol producing carbon dioxide utilisation system embedded in the energy system. The choice to produce methanol is based on its current mature commercial status and on growing global demand, which makes it an attractive product. The concept proposed considers only one system actor: a wind power producer with a typical operating wind power generation portfolio that invests in a new technology to maximise the total profit. The core of the business model is based on decisions for: (i) selling the wind power in the day-ahead or intraday bidding sessions of the power market or, (ii) producing methanol to be sold to third parties. Several scenarios are tested within the proposed business model to define optimum conditions. Limitations for the economic feasibility of the methanol plant integration into a market with an increasing integration of renewable energy are also highlighted. Results show that producing methanol instead of selling the wind power generated in the market is more profitable when the methanol plant size is three times smaller than a conventional and when power is generated by high speed winds. Under such conditions, the power market energy mix has high amounts of wind power and thus, already a significantly lower carbon dioxide emissions rate. Wind power supplied to the small methanol plant is less than 1% of the total wind energy produced. Furthermore, the wind producer could increase profits by up to 33% by integrating methanol production into their business strategy rather than selling all the energy produced in the power market.

Abbreviations: AF, availability factor; CAPEX, capital expenditure; OPEX, operating expenditure; CCS, carbon capture and storage; CCU, carbon capture and utilization; CDU, carbon dioxide utilization; CCUS, carbon capture, storage and utilization; CRI, Carbon Recycling International; DA, day-ahead market; DC/AC, direct current/alternating current; EC, European Commission; EMHIRES, European Meteorologically derived High Resolution Renewable Energy Sources; EU, European Union; F, wind power forecasted; GHG, greenhouse gases; ID, intraday market; ISBL, inside battery limits; L, actual load; LCA, life cycle assessment; LF, load forecast; NG, natural gas; PDA, price in the day-ahead market; PID, price in the intraday market; Pmet, price of methanol; REE, Red Eléctrica de España; RES-E, Renewable Energy Sources for Electricity; T, level of the tank to store methanol; TSO, transmission system operator; WP, actual wind power; WPF, wind power forecasting; WPFE, wind power forecasted error

* Corresponding author.
E-mail address: iratxe.gonzalez-aparicio@ec.europa.eu (I. González-Aparicio).

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1. Introduction

1.1. Background

In February 2015, the European Commission (EC) published its Energy Union Package [1] stating a clear ambition to be the world leader in renewable energy. To fulfil this objective, it must lead the development of the next generation of renewable technologies, but also integrate the energy produced from renewable sources into the energy system in an efficient and cost-effective manner. However, fluctuations in renewable energy production require appropriate management and carbon dioxide utilization (CDU) processes may complement the move in this direction. The Strategic Energy Technology (SET) Plan [2] embraces both renewable energy production and CDU as priorities and sets a clear path in translating these into concrete actions. This paper attempts to address both of these priorities by examining a combined concept. The potential for economic benefit for a project proponent willing to support such a concept is also examined.

Literature studies [3–5] indicate that CDU processes using hydrogen as raw material should have access to renewable hydrogen. Today most hydrogen is produced from natural gas, but there are ways to produce hydrogen from renewable energy sources for electricity (RES-E). One example is using wind power to run electrolysis equipment that transforms water into hydrogen, mostly for power-to-gas applications [6–8]. Pilot-scale demonstration plants have confirmed the viability of producing methanol from captured carbon dioxide (CO_2) and hydrogen from electrolysis [9].

Methanol is used for the production of several industrial chemicals and as a liquid fuel to replace conventional sources of energy. Global demand for methanol is expected to increase from 60.7 million tonnes in 2013 to more than 109 million tonnes in 2023, with an average annual growth rate of 6 percent [10]. Thus, methanol can be an attractive commodity from a wind power producer's perspective provided that “low-cost” electricity is available. In this study it is assumed that electrolysis runs on wind power at a scale with low power requirements. This means that power fed to electrolysis is not enough to displace other sources in the grid.

Longer term objectives for Europe are laid out in the roadmap for moving to a competitive low carbon economy in 2050 [11], the Energy Roadmap 2050 [12] and the Transport White Paper [13]. These dictate that process concepts must be in line with environmental and climate change mitigation targets in the EU. In CDU processes, carbon dioxide is used as a feedstock but using CO_2 as raw material instead of fossil fuels does not necessarily result in a decrease of carbon emissions. Such processes must be evaluated on the same basis throughout the whole chain to verify any environmental benefit [14–16].

Abanades et al. [17], in a recent study found that that the mitigation potential of CO_2 utilisation processes cannot exceed 50% compared to equivalent processes employing geological storage of CO_2. As the debate on the benefit of CDU processes in reducing CO_2 emissions is ongoing, the analysis presented here focuses on the potential of the concept examined from a business standpoint. At the scale considered, the power directed from the grid to the CDU plant is not significant to alter the overall climate change mitigation benefit gained from the system as a whole.

1.2. Literature review and industrial initiatives

CDU processes are gaining increasing interest both within the scientific community and the industry. While such processes will not replace geological storage as a tool to reduce anthropogenic emissions and fight against climate change, its contribution should not be ignored as a local alternative. A detailed review of the most recent studies and industrial activities available in the literature so far are devoted to:

(i) Evaluating the technical viability to produce methanol from captured CO_2 and hydrogen from electrolysis by pilot-scale demonstration plants. For example, in 2008, Mitsui Chemicals Inc. built a pilot plant to synthesise methanol from CO_2 and hydrogen in Osaka, Japan. The installation uses CO_2 emitted from plants and the hydrogen obtained from water photolysis [18]. Methanol has been also synthesised from CO_2 by Carbon Recycling International operating their first commercial demonstration plant in Iceland. The location of this plant provides access to very low-cost electricity and CO_2 from a geothermal source, allowing for the company to claim sustainability of their product [19]. Norway (Utsira wind-energy system) and Ireland report different experiences in the field of chemical storage of electricity by producing hydrogen that is stored and later converted into electricity in a fuel cell or in a hydrogen combustion engine [15]. The Horizon 2020 project MefCO2 [20] aims at using surplus RES-E to produce chemicals and fuels from CO_2 captured from coal power plants. The German Ministry of Education and Research has also financed several projects on chemical energy storage (water electrolysis and hydrogen production combined with CO_2 use) [21]. Sternberg and Bardow [16] introduced the concept of Power-to-X pointing out different storage methods with X being power, mobility, heat, fuels or chemicals. The study further concluded that the highest environmental benefits are obtained when using the surplus energy in heat pumps and electric vehicles, followed by large scale energy storage systems (pumped hydro storage, compressed air energy storage, and redox flow batteries) hydrogen generation and batteries.

(ii) Other studies focus on fundamental research issues such as the catalytic route towards methanol production [22,23]; and the co-production of electricity and fuels with CO_2 utilisation has been studied by several groups [24–26]. Further, [27] evaluated the potential of methanol synthesis in Europe using CO_2 as raw material. Presenting results of a techno-economic and environmental assessment, they discussed the conditions for a CDU methanol plant becoming competitive to its conventional production.

(iii) From the renewable energy perspective, recent RES-E production studies [28–39] indicate that variable renewable sources like wind and solar need to be coupled with energy storage devices for surplus electricity generation. A recent study [40] proposed methanol production from CO_2 and hydrogen as a chemical storage of the wind and solar energy. The study used non-linear programming to solve a trade-off between investment and production capacity. Solar panels were used as a case study for Spain and wind turbines for the UK. Martin and Grossmann [41] looked at Spain as a case study for optimal integration of renewable based processes for a number of products including methanol. However, they do not link their proposal with the relevant business model and real power market operations.

Additionally, to the best of the authors' knowledge, no literature studies exist looking to unlock the understanding of the conditions (including methanol production, dimensions and utilisation factor of the commercial plant, CO_2 and methanol prices and demand required) under which methanol can become an attractive product within the real energy market operations. From the renewable energy producer perspective, there is no research that explores the CDU methanol production as a complementary new technology to maximise revenues on the power market bidding strategies. The novelty of our study contributes to fill these gaps. Based on the number of studies reviewed, the main scientific questions that still need to be answered are the following:

i. whether the excess of renewable electricity generation unused or not supplied to the grid (surplus electricity) is enough to feed a conventional CDU plant while being profitable for the real market conditions;
ii. The conditions required for a renewable energy producer to invest