Title: Opportunities and challenges of green hydrogen in the energy transition framework: analysis of potential cross-border cooperations through a multi-dimensional approach

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Summary

To tackle climate change issues and to achieve the decarbonization targets, effective pathways enabling the energy transition process must be developed, exploiting renewable energy sources, electrification, new clean technologies, storage solutions, and strategic interconnections. Even if energy-based, the transition represents a changeover involving the broader social, techno-economic, environmental, and geopolitical aspects; it is an intrinsically multi-disciplinary process that evolves over time and space and will reshape countries' identities. In this context, policymakers' decisions and actions could slow down or speed up the process; supporting informed interventions in the decision-making process becomes crucial.

For the purposes of the research, different instruments are exploited; geomatics, scenario analyses and modelling, qualitative and quantitative indicators, and multi-criteria decision methods are integrated to elaborate powerful science-stakeholder-policy tools, able to tackle the multi-disciplinarity of the problems. The methodological approach is developed on the concepts of (i) predisposition, (ii) multi-dimensional suitability, (iii) multi-level competitiveness. Using specific indicators for a multi-criteria analysis, the first step allows for a preliminary assessment of the availability of resources and infrastructure, the social acceptance, the environmental issues, and the geopolitical conditions, concerning the development of new technologies or strategies. Secondly, the combination of spatial analyses with multi-criteria assessment is exploited to spatially define the multi-dimensional suitability of alternatives enabling strategic energy planning. As last step, scenario analyses unlock the possibility to study different long-term perspectives involving the whole energy system, to better investigate the concept of competitiveness.

The research and its main applications focus on green hydrogen, produced through water electrolysis supplied by renewable energy and which represents a key player in the transition. The main goal is to study hydrogen not only on a technical perspective, but including social benefits and barriers, environmental issues, and economic and geopolitical standpoints, if green hydrogen is produced in North Africa and imported by Europe. In a world that will be completely

reshaped by the transition, developing a structured science-based decision-making process can represent a win-win option for all the dimensions affected by the transition and all the countries involved in strategic interconnections. In this regard, it is needed to investigate the role that specific countries can have in the ongoing process, especially in case of new or renewed alliances when new clean solutions like hydrogen are adopted. The preliminary assessment for predisposition exploits the PROMETHEE II multi-criteria method; Algeria, Egypt, Libya, Morocco, and Tunisia are assessed through the elaboration of twelve different criteria belonging to Society, Technology, Atmosphere and land, Geopolitics, Economy (i.e., the so-called "STAGE" view), collected from literature or self-elaborated. By weighting these criteria according to specific experts' preferences, Morocco, Tunisia, and Algeria are ranked as the most predisposed to green hydrogen production. Secondly, the methodological approach deepens the multi-dimensional suitability of these three countries; different drivers and barriers are spatially analyzed, to assess the land suitability in terms of solar hydrogen production (i.e., water electrolysis enabled by solar electricity) and wind hydrogen production (i.e., water electrolysis enabled by wind power plants). In this way, a detailed mapping is developed, making use of spatially defined data, through the combination of the Analytic Hierarchy Process method and GIS techniques; it allows to obtain a classification of different ranges of suitability. By exploiting this Multi-criteria Spatial Decision Support System, ten different spatially defined criteria are elaborated; the majority of the available land under analysis is classified as moderately or highly suitable, even if the most favorable areas in terms of availability of resources are often negatively influenced by the geopolitical or economic assessment. Finally, to adequately investigate the concept of multi-level competitiveness, the energy system modelling through TIMES is exploited; under specific assumptions, the Levelized Cost of Hydrogen for the countries of interest is estimated, in parallel with the alternative transport modes and costs, to collect valuable techno-economic inputs for scenarios working on uncertainty of parameters. Analyzing to what extent Europe will rely on green hydrogen import to achieve carbon-neutrality by 2050, the role of trade is estimated as crucial, even if sensitive to uncertain factors.

This structured science-based decision-making approach could be appropriate for policymakers, investigating the complexity of the energy transition towards carbon-neutrality, allowing to prioritize energy security and affordability, and geographically address the multi-level impacts of green hydrogen adoption, stressing if and how it can be techno-economic, social, geopolitical, and environmental competitive.