DX.DOI.ORG//10.19199/2022.165.1121-9041.032

Factors influencing hydrogen's strategy in practice: a panel data analysis

Roberto Fazioli*
Francesca Pantaleone*

* University of Ferrara,
Department of Economics
Corresponding author:
Roberto.fazioli@unife.it

The aim of this paper is to analyze the factors affecting hydrogen as well as Carbon Capture and Storage Technologies ("CCS") policies with refer to countries' upstream capacity of hydrocarbon activities. By using a panel data of 79 countries in 20 years, the interactive model will take into consideration Oil Reserves in relationship with Fossil Fuel Consumption, Blue or Green hydrogen projects and other variables with respect to countries. Stata 17 was used for the analysis. The results confirm the hypothesis that countries with high fossil fuel consumption rather invest in blue hydrogen instead of green, towards a "zero-carbon-emission" perspective, but oil capacities and reservoirs still pushes down energy transition. Moreover, those countries which are able to invest in hydrogen projects have good institutional and economic situation to do so. Future research should exploit Green Finance policy decision criteria on green and blue hydrogen.

Keywords: *blue hydrogen, green hydrogen, oil reserve, sustainability, energy transition, carbon capture and storage.*

1. Introduction

The growing international concerns of climate change and oil import dependence are not a surprise, such that a greater interest in hydrogen energy has come as a consequence [1]. Today, several factors have led to growing interest in a hydrogen energy economy, especially for transportation and the need to store renewable electricity supplies [2]. However, very few empirical works have been developed to address the crucial question of "how" to spread the use of hydrogen, or "how to get it". Today, in fact, the academic and political debate has already assumed the need for the use of hydrogen, but still unclear and unambiguous are the positions regarding the types of hydrogen production process that must be perpetuated and implemented for the so called "sustainable energy transition" [3]. Policy plays a key role in the promotion of different paths of energy sources exploitation, and much research has been conducted to assess its effects on renewable energy innovation [3, 4].

The aim of this paper is to analyze the status of green transition for oil-dependent countries, especially in relationship with newest hydrogen policies worldwide.

This paper is structured as follows: the introduction will cover an overview of the current political and economic framework, trying to emphasize the importance of investing in hydrogen and its related costs. The empirical analysis will then focus on the investigation of which factors better and mostly impact oil capacities and reservoirs of countries, with respect to green projects. In particular we are interested in estimating the effort towards overall hydrogen projects, considering recent uptakes and findings from both literature and governments' agenda. The idea that stimulated this analysis, methodologically based on a Panel Data Set of observations on 79 countries, concerns the influence and role of dependence on hydrocarbons, such as oil, on the choices to concretely develop the prospects for exploitation of Hydrogen, as a primary energy source considered more sustainable. So, our focus is to understand if oil-dependent countries are currently investing in hydrogen, and whether they are more focused on blue or green hydrogen. The results will show that fossil fuel consumption, pressured by recent policies and institutions, relates to green policy projects and in particular with blue Hydrogen, whereas we can not assume the same for countries with big oil capacities and reserves.

1.1. Investing in Hydrogen

The strategic repositioning of "national" energy policies has resumed the progressive affirmation of an increasingly wide collection of consensuses on the issues of sustainability [5], which has also used the renewed the need for energy policies of independence and autonomy. This happened in particular ways in countries which had and are currently having difficulties in importing hydrocarbons from countries of verified complexity, variability, and direct and indirect burdens [6].

The search for an increasingly sustainable national energy mix needs to be viewed in accordance with the search for national or local autonomy in the generation of green energies, which are becoming more and more essential to the economic development of each nation [7]. National policies have followed this lead by focusing on sustainable energies, both directly and indirectly financed from governments [8]. CCS and hydrogen are becoming the main characters of a new Sustainable Development Scenario all over the world. Policymakers and experts argue about whether to invest in green or blue hydrogen, but the different point of views seem to converge into finding massive public support to enhance the efficient hydrogen supply chain. The European Commission's strategy "A hydrogen strategy for a climate-neutral Europe" [9] is already addressing the ways in which to exploit hydrogen investments, and finding the necessary instruments. On the one side, there is "green" hydrogen with low carbon emissions, and on the other there is the intent of developing infrastructures for hydrogen transport and storage.

The New Green Deal plays a crucial role in improving energy efficiency, energy autonomy and reaching sustainability goals: hydrogen strategies have been implemented inside the New Green Deal. The strategy adopted by the European Commission foresees three phases – 2020-2025, 2025-2030, and 2030-2050 – which assume objectives such as [9]:

- Reducing hydrogen costs of production from industrial processes with low Greenhouse Gases ("GHG") emissions.
- Exploiting all possible synergies with existing and feasible infrastructures for the logistical diffusion of the potential of hydrogen.
- Reducing the cost of generating renewable electricity, including the reduction of the hydrogen costs of production due to industrial processes with low GHG emissions.
- Reductions in the capital expenditures of the electrolysers, in particular the large ones: from about 900 €/kW today to 450 €/kW in 2030 (this forecast is slightly more optimistic than that of the aforementioned IEA ratio, which indicates 550 €/kW) and down to 180 €/kW after 2040.
- Exploiting all of the possible synergies with existing and feasible infrastructures for the logistical diffusion of the potential of hydrogen. This includes maximizing the value of the innovations introduced by the use of hydrogen in the verticalization of industrial processes.
- In the long term (after 2040), green hydrogen should reach full maturity and become competitive; in the meantime, space and incentive should be given to blue hydrogen with CCS.
- Blue hydrogen investments should progressively increase through subsides, pilot projects, and EU and national funds, in order to boost both demand and offers.

We are close to a turning point with respect to the goals mentioned above. Between November 2019 and March 2020, market analysts increased the list of planned global investments in electrolysers from 3.2 GW to 8.2 GW by 2030 (of which 57% will be in Europe) [10].

The number of companies that have joined the International Hydrogen Council grew from 13 in 2017 to 81 as of today. The Council aims to promote the meaningful use of hydrogen in various strategic fields, and to identify the current limits that must be solved thanks to the governments' support [11].

1.2. Hydrogen and CCS

Hydrogen is the new resource which is seen as a new achievable sustainable perspective for green energy mix policies. It can both be used as energy carrier and an energy source. Hydrogen has been labeled according to its original energy source:

- "Grey" hydrogen, from natural gas to hydrogen.
- "Brown" hydrogen, from coal to hydrogen.
- "Blue" hydrogen, from natural gas to hydrogen with the storage of CO_2.
- "Green" hydrogen: from water, via electrolysis, to hydrogen. This is the only method which is usually considered to be a "100% Green" solution to create clean power energy.
- "Purple" hydrogen, from electrolysis supported by nuclear energy.

However, there is another potential way to view hydrogen: as energy storage. Batteries may be a cheaper means of storing energy in the short-term, but hydrogen can be stored indefinitely, offering a potential solution to the current challenges weighing on the energy industry.

Green hydrogen is more and more often considered to be a "game changer" in some sort of "fight against climate change", because it usually enables the decarbonization of difficult-to-decarbonize sectors. Green hydrogen can convert wind and solar energy to a flexible zero-carbon fuel that can displace many fossil fuel applications. The demand for this hydrogen already exists, with some 100 million metric tons of hydrogen already in use in industrial applications. Most of today's hydrogen is produced by using steam methane reforming or other methods to extract hydrogen from fossil fuels. Green energy could decarbonize this existing industry by the use of curtailed wind and solar energy to split water into hydrogen and oxygen by way of electrolysis.

According to the European Commission's July Hydrogen Strategy [8], the actual indicative costs for hydrogen production today are:

- 38€/MWh for current high-carbon production;

- 50€/MWh for “blue” hydrogen with CCS;
- 65-135 €/MWh for “green” hydrogen.

It is important to remark that these costs – especially those related to blue hydrogen – are merely indicative, because they are very location specific. Moreover, because there are some difficulties in finding the right metal hydrides to match with the necessary criteria, the possibility of a storage system of hydrogen is still uncertain [12].

It is also important to consider the costs of developing an efficient infrastructure system: according to Enagàs, Snam and other companies [13], the investment costs of a complete infrastructure development – not including storage, distribution pipelines and CO_2 infrastructures – vary from 27 to 64 billion euro, covering full capital costs of the project, while OPEX costs might range from 106 to 3.5 billion euro. Most of the average total costs for these projects are still under evaluation, but it is a common fact that hydrogen and CCS plants are very expensive – especially in capital and operating costs – and unfortunately, they do not seem to provide a clear net margin in the short-term due to their high production costs, as mentioned before in this paper. The European Hydrogen Alliance [9] was born to sustain a financing solution: governments should support local/national private entities to enhance investments in both blue and green hydrogen. It is also worthwhile to mention the importance of the cost reduction potential in the long term for those policies.

Carbon capture also plays a crucial role in energy transition, even if it remains an area of debate. According to the “Global Status of CCS” Report [13], CCS facilities can be summarized into:

- Large-scale CCS facilities, which are able to capture large capacities of CO_2 from industrial sources and power generation, including transport and storage hubs projects, of around 400-800 ktpa. Those facilities must be covered by commercial return in both the capture and storage phases.
- Small-scale CCS facilities, which are able to capture CO_2 from power or industrial sources under the abovementioned thresholds. These facilities are more for the testing of strategies, and they do not expect a commercial return on those projects.

Current CCS facilities are able to capture 40Mt of CO_2 per year. As the decarbonization of one ton of steel requires 627 cubic meters of green hydrogen, in a steel plant with an annual production of 4 million tons of steel the electricity required by a polymer electrolyser to make available all of the hydrogen needed would be about 8,800 GWh. To power it, all of the electricity (8,400 GWh) generated by the large offshore park of 2.8 GW, planned in the Channel of Sicily, would not be enough. Assuming that, in 2030, the efficiency of the electrolysers is a little higher than expected today, linked to wind energy sources, it would be possible to decarbonize half of the 8 million tons of steel which, according to the Federmanager study, should still be produced in blast furnaces. Moreover, the use of photovoltaic plants would require the total employment of 6,000-7,000 hectares: this objective seems unrealistic, because this technology will have to provide the most important share of the energy required to achieve the other objectives of the new PNIEC, revised upwards.

Having stated that countries need to find new technologies and invest in eco-innovation to meet the expectations held by the New Green Deal and Paris Agreement, understanding which factors do affect investment policies in hydrogen is not as straightforward as projected.

According to the IEA [14], in the long-run 40% of the global hydrogen produced will be blue, and 18% of this production will be captured by attached CCS plants. As a consequence, countries with high fossil fuel consumption and oil reserves might decide to invest in these policies to mitigate their emissions levels.

The literature regarding the relationship between green technologies and fossil fuel countries and factors is wide. Some authors assess that the so-called substitution effect between green and non-green technologies does not occur all of the times [15]. In particular, Gursan [16] showed that indirect effects linked to natural gas can outweigh the direct ones and constitute a bridge to renewables or lock-in to fossil fuels.

It is known that oil & gas companies, along with energy company framework in general, grants long product life cycles, slow turnover of existing equipment, low volume production of new equipment, low operating costs per unit in existing large-scale systems. There is huge competition between different technologies, and usually green transitioning requires whether to switch to renewable sources or to adopt expensive auxiliary equipment’s, like CCS [17]. Pressures coming from investors, regulation policies and institutions might mitigate radical innovations towards low-carbon energy transition. In particular, a broadened piece of research from Noailly and Smeets [18] considering renewable energies in general terms showed that firms specializing in renewable technologies are more vulnerable to financing constraints than firms investing in fossil fuels. This result holds for small and large firms as well. This might mean that investing in renewables is riskier than investing in fossil fuel.

Wietschel *et al*. [19] addressed the question from several points of view, including input-output, a general equilibrium model, system dynamics and econometric analysis. They concluded that hydrogen as an energy carrier might be linked with GDP, welfare and employment at both the national and regional level; in particular, competitiveness might be the trigger to incentivize hydrogen investments.

Tseng *et al*. [20] used a Market-Allocation ("MARKAL") model to estimate the impacts on hydrogen in the US economic energy system, discovering that, overall, a hydrogen economy might boost energy efficiency by lowering the consumption of oil and derivatives. They also addressed the fact that, in order to fight the most impeding cost-barrier of hydrogen production, coal seems to be the most competitive way to produce it, without considering its consequences on emissions. They also stressed the importance of capturing the CO_2 deriving from gray/blue hydrogen production, even though it might add 25% or 30% to the overall costs of hydrogen production [21]. Nevertheless, there seems to be a trend in the cost-reduction of hydrogen production which leads to a massive reduction in the spread of investment costs [22]. Some of the reasons might rely on improved supply chains and higher-volume production, along with technology innovation.

A similar approach has been used by Kawakami *et al*. [23], who analyzed the impact of CO_2 targets on Japan's energy system towards 2050. In their research, among other factors, they considered GDP, fossil fuel and hydrogen import spending, the average energy price and energy supply, the carbon price and the amount of hydrogen introduced. Their research shows that emission reduction targets might not be enough to push countries towards energy transition, due to greater economic pressure.

Lee [24] forecast the economic consequences of hydrogen on South Korea's energy system through a general equilibrium model, stating that hydrogen development might lead to the reduction of the production cost and GDP growth in the end. Most importantly, he concluded that hydrogen energy needs to come from non-fossil fuel sources in order to effectively reduce greenhouse gases emissions, in which government intervention plays a crucial role.

2. Materials and Methods

2.1. Rationale

Following the abovementioned examples from the literature, this paper aims to address the research gap of the understanding of macroeconomic outcomes on hydrogen from a different point of view and with respect to current policies. In particular, choosing whether to invest in blue or green hydrogen projects might rely on the nature of the country and its dependance on fossil fuel consumption and hydrocarbon capacities. Indeed, we observe the ongoing efforts of different nations to use hydrogen to reduce their dependence on petroleum imports. About 9 million tons of hydrogen are produced each year in the US and 50 million tons worldwide, mostly and most cheaply from the steam reforming of natural gas [25]. Dunn [26] opened their introduction with the depiction of ongoing efforts by different nations to reduce their dependence on oil. He suggests that nations' renewed interests in hydrogen are mainly due not only to the advent of technological advances but also to the resolution for risk posed by the current dependence on petroleum use.

By looking at IEA's [14] hydrogen policy database, we can observe that only 66 projects out of 222 are financed by private investments: the most important are the hydrogen refueling station in Netherlands, the NCG conversions to H2 in the UK, and several power supply and demand projects in Brasil. Yara and Evoenergy are financing a renewable ammonia plant and hydrogen test facility in Australia, and there are some ongoing investments in the transport sector from automotive industry companies. Most of the projects are financed by public funds or public-private partnerships. The range of funding amounts (national currency 2018) might be very wide, like the 250 million euro "National Innovation Programme Hydrogen and Fuel Cell Technology" project financed by the German Ministry of Transport and digital infrastructure. According to the EEA Report [9] on sustainability transition in Europe, there are some remarkable fiscal sustainability risks for Belgium, Spain, Italy, Luxembourg, and Hungary in the medium and long term; matching with our hypothesis, evidence of hydrogen and CCS projects in those countries is lacking. In the US, some CCS projects will benefit from the California low-carbon fuel standard (LCFS) and 2018's tax credit law [27].

For the reasons explained above, we expect to see a relationship between H2-CCS policies and the Government's GDP per capita, which is necessary to sustain those initiatives. Following Nicolli and Vona's [28] approach to heterogeneous policies and technologies, we considered blue and green policies based on IEA's [14] Hydrogen Policies Database and IOGP's (2020) Global CCS projects. We constructed a categorical dummy which takes value one for Blue Hydrogen projects, value two for Green ones and value three if no hydrogen projects exist or have existed in that country. We considered both past hydrogen policies and announced initiatives which have not yet started. This is because most of the observed policies started in 2020, but most of their costs were already included in 2019's budgets. In order to do so, we have constructed a panel dataset from 2000 to 2019 period. Then, we will take into consideration fiscal balance, trade balance and other variables indirectly related to oil reserves and green policy measures.

2.2. *Data Analysis*

On overall, most part of data has been retrieved from the GlobalEconomy dataset, while the Fossil Fuel Consumption data of 2019 has been retrieved from Our World in Data [29] and data on hydrogen has been taken from IEA database [14]. We took into consideration 79 countries for the whole period, considering the information available.

From our dataset it turned out that among 79 countries, 32 have invested in CCS or hydrogen policies. Of these, as many as half show a dualism of their CCS-H2 policy. This result highlights some important remarks: those countries investing in CCUS and hydrogen policies for decarbonization targets are very solid innovative countries like Denmark, the Netherlands and Germany, with a very positive economic and financial situation for those countries. There are a few exceptions, such as Spain, Thailand, Argentina, and Italy; further exploiting the nature and the background of green policies and financing in those countries goes beyond the aim of this paper, but it is important to underline that the European Union is providing solid financial sustenance to fulfill New Green Deal strategies towards 2030 [30].

Tab. 1 shows a brief description of the variables used for the model estimation, while Table 2 reports the descriptive statistics.

On overall, the dataset appears quite balanced. The maximum and minimum values suggest that there are consistent differences within the countries. We interpret oil reserves as the ability for each country to elaborate hydrocarbons upstream, including those reserves which can be potentially recovered. The categorical variable created ad hoc for the analysis will explain how different hydrogen policies will relate with the dependent variable. In addition to those, we have decided to include several control variables following literature approach.

We have decided to include control variables to better estimate our model. Following Wietschel *et al*. [19] approach, we have included GDP and trade balance to assess wealth and competitiveness. Fiscal balance represents a proxy for evaluating the propensity of countries to use public debt for financing green policies.

Following Kawakami's [23] approach, Fossil Fuel consumption has been inserted and it is estimated in KW/h. Following Lee's approach, we have included capital and labor since productivity might influence energy scenarios. All of the variables are expressed as per capita values in order to avoid bia-

Tab. 1 – Variable summary.

Variable name	Storage type	Display Format	Variable label
Oil storage	Double	%10.0g	Oil reserves, billion barrels
GDP	Double	%10.0g	GDP per capita, current U.S. dollars
Capital	Double	%10.0g	Capital investment as % of GDP
Labor	Double	%10.0g	Labor force, million people
Trade Balance	Double	%10.0g	Trade balance as % of GDP
Fiscal Balance	Double	%10.0g	Fiscal balance as % of GDP
Fossil Fuel Cons	long	%10.0g	Fossil fuel consumption
BankCredit	Double	%10.0g	Bank credit to institutions and companies, % of GDP
H2policy	Long	%9.0g	1=blue, 2=green, 3=none

Source: author's computation.

Tab. 2 – Descriptive statistics.

Variable	Obs	Mean	Std. dev.	Min	Max
Oil storage (billion barrels)	1314	13.8857	42.76354	0	295.35
GDP (USD per capita)	1327	21314.83	21277.64	390.09	118823.6
Capital (% of GDP)	1308	24.58524	6.278366	10.22	57.99
Labor (million people)	1328	32.80453	103.2681	.17	787.18
Trade Balance (% of GDP)	1308	2.976804	10.64408	-25.12	48.45
Fiscal Balance (% of GDP)	1263	-1.347506	6.54597	-89	43.3
Fossil Fuel Cons (KWh)	1328	1299824	3615104	11	3.5e^07
BankCredit (% of GDP)	1328	13.85276	11.03191	.04	74.68
H2policy	1328	2.28012	.8945094	1	3

Source: author's computation

sed information due to the different magnitudes of countries' indices. The correlation matrix showed no significant correlations between variables. We have decided to convert variables into logarithmic form to reduce the effect of outliers and obtain residuals that are approximately symmetrical distributed. By doing so, heteroskedasticity should be mitigated. Moreover, we are more interested in examining the marginal changes in explanatory variables in terms of multiplicative – percentage – changes in the dependent variable.

We have dropped missing observations to achieve a more balanced panel dataset.

2.3. Model Framework

Considering the log-linear form of the dependent variable, but also the categorical variable of our interest, the dummy variable interaction expansion model seems to be the best fit for the analysis. We have also inserted an interaction term between the dummy variable associated with Fossil Fuel consumption to better assess the relationship between an eventual "green" orientation in a "grey" economy. By using interaction variable, we are asking the regression model to assess different slopes in the interaction terms for different levels of categorical variable.

The model estimation would be:

$$y = \beta_0 + \beta_1 \log GDP + \beta_2 \log Labor + \beta_3 \log Trade + \beta_4 \log Fisc + \beta_5 \log Credit + \beta_6\, h2policy2 + \beta_7\, h2policy3 + \beta_8\, h2policy2 \cdot \log FossFuel + \beta_9\, h2policy3 \cdot \log FossFuel$$

As explained by te Grotenhius *et al.* [31], this framework is useful if main effects represent a grand mean effect, while the interaction effects are deviations from the grand mean, in case of unweighted balanced data, which is our case and in general for linear models. In particular, Cobb-Douglas loarigthmic form reduces the effects of outliers because logarithms tend to make the tend "flat". It has smaller values in terms of "magnitude", which also explains the difference of the estimated coefficient with respect to the level-level model. The logarithimic form express values in terms of their elasticity and facilitates the interpretation of results. However, as Zhu *et al.* [32] reports, one problem related to the Cobb-Douglas production function might be the violation of strict exogeneity of variables, since there might be various factors affecting the output level and the choice of inputs at the same time. In this case, it might not be a problem because we have considered exogenous uncorrelated variables. Despite this, omitted variable bias might still be a problem in our model since the uncertainty of considering all elements for best estimation fit. Moreover, in this case we did not include time effect element because we do not think that there are unexpected variations or special events which might affect the outcome variable.

Tab. 3 – Interaction model results.

logOilStor	Coefficient	Robust std.err.	t	P>|t|	[95% confidence interval]	
Loglabor	-.1246371	.1858277	-0.67	0.503	-.491163	.2418888
Logtrade	1.023285	.1621535	6.31	0.000	.7034544	1.343116
Logfisc	.5512914	.0986375	5.59	0.000	.3567391	.7458437
Logcredit	-.2442689	.2186657	-1.12	0.265	-.6755644	.1870265
logGDP	-.3448266	.1924432	-1.79	0.075	-.7244009	.0347476
_ih2policy_2	9.307176	2.691088	3.46	0.001	3.999283	14.61507
_Ih2policy_3	-2.377526	2.697626	-0.88	0.379	-7.698314	2.943263
logFoss	.7075578	.1705108	4.15	0.000	.3712428	1.043873
_Ih2pXlogFo_2	-.7771422	.214607	-3.62	0.000	-1.200432	-.353852
_Ih2pXlogFo_3	.1368713	.1964806	0.70	0.487	-.2506664	.524409
_cons	-5.548253	3.195184	-1.74	0.084	-11.85042	.7539158
Number of obs	203		R-sqiared	0.5137		
F(10,192)	38.02		Prob>F	0.0000		

Source: author's computation

3. Results

3.1. Model Estimation

Tables 3 shows the results estimated from the interaction model. We have considered a robust estimation to reduce heteroskedasticity bias during estimation process.

As expected, Stata has dropped a lot of information during the estimation. As we already know, the R-squared explains how well explanatory variables account for changes in the dependent one. As expected, omitted variable bias led to an R-squared equal to 51%, which is quite satisfying, although there might be several factors not considered in the model which might affect our dependent variable. The F-value and the Prob>F equal to zero means that, on overall, the model applied can statistically significant predict the dependent variable.

It is important to remind that Stata omits the first value of the categorical variable – which in our case would be “presence of blue hydrogen projects” as reference group. The indicative variable is generated with “_I” term put at the beginning of the variable. In general, indicative variable will express difference in means: when the dummy is zero, the expected value of the outcome is equal to the intercept, considering only a hypothetical relationship between the dependent and categorical variable. In this case, the coefficient of hydrogen corresponds to the difference between the mean of the outcome for having green projects rather than blue ones, or having no hydrogen projects at all.

Unfortunately, only few variables turned out to be statistically significant. The Trade and Fiscal balance has a positive correlation with Oil Reserves at 1% statistical significant level. The results confirm that oil is very important for export strategies. Statistically speaking, an increase of 1% in those variables lead to an increase of about 1% and 0.5% of Oil Reserves. This also positvely impact fiscal balance of the country.

What seems even more interesting is that the variable Fossil Fuel Consumption is statistical significant at 1% level, meaning that an increase of 1% in Fossiil Fuel consumption for a country lead to an increase of 0.7% of oil reserves. Reagarding the categorical variable, at a first sight, it is important to assess that oil reserves in correlation with fossil fuel negatively affect green hydrogen policies in favor of blue ones. We can notice that for a unit increase in Fossil Fuel consumption there is a decrease of Green Hydrogen projects with respect to the Blue ones, which impacts the oil reserve capacity. This means that oil reserves countries do have high fossil fuel consumption, as expected, and to reach decarbonization targets they are propensing towards blue hydrogen.

3.2. Discussion

The outcome of the estimation shows that fossil fuel consumption is positively linked to green projects like hydrogen, oil-dependent countries are still behind in finding the right way to reach the decarbonization target of 2050 or similar goals and most of the countries investing in hydrogen are indeed “wealthy” countries that have not suffered much from European austerity or are international rich countries. Of course this is connected to oil capacities since the major oil&gas countries gauns huge revenues from that. Despite the results shows a potential positive correlation between hydrocarbon capacities and green hydrogen projects, by looking at the data we can notice that the green transition is yet far from achievement, especially in big oil exporters [33,34]. This fact is confirmed by our results, which show that trade balance is positively correlated with oil reserves. Moreover, deficit-oriented policies tend to undermine public debt financing.

In fact, although 14 member states have included hydrogen in their national policy agenda for alternative infrastructure frameworks [35], countries with large oil reserves which are not currently investing in hydrogen policies, such as Egypt, Hungary, Kuwait, Russia and others, still rely on oil and gas to create and supply power demand at both the national and international levels. While it seems quite obvious the connection between fossil fuel consumption and hydrocarbon capacities, decision-making in green technologies investment seems to be trivial to assess. From the results above we can suppose that green hydrogen seem to be the most attractive energy source for long-term energy efficiency solution. However, there are still huge barriers which mitigate the investments on those technologies, in favor or other renewable ones or mostly in favor of a more “economic” Blue hydrogen project.

4. Conclusions

The aims of his paper to analyse factors influencing energy sustainable policies have finally emphasized the relationship between oil reserves storage of countries and hydrogen policies; indeed, as our results well show while fossil fuel consumption is positively linked to green projects like hydrogen, oil-dependent countries are still behind in finding the right way to reach the decarbonization target of 2050 or similar goals.

Investing in green policies requires huge efforts from both private and public funding. Moreover, the risk associated to those projects is generally really high, which mitigates the willingness of investors to pay for those “risky” R&D expenditures. As a consequence, we could take into considerations other important elements such as the private credit to government institutions and public companies, trade and fiscal balance, and other control variables. Our panel data analysis show a situation in which pathway toward decarbonization is very far from being achieved. In this sense, it is essential to build strategies for low carbon emissions which are not only efficient in reaching the targeted goal, but also in terms of profitability, cost-reduction and transparency towards stakeholders and investors. Policymakers should define strategies based on most recent researches’ outcomes, always taking into considerations the crucial role of private investments for sustaining those initiatives. Private-Public-Partnerships should be incentivized to attract know how, reduce uncertainties, and mitigate a potential failure risk of the so called "sunk costs" of R&D expenditures for green projects.

Institutional Review Board Statement: Not applicable
Informed Consent Statement: Not applicable
Data Availability Statement: The data used in this paper can be found in:
[Dataset] Global economy, world economy. (n.d.). Retrieved May 01, 2021, from https://www.theglobaleconomy.com/
[Dataset] IEA (2020), Hydrogen Projects Database, IEA, Paris https://www.iea.org/reports/hydrogen-projects-database

References

Abe, J.O., Popoola, A.P.I., Ajenifuja, E., Popoola, O.M., (2019). Hydrogen energy, economy and storage: Review and recommendation. *Int. J. Hydrog. Energy* (*44*) 15072-15086, doi:10.1016/j.ijhydene.2019.04.068

Barbieri, N., Marzucchi, A., Rizzo, U., (2021). "Green technologies, complementarities, and policy," SEEDS Working Papers 1021, *SEEDS*, Sustainability Environmental Economics and Dynamics Studies, revised Sep 2021.

Biresselioglu, M.E., Karaibrahimoglu, Y.Z., (2012). The government orientation and use of renewable energy: Case of Europe. *Renew. Energy (47)*, 29-37, doi:10.1016/j.renene.2012.04.006

Chun, D., Hong, S., Chung, Y., Woo, C., Seo, H., (2016). Influencing factors on hydrogen energy R&D projects: An ex-post performance evaluation. *Renew. Sustain. Energy Rev (53)*, 1252-1258, doi:10.1016/j.rser.2015.09.074

Ding, H., Su, B., Zhou, D., Wang, Q., (2021). Literature Review on Renewable Energy Development and China's Roadmap, *Front. Eng. Manag. (8)*, 212-222, Degun Zhou's Lab, China.

Ding, H., Zhou, D., Zhou, P., (2020). Optimal policy supports for renewable energy technology development: A dynamic programming model. *Energy Econ. (92)*, 104765, doi:10.1016/j.eneco.2020.104765

Dumas, M., Rising, J., Urpelainen, J., (2016). Political competition and renewable energy transitions over long time horizons: A dynamic approach. *Ecol. Econ.* (*124*), 175-184, doi:10.1016/j.ecolecon.2016.01.019

Dunn, S., (2012). *Hydrogen Futures: Toward a Sustainable Energy System (Worldwatch Institute, 2001)* (26), Reviewed 2012 by Dunn S. in Syracuse Science & Technology Law Reporter, Spring: Berlin/Heidelberg, Germany.

European Commission. A hydrogen strategy for a climate-neutral Europe. In Communication from the Commission to the European Parliament, the Council, the European Economic and Social Com-Mittee and the Committee of the Regions Global CCS Institute; Global Status of CCS 2020: Melbourne, Australia, 8 July 2020.

Finon, D., Lamy, M., Menanteau, P., (2001). *Prices versus Quantities: Environmental Policies for Promoting the Development of Renewable Energy*, Institut d'Economie et de Politique de l'Energie: Paris, France.

Finon, D., Perez, Y., (2007). The social efficiency of instruments of promotion of renewable energies: A transaction-cost perspective. *Ecol. Econ. (62)*, 77-92, doi:10.1016/j.ecolecon.2006.05.011

[dataset] Global Economy, World Economy. 1 May 2021, Available online: https://www.theglobaleconomy.com/ (accessed on 01/05/2021).

Global CCS Institute. Global Status of CCS 2020, November Report, Global Carbon Capture and Storage Institute; Australia, 2021 Melbourne, Australia.

Grotenhuis, M.t., Pelzer, B., Eisinga, R., *et al.*, (2017). A novel method for modelling interaction between categorical variables. *Int J Public Health* (62), 427-431. https://doi.org/10.1007/s00038-016-0902-0

Gürsan, C., de Gooyert, V., (2021). The systemic impact of a transition fuel: Does natural gas help or hinder the energy transition?, Renewable and Sustainable Energy Reviews (138), 110552, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2020.110552

Hart, P., Freund, P., Smith, A., (1999). *Using Hydrogen – Today and Tomorrow*, IEA Greenhouse Gas R&D Programme: Cheltenham, UK.

IEA, (2020). *Hydrogen Projects Database*, IEA: Paris, France, Available online: https://www.iea.org/reports/hydrogen-projects-database (accessed on 01/05/2021).

International Renewable Energy Agency, (2018). *Renewable Energy Policies in a Time of Transition*, pp. 1-112, ISBN 978-92-9260-061-7, United States.

Johnston R.J., Blakemore R., Bell R., (2020). The role of oil and gas companies in the energy transition. Atlantic council gobal energy center, ISBN: 978-1-61977-085-0.

Kawakami, Y., Matsuo, Y., Kako, M., Hachiuma, T., Yanagisawa, A., (2013). *The Economic Impact of the Introduction of Hydrogen into Japan's Energy Systems towards 2050*, Institute of Energy Economics: Tokio, Japan.

Kelly, G., (2006). Renewable energy strategies in England, Australia and New Zealand. *Geoforum*, *38*, 326-338, doi:10.1016/j.geoforum.2006.08.002.

Lægreid, O.M., Povitkina, M., (2018). Do Political Institutions Moderate the GDP-CO_2 Relationship? *Ecol. Econ (145)*, 441-450, doi:10.1016/j.ecolecon.2017.11.014

Lee, S.-H., (2016). The Impact of the Introduction of Hydrogen Energy into the Power Sector on the Economy and Energy. *J. Korea Acad. – Ind. Coop. Soc. (17)*, 502-507, doi:10.5762/kais.2016.17.8.502.

Muthmann, D., (2020). European Hydrogen Backbone, Guidehouse, Madrid Forum 14 October 2020, Madrid.

NERSA (National Energy Regulator South Africa) Report, (2009). *Rules on Selection Criteria for Renewable*

Energy Projects under the REFIT Programme, NERSA.

Nicolli, F., Vona, F., (2016). Heterogeneous policies, heterogeneous technologies: The case of renewable energy. *Energy Econ (56)*, 190-204, doi:10.1016/j.eneco.2016.03.007

Noailly, J., Smeets, R., (2021). Financing Energy Innovation: Internal Finance and the Direction of Technical Change. *Environ. Resour. Econ.* 1-25, doi:10.1007/s10640-021-00602-9.

Oliver, N.K., (1995). The log transformation is special. *Statistics in Medicine* 14(8):811-819. doi:. (PDF of dubious legality available at http://rds.epi-ucsf.org/ticr/syllabus/courses/25/2009/04/21/Lecture/readings/log.pdf).

Saba, S.M., Müller, M., Robinius, M., Stolten, D., (2018).The investment costs of electrolysis – A comparison of cost studies from the past 30 years. *Int. J. Hydrog. Energy (43)*, 1209-1223, doi:10.1016/j.ijhydene.2017.11.115

Salim, R.A., Rafiq, S., (2012). Why do some emerging economies proactively accelerate the adoption of renewable energy? *Energy Econ (34)*, 1051-1057, doi:10.1016/j.eneco.2011.08.015

Tseng, P., Lee, J., Friley, P., (2005). A hydrogen economy: Opportunities and challenges. *Energy (30)*, 2703-2720, doi:10.1016/j.energy.2004.07.015

US Department of Energy (DOE), National Hydrogen Energy Roadmap. Toward a More Secure and Cleaner Energy Future for America. In Proceedings of the Results of the National Hydrogen Energy Roadmap Workshop, Washington, DC, USA, 2-3 April 2002.

Viklund, M., (2004), Energy policy options – from the perspective of public attitudes and risk perceptions. *Energy Policy (32)*, 1159-1171, doi:10.1016/s0301-4215(03)00079-x.

Wietschel, M., Jokisch, S., Boeters, S., Schade, W., Seydel, P., (2010). Macroeconomic impacts of hydrogen. In *The Hydrogen Economy: Opportunities and Challenges*, Ball, M., Wietschel, M., Eds., Cambridge University Press: Cambridge, UK, pp. 529-562.

Zhu W., Zhang Z., Li X. e*t al.*, (2019). Assessing the effects of technological progress on energy efficiency in the construction industry: a case of China*, Lawrence Berkeley National Laboratory*, doi: 10.1016/j.jclepro.2019.117908

Acknowledgments

Conflicts of Interest: The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; or expert testimony or patent-licensing arrangements) or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.