UNIVERSITÀ DEGLI STUDI DI FERRARA
DIPARTIMENTO DI ECONOMIA E MANAGEMENT
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MACROECONOMIC FACTORS INFLUENCING PUBLIC POLICY STRATEGIES FOR BLUE AND GREEN HYDROGEN

Roberto Fazioli, Francesca Pantaleone

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Macroeconomic factors influencing public policy strategies for Blue and Green Hydrogen

Roberto Fazioli
Università di Ferrara
Dipartimento di Economia e Management
e
Francesca Pantaleone
Università di Ferrara
Dipartimento di Economia e Management

ABSTRACT

The aim of this paper is to analyze the factors affecting Hydrogen and CCUS policies, taking into considerations Fossil Fuel Consumption, Oil Reserves, Debt/GDP Ratio, Trilemma Index and other variables with respect to OECD countries. STATA 17 has been used for the analysis. Results confirmed the hypothesis that countries with big fossil fuel consumption and oil reserves are investing in Blue Hydrogen and CCUS towards a "zero-carbon-emission" perspective. Moreover, countries with good Debt/GDP ratio are most favorable to Green policies by raising their Public Debt, since Foreign Direct Investments are negatively correlated with those kinds of policies. Blue Hydrogen combined with CO2 capture seems to be the most favorable policy in the short-term. Future research should exploit Green Finance policy decisions criteria on Green and Blue Hydrogen.

Keywords: blue, green, hydrogen, CCS, green finance

1. INTRODUCTION

CCS and Hydrogen are becoming main characters of a new Sustainable Development Scenario in all over the world.

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

The search for increasingly sustainable national energy mix needs to be viewed in accordance with the search of national or local autonomy in the generation of green energies, which are becoming more and more essential to the economic development of each nation. National policies have followed this lead by focusing on sustainable energies, both directly and indirectly financed from governments. New Green Deal plays a crucial role in improving energy efficiency, energy autonomy and reaching sustainability goals.

Hydrogen is the new resource seen as new achievable sustainable perspective for green energy mix policies. It can be both used as energy carrier and energy source. UE launched an hydrogen strategy in 2020 to accelerate investments on hydrogen. Recently, hydrogen strategies have been implemented inside the New Green Deal, to achieve energy transition through three key points:

- Reducing hydrogen costs of production from industrial processes with low GHG emissions.
- Exploiting all possible synergies with existing and feasible infrastructures for the logistical diffusion of the potential of hydrogen.
- Maximizing the value of the innovations introduced by the use of hydrogen in verticalization of industrial processes.

Policymakers and experts argue whether to invest in green or blue hydrogen, but different point of views seem to converge into finding a massive public support to enhance efficient hydrogen supply chain. The European Commission's strategy "A hydrogen strategy for a climate-neutral Europe" (COM(2030)301, 2020) is already addressing how to exploit hydrogen investments and which are the necessary instruments. From one side there is the "green" hydrogen with low carbon emissions, and on the other there is the intent of developing infrastructures for hydrogen transport and storage.

The strategy adopted by the European Commission foresees three phases [2020-2025, 2025-2030, 2030-2050] which assume objectives such as:

- Reducing the cost of generating renewable electricity.
- Reductions in the CAPEX of the electrolysers, in particular large size ones: from about 900 €/kW today to 450 €/kW in 2030 (forecast slightly more optimistic than that of the aforementioned IEA ratio, which indicates 550 €/kW) and down up to 180 €/kW after 2040.
- 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 the blue hydrogen with CCS.
- Blue hydrogen investments should progressively increase through subsides, pilot projects, EU and national funds, to boost both demand and offer.

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 from 3.2 GW to 8.2 GW of electrolysers by 2030 (of which 57% in Europe).

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

2. THE COLORS OF BLUE HYDROGEN

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 storage of CO2
- "Green" Hydrogen: from water – electrolysis – to Hydrogen. This is the only usually considered as "100% Green" solution to create clean power energy.
- Purple" Hydrogen: electrolysis supported by nuclear energy

Green hydrogen is more and more considered as a "game changer" in some sort of "fight against climate change", because it usually enables decarbonization of difficult to decarbonize sectors. Green hydrogen can convert wind and solar to a flexible zero carbon fuel that can displace many fossil fuel applications. 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 using curtailed wind and solar energy to split water into hydrogen and oxygen by way of electrolysis.

But 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 current challenges weighing on the energy industry.

The role of blue hydrogen — hydrogen produced with carbon capture or other emissions-reducing technologies — also remains an area of debate. Indeed, green hydrogen remains too expensive and blue hydrogen could provide a bridge in the near-term, while also reducing emissions from existing industries. Natural gas production currently produces excess methane, which is burned off as a means of disposal. But that gas could be captured and converted into hydrogen, reducing more emissions in the near-term.

According to European Commission's July Hydrogen Strategy (2020), the actual indicative costs for the 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, since they are very location specific.

It is also important to consider the costs of developing an efficient infrastructure system: according to Enagàs, Snam and other companies (2020), the investment costs of a complete infrastructure development - not including storage, distribution pipelines and CO2 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 CCUS plants are very expensive – especially on capital and operating costs - and unfortunately, they do not seem to provide a clear net margin in the short-period due to the high production costs, as mentioned before in this paper. According to the European Commission's July Hydrogen Strategy (2020), the European Hydrogen Alliance has been born to sustain financing solution: governments should support local/national private entities to enhance investments in both Blue and Green Hydrogen. It is also worth to mention the importance of cost reduction potential in the long term for those policies. Chapman et al. (2019:6371) have showed that hydrogen can be efficiently used for transport sector reducing 30% of CO2 emissions. By observing the latest CCS plants, it is easy to notice an evident cost reduction with respect to their predecessors: new plants can benefit from technology spillovers - increased learning-by-doing - and scale economies. Adding more projects will trigger commercial and industrial synergies through exploiting supply chains and reducing the unit cost of CO2 storage.

Hydrogen can be transported through re-converted natural gas pipelines: because it is less dense than natural gas, energy capacity transport needs to be converted to adjust the right volumes of hydrogen.

3. *CCS FACILITIES*

According to the "Global Status of CCS" Report (2020), CCS facilities can be summarized into:

- Large scale CCS facilities, which are able to capture large capacities of CO2 from industrial sources and power generation, also including transport and storage hubs projects - around 400-800 ktpa -. Those facilities must be covered by commercial return in both capture and storage phases.
- Small scale CCS facilities, which are able to capture CO2 from power or industrial sources under the abovementioned thresholds. These facilities are more for testing strategies and they do not expect a commercial return on those projects.

Current CCS facilities are able to capture 40Mt of CO2 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 the hydrogen needed would be about 8,800 GWh. To power it, would not be enough all the electricity (8,400 GWh) generated by the large offshore park of 2.8 GW, planned in the Channel of Sicily. By 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, since 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.

4. EMPIRICAL ANALYSIS

4.1. RATIONALE

This paper will focus on what discussed before to better address those policies under an econometric point of view. Two key hypotheses will be considered in particular:

- H1: Public debt play a major role in Hydrogen and CCS projects.

The core of this hypothesis is to stress out the main CCUS – Hydrogen policies determinants and their relationship between Green policy intensity and variables that might impact policymakers' decisions. By looking at IEA's (2020) 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 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 transport sector from automotive industry companies. Most of the projects are financed by Public funds or Public-Private-Partnerships. The range of funding amount (national currency 2018) might be very wide, like the 250 million euro "National Innovation Programme Hydrogen and Fuel Cell Technology" project financed by German Ministry of Transport and digital infrastructure. According to EEA Report (2019) on Sustainability transition in Europe, there are some remarkable fiscal sustainability's risks for Belgium, Spain, Italy, Luxembourg and Hungary in the medium and long term; matching with our hypothesis, evidence of Hydrogen and CCUS projects in those countries are very few. In US, some CCS projects will benefit from the California low-carbon fuel standard (LCFS) and 2018's tax credit law (Global CCS Institute, 2020).

For the reasons explained above, we expect to see a relationship between H2-CCS policies and Government's Public Debt which is necessary to sustain those initiatives. Following Nicolli and Vona (2016:194) approach on heterogeneous policies and technologies, we have considered Blue and Green policies based on IEA's (2020) Hydrogen Policies Database and IOGP's (2020) Global CCUS projects. We have constructed a dummy variable equal to one which corresponds to countries currently performing Hydrogen policies, and an analogous dummy for CCUS policies. We have considered both current active and announced initiatives, yet not started. This is because most of the observed policies started in 2020, but most of their costs were already included in 2019's budgets. This is the main reason why we have decided to consider a cross-sectional dataset taking into consideration 2019 as base year. Another reason is because we wanted to avoid some biases on macroeconomic indices due to the covid-19 pandemic for the year 2020. Then, we will take into consideration Foreign Direct Investments and other variables indirectly related to Green policy measures.

- H2: Blue Hydrogen and CCUS policies are carried out by more fossil-fuel dependent countries.

This hypothesis came out from the core idea that Hydrogen and CCUS have strict correlation, driven by decarbonization strategies. There currently are seven projects regarding generation of Hydrogen from fossil fuels with CCUS, which lead to an annual production of 0.4 MtH2 and CO2 capture close to 6MtCO2. This dualism also facilitates the reduction of the costs related to the creation of a Co2 capture plant - which often becomes unsustainable on its own - or a completely Green system based on water electrolysis. By reducing the price of electricity, it is possible to reduce the cost of hydrogen production; another possibility is to split the design of steam methane reformer from the CO2 capture and compression plant, to optimize the cost-saving of overall process. New CO2 plants are indeed focused on minimizing the steam extraction inefficiencies and recovering waste heat from the plant steam cycle. Moreover, it is important to underline that hydrogen produced from gas or coal is obtained with less electricity sources if compared to the green one. As Zapantis (2021) reports, a production of 1.76Mt of hydrogen from steam methane reformation with CCS implies four CO2 injections over 2km2 plant. In particular, Europe can benefit from blue hydrogen-CCS production due to large industrial clusters, pipelines and geological storage potential.

According to the IEA (2021: 71), in the long-run 40% of global hydrogen produced will be Blue and 18% of this production will be captured by attached CCUS plants. It is expected to think that countries with high fossil fuel consumption and oil reserves have decided to invest in these policies to mitigate their emissions levels.

To capture this hypothesis, we have constructed a categorical variable that assumes value 0 for CCUS policy types, value 1 for countries currently having both CCUS and Hydrogen policies in place, value 2 for Hydrogen policies and value 4 for none of the above.

4.2.DATA ANALYSIS

Most of the data are retrieved from GlobalEconomy dataset, while Fossil Fuel Consumption data of 2019 are retrieved from Our World in Data. We have taken into consideration 71 countries for 2019 period, considering information available. Cross-sectional analysis has been chosen to avoid spatial autocorrelation in per capita income in relation to other explanatory variables (Antunes et al., 2020: 227).

Table 1 in the Appendix report a first look at the dataset considering the two dummy variables created for paper's analysis.

It shows that of 71 countries, 32 have invested in CCS or hydrogen policies. Of these, as many as half show a dualism of CCS-H2 policy. In the table, the "H2 only" policies uncover green hydrogen policies currently in progress or already in place. This figure highlights some important remarks – that countries investing in CCUS and hydrogen policies for decarbonization targets are very solid innovative countries – like Denmark, Netherlands, Germany -, with a very positive economic and financial situation for those countries. There are few exceptions such as Spain, Thailand, Argentina, 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 European Union is providing solid financial sustain to fulfill New Green Deal strategies towards 2030.

Table 2 shows brief description of variables used for the model estimation, while Table 3 reports Descriptive Statistics.

Table 2. Variables summary

Variable Storage	Display	Value
name type	format	label Variable label
H2_policy byte	%10.0g	0-no H2 policy; 1-H2 policy
CCS byte	%10.0g	0-no CCS policy; 1-CCS policy
Policy_type long	%9.0g	CCS only - CCUS+H2 - Green H2 - none
FossFuelCons double	%10.0g	Fossil Fuel cons, in k (2019)
Tril_Index double	%10.0g	Tilemma Index (2019)
Oil_reserves double	%10.0g	Oil reserves, billion barrels (2019)
DebtGDPratio double	%10.0g	debt/GDP (2019)
FDI double	%10.0g	Foreign Direct Investment, % of GDP

InnovationIndex double	%10.0g	Innovation Index (2019)
MonetaryFreedom	%10.0g	Monetary Freedom Index (2019)
Governmenteff	%10.0g	Government effectiveness (2019)

Source: author's computation

Table 3. Descriptive Statistics

Variable	Obs	Mean	Std. dev.	Min	Max
H2_policy	71	.3521127	.4810284	0	1
CCS	71	.3239437	.4713097	0	1
Policy_type	71	3.126761	1.081396	1	4
FossFuelCons	71	1457.958	4744.996	9.701	33512.49
Tril_Index	71	71.91408	7.901199	47.8	84.3
Oil_reserves	71	19.50056	55.63106	0	302.81
DebtGDPratio	71	61.32014	43.61375	8.4	238
FDI	71	3.627606	13.12158	-16.06	103.93
Innovation Index	71	42.67183	11.01136	23.3	67.2
MonetaryFreedom	71	76.98873	11.4682	0	88
Governmenteff	71	.07	1.001144	-2.02	1.94

Source: author's computation

The first two variables are the binary dependent variable that will be analyzed to better address determinants on hydrogen and CCS policies. "Policy type" is the categorial variable addressing whether observed countries are investing on CCS, Hydrogen, or both (in a cooperation between Blue hydrogen and CO2 storage). On overall, the maximum and minimum values suggest that there are consistent differences within countries. Fossil Fuel consumption is the first independent variable and it is estimated in KWh. The second variable represents Oil reserves per country, including those reserves which can be potentially recovered. Debt/GDP ratio is the main indicator for evaluating country's attitude towards hydrogen or CCS investment policies. Trilemma Index indicates the total rating of national energy system performance considering all three variables – energy security, energy equity and environmental sustainability -. It represents the ability of a country to mitigate potential risks correlated to climate and environmental changes, including decarbonization strategies. Energy equity represents power access and basic-energy resources affordability, while energy security focus on reliability on infrastructure and domestic/external energy resource balance. In the latest year, access to electricity and clean cooking have increased by 87% and 75% respectively, while the energy mix is shifting towards renewable energy sources, which has increased by 7% in 2020 with 200GW more of capacity production plants (Greenreport, 2018).

In 2019 Switzerland was the most performing country with an index of 84.3, followed by Sweden – 84.2 – and Denmark – 84 -. The last one is a proxy for both eco-innovation and knowledge.

Foreign Direct Investments is intended as the net inflow from foreign investors. Monetary Freedom Index, as proxy for governments' stability considering weighted average inflation rate of the last three years and price controls. It varies from 0 to 100. The third one is government effectiveness as proxy for people's perception on country's quality on public services and independence from political pressure, including good standards for policies formulation and implementation. It ranges from -2.5 to 2.5.

All variables are in per capita value to avoid biased information due to different magnitude of countries' indices. Correlation matrix showed high correlation between Trilemma Index and

Innovation Index. For the purpose of this paper, Trilemma Index will be considered as proxy for sustainable activities and environmental innovation impact.

4.3. MODEL FRAMEWORK

Considering the dichotomic and categorical variable of dependent variables, both logit and probit – in their multinomial form for categorical variable - could have been a valid choice for this framework.

As explained by Hahn&Soyer (2005), probit and logit models fit the data likewise well in small datasets, with the difference that probit model assumes normal regression for distribution of residuals. Even though logit model is often preferred by researchers due to its easier interpretation of coefficients, we have decided to proceed with probit and multinomial probit, considering that the difference in two cumulative distributions is not so significative, but with the pros that probit model allows to relax the IIA intake in part, dividing the various alternatives into various similar subgroups, but independently from the others. Multinomial probit model completely relaxes IIA assumption allowing residuals – in matrix form – to be correlated. For these reasons we believe that probit estimation provides better and more consistent results.

Assuming Y as dependent binary variable, the probit model will be represented as:

$$P(Y_i = 0|x_1, x_2, \dots x_7) = \Pr(Y_i^* \leq 0) = \phi\left(x_i^T \beta\right)$$
$$= 1 - \phi(\beta_0 + \beta_1 X_{fossil\ fuel\ consumption} + \beta_2 X_{oil\ reserves} + \beta_3 X_{Trilemma\ index} + \beta_4 X_{DebtGDPRatio} + \beta_5 X_{Foreign\ Direct\ Investments} + \beta_6 X_{Monetary\ Freedom} + \beta_7 X_{Government\ effectiveness})$$

$$P(Y_i = 1|x_1, x_2, \dots x_7) = \Pr(Y_i^* > 0) = \phi(x_i^T \beta)$$
$$= \phi(\beta_0 + \beta_1 X_{fossil\ fuel\ consumption} + \beta_2 X_{oil\ reserves} + \beta_3 X_{Trilemma\ index} + \beta_4 X_{DebtGDPRatio} + \beta_5 X_{Foreign\ Direct\ Investments} + \beta_6 X_{Monetary\ Freedom} + \beta_7 X_{Government\ effectiveness})$$

$$Model\ 1: Y_{1_i} = \begin{cases} 0\ with\ no\ Hydrogen\ Policy \\ 1\ with\ Hydrogen\ Policy \end{cases}$$

$$Model\ 2: Y_{2_i} = \begin{cases} 0\ with\ no\ CCS\ Policy \\ 1\ with\ CCS\ Policy \end{cases}$$

Where ϕ is the cumulative distribution function of standard normal distribution.

The first model will consider Y as dichotomous variable assuming value zero/one for absence/presence of hydrogen policies in that country. The second one will replicate the model, considering absence/presence of CCS policy as new dependent variable. The estimated curve will be an S-shaped cumulative normal distribution.

A third model will be finally computed to estimate Probit model on categorical variables, assuming value 0 for CCS policy, 1 for integrated CCS-H2 policy, 3 for Green H2 policy and 4 for absence of those policies for each observed country.=

$$Model\ 3: Y_{3_i} = \begin{cases} 1\ with\ CCS\ policy \\ 2\ with\ CCS + Blue\ H2\ policy \\ 3\ with\ Green\ H2\ policy \\ 4\ with\ no\ CCS/H2\ policy \end{cases}$$

Fit and diagnostic tests have been carried out before running the model. Heeteroskedasticity is a very common and discussed problem in models like probit, simply because a dependent variable is a probability which will express uncertainties deriving from omitted variable bias issue. In this case we have corrected this issue with robust estimation in Stata.

4.4. RESULTS AND INTERPRETATION

Table 4 and 5 show results estimated from binary probit models through maximum likelihood method.

Table 4. Binary Probit model 1 results

Esimated probit model on hydrogen policy						
Variable	**Coefficient**	**std. err.**	**z**	**P>z**	**[95% conf.**	**interval]**
FossFuelCons	.0014202	.0004119	3.45	0.001	.0006128	.0022275
Tril_Index	.210363	.0633927	3.32	0.001	.0861156	.3346104
Oil_reserves	-.0073881	.0045246	-1.63	0.102	-.016256	.0014799
DebtGDPratio	.0191029	.0061923	3.08	0.002	.0069663	.0312396
FDI	-.0702348	.0282648	-2.48	0.013	-.1256328	-.0148368
MonetaryFreedomIndex	.0045349	.0215461	0.21	0.833	-.0376947	.0467644
Governmenteffectiveness	.2961982	.2308718	1.28	0.200	-.1563023	.7486987
_cons	-18.22392	4.918261	-3.71	0.000	-27.86354	-8.584306
Log likelihood	-21.488297					
Wald chi2(7)	21.26					
Cragg&Uhler R-sq	0.687					
Prob>chi2	0.0034					

Source: author's computation

Table 5. Binary probit model 2 - Results

Estimated probit model on CCS policy						
Variable	**Coefficient**	**std. err.**	**z**	**P>z**	**[95% conf.**	**interval]**
FossFuelCons	.0012508	.0003285	3.81	0.000	.000607	.0018947
Tril_Index	.1032483	.0331886	3.11	0.002	.0381999	.1682968
Oil_reserves	.0102415	.0053245	1.92	0.054	-.0001944	.0206773
DebtGDPratio	.0055436	.0035196	1.58	0.115	-.0013546	.0124418
FDI	-.0486122	.0298179	-1.63	0.103	-.1070542	.0098298
MonetaryFreedomIndex	.0522676	.020892	2.50	0.012	.0113199	.0932152
Governmenteffectiveness	-.1631639	.2069373	-0.79	0.430	-.5687537	.2424258
_cons	-13.37904	3.024641	-4.42	0.000	-19.30722	-7.450849
Log likelihood	-26.780267					
Wald chi2(7)	29.97					
Cragg&Uhler R-sq	0.554					
Prob>chi2	0.0001					

Source: author's computation

The Wald Likelihood tests show that at least one of the predictors' regression coefficient is different from zero. Moreover, the p-value confirm the goodness of fit of the model rejecting the hypothesis that at least one of the coefficients in the models are equal to zero. Cragg & Uhler's R-squared for the models are 0.687 and 0.554 respectively, highlighting that the models predict quite well the outcome of H2/CCS policy likelihood. Differently from OLS and similar models, results report z-statistics as ratio of coefficients with respect to standard errors. P-values reflect the probability of z test statistics under null hypothesis that its coefficient is zero.

Coefficients interpretation for probit distribution is not straightforward. It is important to remind that for these kinds of models, change in coefficients depends both on their starting values and other variables. In general terms, an increase of X leads to B change in z-score of Y. The constant terms are both statistically significant and not so different in their z-statistics. As expected, if all coefficients are zero, the predicted probability of Hydrogen or CCS policy seems to be extremely low. It underlines the fact variable chosen for the estimation might well explain – at least partially - determinants affecting those policies. The results also show that Debt/GDP ratio turned out to be statistically significant at 10% level for the first model, given all other predictors in the model. This result has to be interpreted along with the negative statistically significant result at 5% level for Foreign Direct investments: an increase in debt/GDP ratio seems to lead to an increase of predicted probability of hydrogen policy, while an increase of foreign direct investments seems to lead to a decrease of the predicted probability. An interpretation of these coefficients might be that countries with a good debt/GDP ratio in first place have been able to invest in hydrogen infrastructure and plants, while those with excessive and heavy Public Debt have been left out from the equation. It matches with data mentioned before: most of the countries investing in hydrogen are indeed "wealth" countries that have not suffered much from European austerity, or international rich countries. This confirms our initial hypothesis that investing in hydrogen requires huge public investments. Also, this is confirmed by the result that foreign direct investments seem to mitigate investment in that sector, meaning that most of the financing must come from local/national level and can not be searched from outsider few international investors.

Both models seem to confirm our second hypothesis. Fossil fuel consumption and trilemma index turned out to be statistically significant at 1% level in both cases, given other predictors in the model: this means that the likelihood of those independent variables seems to increase as the explanatory variables increase. As fossil fuel consumption and trilemma index increase, tendency to have in place CCS or Hydrogen policies increases as well to fulfill carbon-reduction policy goals.

The monetary freedom index is statistically significant at 5% level for the second model, which means that an increase of price stability seems to be positively connected with the likelihood of a CCS investment policy.

To better address coefficient interpretations, the relationship between specific variables and probability outcome will be addressed through marginal effects. Results are shown in table 6 and 7.

Table 6. Marginal effects after probit (Model 1)

dy/dx	**std. err.**	**z**	**P>z**	**[95% conf.**	**interval]**	
FossFuelCons	.0002381	.0000561	4.24	0.000	.0001282	.0003481
Tril_Index	.0352753	.0069206	5.10	0.000	.0217113	.0488394
Oil_reserves	-.0012389	.0007298	-1.70	0.090	-.0026693	.0001915
DebtGDPratio	.0032033	.0008699	3.68	0.000	.0014983	.0049083
FDI	-.0117775	.0044253	-2.66	0.008	-.0204509	-.0031041
MonetaryFreedomIndex	.0007604	.0036112	0.21	0.833	-.0063173	.0078382
Governmenteffectiveness	.0496688	.0367136	1.35	0.176	-.0222886	.1216262

Source: author's computation

Table 7. Marginal effects after probit (Model 2)

dy/dx	**std. err.**	**z**	**P>z**	**[95% conf.**	**interval]**	
FossFuelCons	.0002614	.0000528	4.95	0.000	.0001578	.000365

Tril_Index	.0215779	.0064657	3.34	0.001	.0089055	.0342504
Oil_reserves	.0021404	.0010695	2.00	0.045	.0000442	.0042365
DebtGDPratio	.0011586	.000708	1.64	0.102	-.0002291	.0025462
FDI	-.0101595	.006076	-1.67	0.095	-.0220682	.0017492
MonetaryFreedomIndex	.0109234	.0040645	2.69	0.007	.0029572	.0188897
Governmenteffectiveness	-.0340997	.0426602	-0.80	0.424	-.1177121	.0495127

Source: author's computation

It seems that on overall, the interpretation given before was pretty accurate by looking at marginal effects. An increase in fossil fuel consumption slightly raises the probability outcome of H2 or CCS policy. On the contrary, it seems that increasing oil reserves slightly decrease the probability outcome of hydrogen policy. This will be better addressed in the next model. Here we do not want to stress out on magnitude of marginal effects or expected probability: we are more interested in analyzing determinants affecting green policies and how variables interact with each other. Therefore, signs of coefficients might give a more accurate interpretation of overall effect rather than expected probability linked to small changes.

The last model aims to further analyze the relationship between Blue and Green hydrogen through categorical variable. Table 8 reports results of multinomial probit model, taking into consideration Blue hydrogen combined with CCS projects as base category.

Table 8. Multinomial probit model 3 – Results

Policy_type	**Coefficient std. err.**	**z**	**P>z**	**[95% conf.**	**interval]**
CCS					
FossFuelCons	-.0020642 .0008646	-2.39	0.017	-.0037588	-.0003696
Oil_reserves	.0070005 .0055228	1.27	0.205	-.0038239	.0178249
Tril_Index	-.47288 .1382811	-3.42	0.001	-.743906	-.201854
DebtGDPratio	-.0248556 .0111908	-2.22	0.026	-.0467893	-.002922
FDI	-.0026835 .0597126	-0.04	0.964	-.1197181	.1143511
MonetaryFreedomIndex	.0151796 .0287181	0.53	0.597	-.0411069	.071466
Governmenteffectiveness	-.818717 .4942396	-1.66	0.098	-1.787409	.1499749
_cons	37.02672 11.19304	3.31	0.001	15.08877	58.96467
CCS_H2	**(base outcome)**				
Green_H2					
FossFuelCons	-.0010754 .0006071	-1.77	0.077	-.0022653	.0001146
Oil_reserves	-.5772029 .2651788	-2.18	0.030	-1.096944	-.057462
Tril_Index	-.277432 .1063659	-2.61	0.009	-.4859052	-.0689587
DebtGDPratio	-.0078606 .0074699	-1.05	0.293	-.0225014	.0067802
FDI	-.0211665 .0644133	-0.33	0.742	-.1474143	.1050813
MonetaryFreedomIndex	-.1012519 .058649	-1.73	0.084	-.2162017	.0136979
Governmenteffectiveness	.16988 .415198	0.41	0.682	-.6438931	.9836531
_cons	31.09923 8.411704	3.70	0.000	14.61259	47.58586
None					
FossFuelCons	-.0033817 .0008494	-3.98	0.000	-.0050464	-.0017169
Oil_reserves	-.0020461 .007836	-0.26	0.794	-.0174044	.0133122
Tril_Index	-.5088215 .1431639	-3.55	0.000	-.7894176	-.2282253
DebtGDPratio	-.0323601 .0122361	-2.64	0.008	-.0563425	-.0083778
FDI	.0942413 .0587688	1.60	0.109	-.0209434	.2094259
MonetaryFreedomIndex	-.0497465 .0354158	-1.40	0.160	-.1191602	.0196672
Governmenteffectiveness	-.2321935 .4533384	-0.51	0.609	-1.12072	.6563334
_cons	47.20772 11.82132	3.99	0.000	24.03836	70.37708

Source: author's computation

Table 9 will better address this topic by examining marginal effects of the model, taking into consideration explanatory "CCS-Blue H2" as base category variable.

Table 9. Marginal effects after multinomial probability model

variable	dy/dx	Std. err.	z	P>z	[95%	C.I.]	X
FossFuel	.0008132	.00027	3.04	0.002	.000288	.001338	1457.96
Oil_reserves	-.0004322	.00179	-0.24	0.809	-.003933	.003069	19.5006
Tril_Ind	.1405383	.04016	3.50	0.000	.061823	.219254	71.9141
DebtGDP	.0083533	.0033	2.54	0.011	.001895	.014812	61.3201
FDI	-.015917	.01508	-1.06	0.291	-.045464	.01363	3.62761
Monetary	.0068601	.00866	0.79	0.428	-.010114	.023834	76.9887
Government	.1316791	.12391	1.06	0.288	-.111172	.37453	.07

Source: author's computation

The last category of the model clearly shows the determinants affecting whether or not investing in blue hydrogen policies for a general country. Higher energy efficiency and possibility to raise debt to finance projects will more likely lead to have a blue hydrogen policy, just like countries with higher fossil fuel consumption. This is also confirmed by marginal effects: if fossil fuel consumption increases by one unit - intended as one thousand KWh -, the blue hydrogen-CCS option probability slightly increases. The trilemma index which is statistically negatively significant at 5% level for both CCS and Green H2 policies over a Blue-CCS one, can be interpreted as the likelihood of preferring a Blue Hydrogen policy over a CCS and – more importantly – a green one. By looking at results for "CCS" and "None" category, fossil fuel consumption seems to directly affect blue and green hydrogen policies rather than CCS only ones. Debt/GDP ratio is statistically negatively significant in the first "CCS" and it has a positive sign in the marginal effect results, which outlines a mild preference on combined Blue hydrogen policy over CCS ones. Its coefficient in "None" category outlines that Debt/GDP ratio seems to trigger investment decisions and again confirm our first hypothesis of the importance of public debt for this kind of policies. Foreign direct investment coefficient is not statistically significant in this model, just like monetary freedom and government effectiveness. On the contrary, while oil reserves were not statistically significant in Model 1 and 2, here an increase of one billion barrels oil reserves would slightly decrease the likelihood for blue H2-CCS policy, but also for a green one, as denoted by results of third category. This means that oil reserves negatively affect both hydrogen policies and it has to be interpreted differently from fossil fuel consumption.

5. CONCLUSIONS

In this paper we have analyzed the relationship between green, blue hydrogen and CCS, through some key variables helping to explain differences between hypothetical blue or green hydrogen strategies. After a brief introduction of the topic, also including an estimation of the actual prices for Green and Blue hydrogen, the analysis focused on fossil fuel dependent countries and public investments trends. Through a probit estimation on 71 countries, considering data of 2019, it has been estimated the likelihood of having a Green hydrogen policy rather than a Blue/CCS one. The major takeovers of the analysis are:

- Fossil fuel dependent countries are willing to invest in hydrogen and CCS policies to mitigate their emission levels and to have a more sustainable energy mix.

Fossil fuel consumption is related to emissions and the zero-carbon emission target worldwide, while oil reserves are strictly correlated to big, oil countries producers and owners, and less correlated to emissions like fossil fuel consumption does. This underlines the fact that there is an huge portion of countries with big oil reserves which are not currently investing in hydrogen policies, as explained by coefficients of the last category. Oil and gas activities still play a major role in worldwide economy and we are very far from assessing a global sustainable strategy. Countries still depend on oil and gas to create and supply power demand at both national and international levels.

- Public debt plays a major role in hydrogen policy investment decisions, also led by the scarcity of foreign direct investments in this sector. Energy efficient countries with efficient Public Debt/GDP ratio are currently investing in (Blue) hydrogen.

Considering that we are considering current nowadays projects, both active and in progress, this shows that now, energy efficient countries are more likely willing to invest in blue hydrogen rather than green one. Results are aligned with EU hydrogen strategy 2020 and New Green Deal.

Cumulative investments in Green Hydrogen in Europe could reach up to €180-470 billion by 2050 and around €3-18 billion for Blue Hydrogen. Analysts estimate that green hydrogen could meet 24% of world energy demand by 2040, with annual sales of the order of 630 billion €. Almost all Member States have included green or blue hydrogen plans in their national energy and climate plans and have joined the "Hydrogen Initiative"14 Member States have also included hydrogen in the context of their national policy frameworks for alternative fuel infrastructure.

Sustainability must also be economic sustainability and investments must also be sustainable in the long term. Today, hydrogen can only be "blue", both for economic and financial reasons and for reasons of available reserves and prospects of technological improvement of CCS. EU is particularly focusing on Blue because it is cheaper. Also, carbon capture plays a crucial role for sustainable goals: although it is not completely carbon neutral, still is useful to reach decarbonization goals.

Further researches should focus on exploiting the relationship between Glue Hydrogen and CCS, also in the light of recent investments and continuous new initiatives undertaken in the last period. Also, it would be interesting to conduct a concrete cost analysis on major projects to evaluate the actual cost-efficient reduction and evaluate a more precise pricing for Green and Blue hydrogen.

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Appendix

Table 1. Countries overview, binary dependent variable.

COUNTRY	H2 POLICY	CCUS
Algeria	0	0
Argentina	1	0
Australia	1	1
Austria	1	0
Azerbaijan	0	0
Bangladesh	0	0
Belgium	1	1
Brazil	1	1
Bulgaria	0	0
Canada	1	1
Chile	0	0
China	1	1
Colombia	0	0
Croatia	0	1
Cyprus	0	0
Denmark	1	1
Ecuador	0	0
Egypt	0	0
Estonia	0	0
Finland	0	0
France	1	1
Germany	1	1
Greece	1	0
Hungary	0	0
Iceland	0	1
India	1	1
Indonesia	0	1
Iraq	0	0
Ireland	1	0
Israel	0	0
Italy	1	1
Japan	1	1
Kazakhstan	0	0
Kuwait	0	0
Latvia	0	0
Lithuania	0	0
Luxembourg	0	0
Malaysia	0	0
Mexico	0	0
Morocco	0	0

Netherlands	1	1
New Zealand	1	1
North Macedonia	0	0
Norway	1	1
Oman	0	0
Pakistan	0	0
Peru	0	0
Philippines	0	0
Poland	0	0
Portugal	0	0
Qatar	0	1
Romania	0	0
Russia	0	0
Saudi Arabia	0	1
Singapore	0	0
Slovakia	0	0
Slovenia	1	0
South Africa	0	1
Spain	1	0
Sri Lanka	0	0
Sweden	1	0
Switzerland	0	0
Thailand	1	0
Trinidad and Tobago	0	0
Turkey	1	0
Ukraine	0	0
United Arab Emirates	0	1
United Kingdom	1	1
USA	1	1
Venezuela	0	0
Vietnam	0	0

Source: author's computation