EVALUATION AND SIMULATION OF THE EUROPEAN HYDROGEN MARKET BASED ON DIVERSE SIMILARITY ANALYSIS

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Abstract

Present status: Innovative technologies in the sector of mobility follow a different pattern of market penetration than traditional markets. Looking at hydrogen technology in Europe, its development can mostly be described through statistical data about the different aspects of the market (namely production volumes, infrastructures, prices, etc.) – including a wide range of countries.

Goals/Tasks: The data-driven, objectivity-focused, analyses consist of three common pillars: simulations (production functions), (anti-discriminatory) assessments, and projections. This paper includes two: a production function about the number of hydrogen-powered automobiles per capita and an anti-discriminatory analysis to generate the phrase "spreading innovation." In a subsequent phase of the study, a forecast will be made.

Method and expectations: Similarity analysis is a method in which a single source code parameter determines the characteristic of the models: if the stairs in the staircase function may be equivalent, then we can only speak about production functions. If the stairs may not be equal, we have the opportunity to establish terms. A production function must always have a genuine dependent variable (number of hydrogen-powered automobiles per population and year for a certain country). The anti-discriminatory models do not need a true dependent variable; instead, they use fabricated Y-values (constants). Production functions may be defined using essentially arbitrary methods (like regressions, neural networks, decision trees, etc.). Only anti-discriminatory similarity studies allow for the formation of terms (c.f. Component-based Object Comparison for Objectivity - https://miau.my-x.hu/myx-free/index_en.php3). The production function for the number of hydrogen-driven cars used objects (32 countries of Europe). All these countries are either direct manufacturers of motor vehicles or are active in the supplier industry. This is a stark contrast to the American or Asian market, which mostly produce or distribute in homogeneous market situations. The following variables (attributes) were selected according to the direction (0 indicating a support, 1 indicating an inhibiting factor), namely the gross public expenditure on R&D, the number of passenger cars produced per capita, the general number of vehicles, the number of hydrogen filling stations, domestic hydrogen production capacities, electricity prices for household consumers, trucks by alternative engine propulsion (electric, hydrogen, bioethanol, biodiesel), petrol prices and the share of zero-emission vehicles in newly registered passenger cars, representing the x-variables. The y-variable, dedicated as the result variable was defined as the number of hydrogen vehicles. The anti-discriminatory model used all the attributes of the above-mentioned production function as independent variables without any subjective weights.

First results: Our findings concerning production functions show that present statistics cannot evaluate all countries. However, most countries are norm-like, meaning they deliberately grow their hydrogen fleet share to meet EU 2030 sustainability targets. It's merely a self-conception to always improve. Some countries demonstrated more over- and underperformance. Before assessing performance, rounding errors were corrected and an inversed test was done to eliminate false positives. Austria, Finland, and notably Germany and Sweden have better framework circumstances (i.e., an R&D-rich policy, a zero-emission demanding market, and fuel infrastructure) than their neighbours yet do not produce enough hydrogen vehicles. While Bulgaria and Poland are still developing, their estimated Y-values are greater,

indicating strong consumer interest in hydrogen technology in the transportation industry. The research also suggests that present criteria indicating hydrogen vehicle market preparedness only allow for a limited number of cars and that various socio-economic levers must be pulled to create a sustainable innovation optimum.

The general validated results in the field of term-creation are reflecting the expert opinions: Some countries like Germany are expected to offer higher potential for the spread of innovative technology than their direct neighbours to the East. The common political and socio-economic anticipation, that highly developed and urbanised countries are doing the best regarding their innovation capabilities is investigated in quantitative dimensions. In a final stage, an aggregated index was expected that, as a novum, does not just look at the average of each country's criteria and disregard the dispersion of places, but strongly values each performance and ranks and analyses the countries. The "innovation diffusion index 2021" for hydrogen technology might identify Finland, Sweden, and the Netherlands as the top three countries with the greatest potential for mid-term commercial success. Iceland excels in multiple factors, including customer-friendly electricity prices, an inviting R&D market, high numbers of hydrogen cars, and high oil prices to motivate customers to switch, but with a very small car market, no domestic hydrogen production, and many traditional-focused customers, it cannot reach the top. However, the strong transdisciplinary positivity toward innovation is slowing development. These observations help researchers determine where institutions can improve most with the least investment.

Argumentations: Why is an anti-discriminatory similarity analysis an appropriate method for creating concepts such as innovation diffusion? The creation of a term is legitimate if related items do not provide the same output result. A term is a scale on which we discuss better spreading, norm like (aka to be expected) spreading, and rather sluggish spreading. Parallel to this, we must be able to derive the system-answer "I-do-not-know," where the direct and inverse models are reflections of each other for all objects.

Limits of the model and Future: The general framework of the COCO-Model in its various adaptations is to allow fact-based, automated vulnerability detection and consecutive advice, where policy mechanisms should take place. However, the model can only decide upon the data it is inserted and thereby can only analyse and reproduce the focus previously applied by the researcher and thereby is subject to an ineliminable bias. To counter this the phenomenon “spreading innovation” will be interpreted not only in space but also in time (see automated SWOT analysis). How does it develop when looking at the past years? Are significant efforts made by institutions and governments alike to identify a time-series based development?

Demo: All original data and corresponding assumptions were based on the dataset available from https://miau.my-x.hu/miau/294/hydrogen_market_analyses_2023_abs.xlsx

Introduction

This article addresses the required policymaking steps for establishing hydrogen-powered individual mobility in Central Europe. By analysing important aspects the R&D budget, the dependence on automobile transport or the proposed costs of a hydrogen infrastructure, influencing this alternative drivetrain's policies, success factors and deficiencies are quantified in order to create the fundamental elements of an integrated policy mix for transcending national borders in an objective way. On the basis of the findings, at first nine variables that can be documented and evaluated using a component-based object comparison for objectivity model were chosen to rank and evaluate current European countries, focusing on EU countries and those with close market ties, and their potential for establishing larger fleets of emission-low vehicles. In order to achieve a more sustainable reconciliation of different spheres of interest on the basis of common (objective) risk interpretations, it is necessary to increase objectivity within European operational mechanisms that are antagonistic at the level of national interests and systemic interests.

Customers faces an enormous number of challenges and barriers like oil-based pollution, single-use products and inefficient governmental regulations in the modern world, rendering sustainable progress and even sustainable life impossible. Numerous human acts of construction, energy production and especially automotive transport lead to environmental degradation via carbon and other fine dust partical emissions. The movement of people and things has a negative impact on both human health and their living surroundings. In times of such significant internal and external change, a well-defined and adaptable strategy is vital. Authorities and consumers seek alternate fuels to expedite the greening of the automobile transportation sector.

Currently, everyone in the business sector works with a broad range of estimations and forecasts. Examples range from simple regressions and averages to more complex neural networks. The formula Y=f(X1,..., Xi,..., Xn) is used by all of these approaches to predict the future values of our attributes.

This approach is applicable to any dataset and may be used repeatedly to create predictions and forecasts under a broad range of input conditions. This may also lead us to mistakenly perceive the relationships between our data and maybe even conclude that there is a causal link between them. All the aforementioned statistical calculations will provide quantitative results as an extra benefit (approximations). It is up to us to determine whether anything is reasonable or realistic (c.f. consistent). Since these calculations always provide a result (a number), we are prone to being deceived about the future of our date (e.g., sales projections, exchange rate projections, etc.).

After a number of trials including data quality evaluation or penalties several assessments regarding current hydrogen performance of nation states could be evaluated.

Goals

The research aims to examine a new quantitative performance assessment of previous policies in order to expose the inefficiencies of countries with a high degree of market penetration in the public eye, but which nonetheless lag behind in relative terms, while revealing the success of hidden champions.

Tasks

The study must address the following issues:

- Is it possible to find factors that relevantly increase or decrease the potential of hydrogen mobility, without falsifying the outcome and dilute it with irrelevant factors (c.f. deriving production functions)?
- Do countries with heavy automotive industry focus react differently to innovative technologies? (c.f. anti-discriminative modelling – each object (country and time) can have the same potential in a different way)
- Eliminate statistically erroneous positives and false negatives (c.f. increasing consistence of partial results)
- Determine how much the present system can reasonably support (c.f. simulations)
- Create an anti-discriminatory model to prevent data dispersion (c.f. data asset/quality management)
- Final: Create a robot-automated decision-making principle/approach for an equitable generalised management concept in order to transform hazardous strategic decision-making into an operational knowledge data base and show a realistic image of a customer-purchasing-based system (c.f. all above-mentioned components integrated into a holistic system) .

Variables and their socio-economic relevance

The number of hydrogen-powered cars was chosen as the unit of measurement and, hence, the first dependent variable (Y) needing a production function for further simulations and evaluations/interpretations. This number was calculated as a relative value on purpose, since only five types of hydrogen-powered cars are now available for commercial and private use in Europe, and absolute numbers would misrepresent the total sales and country of origin of the vehicles (from point of view of similarities). Due to the present limited number of sales, it is anticipated that these vehicles will only be purchased by so-called early adopters. This refers to buyers who purchase autos based on their belief in the technology, despite the market's immature state (refuelling infrastructure, purchase price, tax incentives, etc.). Due to the minuscule proportion, the present distribution of the elements provides insight into the average customer, since he or she views the aforementioned minimal market advances as necessary and does not otherwise consider them when making a choice.

The following variables were chosen as independent variables (Xi), with a plus sign indicating a positive impact and a minus sign indicating a limiting influence on the number of hydrogen cars:

Variable	Measuring unit	Expectation regarding effect	Explanation
Gross public expenditure on R&D	per capita	+	This statistic indicates how much a country spends in R&D via grants, research proposals, and bonuses. It encourages innovative technologies, such as hydrogen technology. Based on (Balsalobre-Lorente et al., 2021; Chen et al., 2022; Wei et al., 2023).

Number of passenger cars	per 1000 inhabitants	+	This ratio indicates the number of automobiles per 1,000 people. It represents the strength of the local auto sector as an employer and its contribution to the local economy. This significant reliance compels both vendors and employers to comply with growing European emission regulations, such as via the use of hydrogen technology. Based on (Blume-Kohout & Sood, 2013; Hermosilla & Wu, 2018).
Number of passenger cars produced	per 1000 inhabitants	+	High-vehicle-density nations depend on automobiles for a variety of reasons (convenience, lack of alternatives, long distances, etc.). They are more responsive to new technology and have higher buying power as a result Based on (Solarin et al., 2022).
The number of hydrogen filling stations	per 1 million inhabitants	+	This variable indicates the total quantity of hydrogen refuelling stations. The infrastructure is more advanced the higher the number. A clear incentive impact exists. Based on (Acheampong et al., 2022; Naeem et al., 2023).
Hydrogen production capacity	Tons per 1 million inhabitants	+	In analysing the hydrogen plans of nations, national governments anticipate that a greater proportion of domestic production will have a favourable impact. Based on (Gordon et al., 2022; Lozano et al., 2022).
Electricity prices for household consumers	Purchasing Power Standard/KWh	-	Increasing electricity costs, the major source of green hydrogen generated by electrolysis using wind or solar energy, are the exact opposite of rising gasoline prices. The commercial adoption of alternative propulsion systems fueled by sustainably produced energy will be greatly hampered by high electricity

			costs. Based on (Durante et al., 2022; Macedo et al., 2022).
Share of zero-emission vehicles in newly registered passenger cars	%	+	Multiple technologies contribute to innovation. In the past, natural gas was a desired energy source that has since been superseded by battery-powered electric vehicles. They are all competing for the same thing, client acceptability and consequently market penetration, like hydrogen. Diverse technological marketplaces give more opportunities for innovation than concentrated ones.
Percentage of alternative fuels (electric, hybrid, etc.) regarding all (+diesel and petrol) new truck registrations	%	+	Ratio relative to the preceding ratio, selected in particular for nations with a strong logistical capacity (e.g. Poland). Although passenger automobiles there continue to depend more and more on gasoline and diesel, the usage of electrification, biofuels, and hydrogen, which are plainly more economically sensible, is on the rise here as well.
Petrol prices	€/l	+	The price of gasoline has a substantial effect on vehicle use. Increases in gasoline costs have an immediate effect on customers, who choose for more fuel-efficient cars and plan their travels in advance. Conversely, favourable gasoline prices give an incentive to retain the status quo. Based on (Frondel & Schubert, 2021).
Number of hydrogen cars	Per 1 million inhabitants	+	The outcome variable and factor to be researched, which was identified as the determining factor for the success of hydrogen technology in personal transportation.

Figure 1. Variables and expected effects

Methodology

This paper follows the structure of previous COCO model publications (Pitlik et al., 2020; Pitlik & Csizmadia, 2021), the underlying methodological aim is to the different data should allow us to recognise a certain trend. During the investigation, attempts were undertaken to locate comparable data from the same or nearby time periods. In this instance, numbers from 2021 were chosen since this was offering the most insights regarding developments in the close future. It is crucial to note that the table does not analyse a wide time frame, but rather simply the year 2019.

Production Functions via COCO:STD

The majority of the data was acquired from reputable public sources, such as statista.com, a German internet statistics and market research site as well as the database of the European commission and the United Nations, respectively. Missing data was based on assumptions of previous years.

In the first phase, the so-called raw numbers must be contextualised so that disparities across countries of various sizes may be avoided. Thus, these numbers were always derived based on certain demographic metrics, currencies, or percentage shares, see Figure 2. Since relativized statistics do not demonstrate an adequate degree of "homogeneity," the data for each country has been rated. In this manner, discrepancies are concealed, and the nations are ranked. Figure 2 demonstrates a quasi pattern-free visual impression (for human eyes). The derivation of production functions must increase the correlation compared to the correlation of the raw independent variables and the dependent one.

Basic data		Electricity price	Public exp. R&D	No. H-fuel stations	No. produced cars	No. Passenger cars	Newly regist. Alt. Trucks	Petrol prices	0-emission pas. Car reg.	Annual H-Prod.	Number of hydrogen cars
	Population	Purchasing Power Standard/KWh	Euro/inhabitant	number	number/ 1000 inhabitants	number/ 1000 inhabitants	%	€/l	%	tons per million capita	Absolute number
AT	8.932.664	0,20	1449,90	0,45	13,89	570,00	8,20	1,45	6,20	19,03	55,00
BE	11.554.767	0,27	1397,90	0,26	19,27	509,00	54,10	1,74	3,30	49,33	85,00
BG	6.916.548	0,20	79,40	0,00	0,00	414,00	0,00	1,29	1,20	31,81	0,00
CR	4.036.355	0,20	179,60	0,00	0,00	433,00	23,30	1,33	1,50	37,16	0,00
CY	896.007	0,25	232,10	0,00	0,00	645,00	0,00	1,48	0,40	0,00	0,00
CZ	10.494.836	0,25	444,40	0,10	105,09	565,00	8,10	1,50	1,60	12,39	9,00
DK	5.840.045	0,26	1621,70	1,03	0,00	466,00	34,40	1,82	7,00	5,14	226,00
EST	1.330.068	0,24	414,20	0,00	0,00	608,00	52,80	1,70	1,90	0,00	0,00
FIN	5.533.793	0,15	1353,70	0,00	16,79	654,00	51,30	1,84	4,30	34,33	1,00
FR	67.656.682	0,19	817,60	0,28	13,53	566,00	36,60	1,62	6,70	12,12	396,00
DE	83.155.031	0,29	1357,10	1,07	37,20	574,00	32,00	1,69	6,40	25,13	1236,00
GRC	10.678.632	0,24	246,80	0,00	0,00	514,00	0,00	1,83	0,80	36,52	0,00
HUN	9.730.772	0,16	260,10	0,00	40,70	403,00	4,70	1,58	2,20	26,72	0,00
ISL	368.792	0,09	1628,60	0,00	0,00	216,00	6,70	2,10	26,20	0,00	27,00
IRL	5.006.324	0,25	899,20	0,00	0,00	458,00	56,30	1,61	4,50	2,00	0,00
ITA	59.236.213	0,24	447,60	0,02	7,50	670,00	19,20	1,61	2,30	14,35	45,00
LVA	1.893.223	0,26	122,60	0,00	0,00	390,00	13,00	1,59	2,10	0,00	0,00
LTU	2.795.680	0,22	222,60	0,00	0,00	560,00	0,00	1,48	1,10	96,58	0,00
LUX	634.730	0,15	1165,00	0,00	0,00	682,00	0,00	1,49	5,50	0,00	3,00
MLT	516.100	0,15	184,10	0,00	0,00	597,00	0,00	1,34	1,20	0,00	0,00
NL	17.475.415	0,13	1105,30	0,40	6,00	503,00	65,90	1,74	20,20	88,70	488,00
NOR	5.391.369	0,15	1489,60	0,00	0,00	514,00	9,90	1,94	51,60	53,79	231,00
POL	37.840.001	0,27	218,10	0,00	6,93	664,00	28,80	1,40	0,80	27,22	74,00
PRT	10.298.252	0,26	346,20	0,00	22,14	540,00	26,80	1,60	5,20	15,54	3,00
ROM	19.201.662	0,31	59,40	0,00	22,10	379,00	79,70	1,32	2,20	12,50	0,00
SRB	6.871.547	0,15	50,00	0,00	3,11	285,71	0,00	1,49	0,00	0,00	0,00
SVK	5.459.781	0,20	168,20	0,00	184,00	447,00	8,70	1,49	1,10	38,46	2,00
SVN	2.108.977	0,20	529,60	0,00	45,46	555,00	0,00	1,24	3,10	0,00	0,00
ESP	47.398.695	0,30	363,90	0,06	35,04	521,00	47,80	1,56	2,10	16,67	19,00
SWE	10.379.295	0,20	1737,40	0,29	24,68	476,00	47,40	1,71	9,30	23,12	63,00
CH	8.670.300	0,21	1988,37	0,00	0,00	537,00	38,60	1,81	7,90	2,31	200,00
TUR	83.614.362	0,27	271,08	0,00	9,24	157,00	0,00	0,94	0,10	0,00	0,00

Figure 2. The objects and attributes with the raw data (source: https://miau.my-x.hu/miau/294/hydrogen_market_analyses_2023_abs.xlsx)

Country	Electricity price	Public exp. R&D	No. H-fuel stations	No. produced cars	No. Passenger cars	Newly regist. Alt. Trucks	Petrol prices	0-emission pas. Car reg.	Annual H-Prod.	No. H-cars	Delta/Fact	Validity
AT	10	6	3	12	9	20	25	9	14	*7157*	**-6,66**	1
BE	27	7	7	10	19	4	8	14	4	*8356*	6	1
BG	13	30	11	19	26	24	30	24	9	*1000*	**2,73**	1
CR	14	27	11	19	25	15	28	23	6	*1000*	-0,9	1
CY	23	23	11	19	5	24	24	30	24	*1000*	-0,9	1
CZ	22	16	8	2	11	21	19	22	19	*1857*	-0,9	1
DK	26	4	2	19	22	11	5	6	21	*39698*	28,4	1
EST	20	17	11	19	6	5	10	21	24	*1000*	-15,58	1
FIN	3	9	11	11	4	6	3	13	8	*1180*	**-5,64**	1
FR	9	13	6	13	10	10	12	7	20	*6853*	-0,9	1
DE	30	8	1	5	8	12	11	8	12	*15863*	**-38,74**	1
GRC	19	22	11	19	17	24	4	28	7	*1000*	-0,9	1
HUN	8	21	11	4	27	23	17	17	11	*1000*	-0,9	1
ISL	1	3	11	19	31	22	1	2	24	*74212*	-0,9	1
IRL	21	12	11	19	23	3	13	12	23	*1000*	-20,17	1
ITA	18	15	10	15	2	16	14	16	17	*1759*	-26,86	1
LVA	25	29	11	19	28	17	16	19	24	*1000*	0,92	1
LTU	17	24	11	19	12	24	23	26	1	*1000*	-0,9	1
LUX	7	10	11	19	1	24	22	10	24	*5726*	-0,9	1
MLT	5	26	11	19	7	24	27	24	24	*1000*	-0,9	1
NL	2	11	4	17	20	2	7	3	2	*28924*	-0,9	1
NOR	4	5	11	19	17	18	2	1	3	*43846*	-0,9	1
POL	28	25	11	16	3	13	26	28	10	*2955*	**19,52**	1
PRT	24	19	11	8	14	14	15	11	16	*1291*	9,06	1
ROM	32	31	11	9	29	1	29	17	18	*1000*	-0,9	1
SRB	6	32	11	18	30	24	21	32	24	*1000*	-0,9	1
SVK	11	28	11	1	24	19	20	26	5	*1366*	-0,9	1
SVN	15	14	11	3	13	24	31	15	24	*1000*	-0,9	1
ESP	31	18	9	6	16	7	18	19	15	*1400*	-0,9	1
SWE	12	2	5	7	21	8	9	4	13	*7069*	**-45,62**	1
CH	16	1	11	19	15	9	6	5	22	*24067*	-0,9	1
TUR	29	20	11	14	32	24	32	31	24	*1000*	0,92	1
Direction	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**			
Correlation	**-0,33**	**-0,02**	**-0,17**	**-0,33**	**0,09**	**0,06**	**-0,02**	**-0,09**	**-0,14**			

Figure 3. Ranking and correlation solution
(source: https://miau.my-x.hu/miau/294/hydrogen_market_analyses_2023_abs.xlsx)

Constructing an anti-discriminatory index

One may now approximately guess (see naïve solution = non-optimized solution) which country or countries are the "best" based on these rankings in an aggregated way (see figure 3). Obviously, personal preferences or interests play a significant role in this context, since not everyone values the same attributes/directions in a subjective (lobby-oriented) world – but not in a causal interpretation where the best model as such should be existing: The best modelling approach is the approach, which is capable of deriving the most robust (objectively close) approximations compared to the facts (in the future). Additionally, it is important to remember that certain traits are subjective, and preferences cannot always be established. The better the more, or the better the less? Based on previous studies, so-called directed preferences have been created (see figure 1).

When comparing the direction and the results of the correlation (see figure 3), it can be evident, that there are differences between the statistical reality and the expected or rather proposed direction, which is based on both the academic standard and (economic) policymaking. It can be observed that public expenditures in research and development by far do not pose any statistical relevance, indicating that blindly spending into any research and development, i.e. by lacking a due-diligence, does not propose any direct influence on the success of hydrogen cars. Direct contrast can also be observed; countries heavily invested in the automotive industry have an opposite effect and seem to reject hydrogen technology quite aggressively. Indicating a direct interest conflict, countries with a high industrial dependency might focus on preserving the status quo in fear of losing market dominance.

The obtained (ranking) data were then analysed using COCO (Component-based Object Comparison for Objectivity) to generate an optimum approximation of the ideality index values. Due to the tiny number, Y was set to 1000000 as a norm before being assigned as a variable (cf. anti-discrimination study - where the constant Y values may be computed for each country using (flexible but interpretable) staircase functions based on the Xi values), yielding the following result:

Stairs	E-Tariffs	Gross p. e. on R&D	No. of hydrogen fuel s.	No. of passenger cars produced	No. of vehicles	% of alternative fuels truck registrations	Petrol prices	Share of zero-emission vehicles	Hydrogen production capacity	No. Of H-cars	Y0	Estimate	Validity	Country	Order	Naive average	Naive order	Difference between orders
Austria	10	6	3	12	9	20	25	9	14	8	1000000	1000049	1	Austria	6	11,60	10	*4*
Belgium	27	7	7	10	19	4	8	14	4	7	1000000	1000051	1	Belgium	4	10,70	6	*2*
Bulgaria	13	30	11	19	26	24	30	24	9	19	1000000	999923	1	Bulgaria	29	20,50	29	*0*
Croatia	14	27	11	19	25	15	28	23	6	19	1000000	999942	1	Croatia	27	18,70	26	*1*
Cyprus	23	23	11	19	5	24	24	30	24	19	1000000	999933	1	Cyprus	28	20,20	28	*0*
Czech Republi	22	16	8	2	11	21	19	22	19	13	1000000	1000031	1	Czech Republic	10	15,30	16	***6***
Denmark	26	4	2	19	22	11	5	6	21	3	1000000	1000025	1	Denmark	13	11,90	11	*2*
Estonia	20	17	11	19	6	5	10	21	24	19	1000000	999984	1	Estonia	22	15,20	15	***7***
Finland	3	9	11	11	4	6	3	13	8	18	1000000	1000065	1	Finland	1	8,60	3	*2*
France	9	13	6	13	10	10	12	7	20	10	1000000	1000041	1	France	7	11,00	8	*1*
Germany	30	8	1	5	8	12	11	8	12	6	1000000	1000016	1	Germany	16	10,10	5	***11***
Greece	19	22	11	19	17	24	4	28	7	19	1000000	999963	1	Greece	24	17,00	22	*2*
Hungary	8	21	11	4	27	23	17	17	11	19	1000000	1000019	1	Hungary	15	15,80	19	*4*
Iceland	1	3	11	19	31	22	1	2	24	1	1000000	1000034	1	Iceland	9	11,50	9	*0*
Ireland	21	12	11	19	23	3	13	12	23	19	1000000	999973	1	Ireland	23	15,60	18	*5*
Italy	18	15	10	15	2	16	14	16	17	14	1000000	1000030	1	Italy	11	13,70	12	*1*
Latvia	25	29	11	19	28	17	16	19	24	19	1000000	999922	1	Latvia	30	20,70	30	*0*
Lithuania	17	24	11	19	12	24	23	26	1	19	1000000	1000004	1	Lithuania	19	17,60	24	*5*
Luxembourg	7	10	11	19	1	24	22	10	24	11	1000000	1000022	1	Luxembourg	14	13,90	13	*1*
Malta	5	26	11	19	7	24	27	24	24	19	1000000	999949	1	Malta	25	18,60	25	*0*
Netherlands	2	11	4	17	20	2	7	3	2	4	1000000	1000063	1	Netherlands	3	7,20	1	*2*
Norway	4	5	11	19	17	18	2	1	3	2	1000000	1000051	1	Norway	5	8,20	2	*3*
Poland	28	25	11	16	3	13	26	28	10	12	1000000	999995	1	Poland	20	17,20	23	*3*
Portugal	24	19	11	8	14	14	15	11	16	17	1000000	1000011	1	Portugal	18	14,90	14	*4*
Romania	32	31	11	9	29	1	29	17	18	19	1000000	999989	1	Romania	21	19,60	27	***6***
Serbia	6	32	11	18	30	24	21	32	24	19	1000000	999917	1	Serbia	31	21,70	31	*0*
Slovakia	11	28	11	1	24	19	20	26	5	16	1000000	1000027	1	Slovakia	12	16,10	20	***8***
Slovenia	15	14	11	3	13	24	31	15	24	19	1000000	1000015	1	Slovenia	17	16,90	21	*4*
Spain	31	18	9	6	16	7	18	19	15	15	1000000	999948	1	Spain	26	15,40	17	***9***
Sweden	12	2	5	7	21	8	9	4	13	9	1000000	1000063	1	Sweden	2	9,00	4	*2*
Switzerland	16	1	11	19	15	9	6	5	22	5	1000000	1000038	1	Switzerland	8	10,90	7	*1*
Turkey	29	20	11	14	32	24	32	31	24	19	1000000	999907	1	Turkey	32	23,60	32	*0*
direction	1	0	0	0	0	0	0	0	0	0								

Figure 4. Results of the ***COCO-Y0*** *Method (source: https://miau.my-x.hu/miau/294/hydrogen_market_analyses_2023_abs.xlsx)*

Results

The results (of the anti-discriminative modelling – see Figure#4), which are commonly referred to as the Innovation Diffusion Index, illustrate how many hydrogen-powered automobiles each country could support in comparison to the average number of cars in the world. Accordingly, Finland, Sweden, and the Netherlands are the top three countries, which is in line with the hypotheses and does not significantly deviate from the naïve predictions. In spite of this, the Czech Republic, Romania, Estonia, Slovakia, Spain, and Germany all deviate quite a little from their initial estimates, with the greatest deviations occurring in increasing order (see Figure 4 – Column "Differences between naïve and optimized ranking values).

The naïve viewpoint gives the dispersion, which is the root of this discrepancy, very little consideration. Germany is especially appealing for a variety of reasons, including the accessibility of hydrogen filling stations and the commercial dominance of the automotive industry, amongst other factors. Nevertheless, it is ranked dead last in one category, which is the price of electricity. This factor has a significant influence (concerning the analysed data universe/OAM see Figure 2&3) on the cost component of the hydrogen that is created, as well as on the future costs related with the purchase of a hydrogen vehicle. When compared to the naïve method, the COCO model places a greater emphasis on the significance of this component. Therefore, according to the naïve perspective, certain countries are superior, even though their dispersion conceals enormous inefficiencies and, as a result, may cause decision makers to reach the incorrect conclusions. The use of large numbers may cloud the problems at hand and make it more difficult to make acceptable adjustments to levers such as the government's budget.

Overall – based on the production function behind the Figure#3, some countries could sustain more hydrogen vehicles than they currently do and thereby offer a higher potential of market establishing, namely Finland, Austria, Belgium, the Netherlands, Norway and Sweden. On the opposite, some countries lack behind in multiple socio-economic factors Serbia, Latvia, and Bulgaria. As an example, Serbia has the lowest R&D expenditure per capita, has a minimal car market relevance, low amounts of zero-emission vehicles and thereby, by default cannot rank high as it is below average in 8 of 10 variables.

Conclusion and future

This quantitative methodological approach was used to develop a model that illustrates Europe's strategic missing-out in hydrogen-electric private mobility, customer responsiveness and technological acceptance of a different propulsion in privately owned cars, and the countries' potential under the status quo.

Economic development and consumer responsiveness are imperilled by ineffective policymaking that impedes market penetration and economic innovation. On the basis of eight criteria, the current status of Central European states in adopting and effectively changing hydrogen-based automobiles was determined using a component-based object comparison technique for objectivity. Ecological, price elasticity, and infrastructure variables are evaluated.

It is crucial to recognise the limits of research notwithstanding its tremendous triumphs. The technique's shortcomings are discussed first. Only Europeans were included in the data and subsequent analysis, and policymakers and innovation strategies concentrated only on the expansion of personal car mobility in this designated area. Consequently, these findings only reflect the situation in its current setting; research in other locales may give dramatically different outcomes owing to substantial variations in autonomy, political decision-making, external repercussions of radical change, industry standards, and managerial practises. In addition, this research did not concentrate on particular brands or companies; rather, it covered a wide range of automobile companies. Moreover, not every facet of innovation was studied. It is not considered that different political conditions have a substantial effect on the innovation policy of each member state. With different political perspectives and consequently considerations regarding how certain policymaking should be carried out, a standardised analysis of policies was attempted as opposed to a deeply individual-focused approach, although this may indicate additional micro-level results not covered by this study. Moreover, due to the fact that the energy sector remains a national asset and is only advised and coordinated to a limited degree at the European level, many states in Central Europe opt to focus on individual and hence less integrated strategies. As the production of energy is limited to a small number of key partners that are heavily invested in specific energy carriers and, as a result, have international dependencies from outside of Central Europe, certain negative effects of oligarchic market structures and entanglements of policymakers and businesses alike tend to reveal irrational strategic leadership or market irregularities on a certain scale. Due to their very different legal and historical backgrounds, it would have been difficult to compare these components' policymaking processes. On the Central European landscape, the question of emission-free and thus green energies is not satisfactorily answered, as many ecologically focused political parties tend to reject the use of nuclear energy as a viable alternative to green energy, whereas the European Union and member states dependent on nuclear energy accept and promote it.

Lastly, the element of decreased emissions must be examined throughout the whole supply chain, since just the emissions from point A to point B are now taken into account. Additional resources and possibly shorter product lifetimes, as well as yet non-existent circular economy components, are not taken into account.

Further empirical emphasis should thus be placed on, but not be limited to, prior-year data as well as other technical trends that may contribute to the success of the hydrogen energy industry.

Parallel, each attribute of the OAM can also be interpreted as dependent variable (Y). This multi-layered interpretation (incl. more years) will lead to an automated SWOT analyses and/or to a kind of data quality assurance where potential statistical errors can be derived.

References

Acheampong, A. O., Dzator, J., Dzator, M., & Salim, R. (2022). Unveiling the effect of transport infrastructure and technological innovation on economic growth, energy consumption and CO2 emissions. *Technological Forecasting and Social Change*, *182*, 121843. https://doi.org/10.1016/j.techfore.2022.121843

Balsalobre-Lorente, D., Zeraibi, A., Shehzad, K., & Cantos-Cantos, J. M. (2021). Taxes, R&D Expenditures, and Open Innovation: Analyzing OECD Countries. *Journal of Open Innovation: Technology, Market, and Complexity*, *7*(1), 36. https://doi.org/10.3390/joitmc7010036

Blume-Kohout, M. E., & Sood, N. (2013). Market size and innovation: Effects of Medicare Part D on pharmaceutical research and development. *Journal of Public Economics*, *97*, 327–336. https://doi.org/10.1016/j.jpubeco.2012.10.003

Chen, C., Gu, J., & Luo, R. (2022). Corporate innovation and R&D expenditure disclosures. *Technological Forecasting and Social Change*, *174*, 121230. https://doi.org/10.1016/j.techfore.2021.121230

Durante, F., Gianfreda, A., Ravazzolo, F., & Rossini, L. (2022). A multivariate dependence analysis for electricity prices, demand and renewable energy sources. *Information Sciences*, *590*, 74–89. https://doi.org/10.1016/j.ins.2022.01.003

Frondel, M., & Schubert, S. A. (2021). Carbon pricing in Germany's road transport and housing sector: Options for reimbursing carbon revenues. *Energy Policy*, *157*, 112471. https://doi.org/10.1016/j.enpol.2021.112471

Gordon, J. A., Balta-Ozkan, N., & Nabavi, S. A. (2022). Homes of the future: Unpacking public perceptions to power the domestic hydrogen transition. *Renewable and Sustainable Energy Reviews*, *164*, 112481. https://doi.org/10.1016/j.rser.2022.112481

Hermosilla, M., & Wu, Y. (2018). Market size and innovation: The intermediary role of technology licensing. *Research Policy*, *47*(5), 980–991. https://doi.org/10.1016/j.respol.2018.03.003

Lozano, L. L., Bharadwaj, B., de Sales, A., Kambo, A., & Ashworth, P. (2022). Societal acceptance of hydrogen for domestic and export applications in Australia. *International Journal of Hydrogen Energy*, *47*(67), 28806–28818. https://doi.org/10.1016/j.ijhydene.2022.06.209

Macedo, D. P., Marques, A. C., & Damette, O. (2022). The role of electricity flows and renewable electricity production in the behaviour of electricity prices in Spain. *Economic Analysis and Policy*, *76*, 885–900. https://doi.org/10.1016/j.eap.2022.10.001

Naeem, M. A., Appiah, M., Karim, S., & Yarovaya, L. (2023). What abates environmental efficiency in African economies? Exploring the influence of infrastructure, industrialization, and innovation. *Technological Forecasting and Social Change*, *186*, 122172. https://doi.org/10.1016/j.techfore.2022.122172

Pitlik, L., & Csizmadia, S. (2021). *Wo lebt sich am besten in Europa?* https://miau.my-x.hu/miau/276/kje/eu/Szilvia%20Csizmadia%20KJO0IX%20Ranking%20EU.pdf

Pitlik L., Rácz Z., Learning Innovation Kft, & MY-X-team. (2020). *Az ADIDAS-történet robotszemmel – avagy a validáció új aspektusai a hasonlóságelemzésben*. https://miau.my-x.hu/miau/273/adidas_story.pdf

Solarin, S. A., Bello, M. O., & Tiwari, A. K. (2022). The impact of technological innovation on renewable energy production: Accounting for the roles of economic and environmental factors using a method of moments quantile regression. *Heliyon*, *8*(7), e09913. https://doi.org/10.1016/j.heliyon.2022.e09913

Wei, L., Lin, B., Zheng, Z., Wu, W., & Zhou, Y. (2023). Does fiscal expenditure promote green technological innovation in China? Evidence from Chinese cities. *Environmental Impact Assessment Review*, *98*, 106945. https://doi.org/10.1016/j.eiar.2022.106945