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Harmonizing Hydrogen Colour Codes: Need for an Economic Policy Framework for a Global Hydrogen Market

Elena-Loredana Ocenic
The Bucharest University of Economic Studies, Romania
ocenicelena22@stud.ase.ro

Abstract

This paper presents an economic policy framework designed to harmonize hydrogen colour codes for the nascent global hydrogen sector, since the current colour code systems suffer from inconsistencies, causing confusion and misinterpretation among industry stakeholders and consumers. This study seeks to contribute to the development of a transparent and well-informed hydrogen market, empowering businesses enhance competitiveness, and foster long-term sustainability through a standardized approach to labelling hydrogen based on its carbon dioxide emissions across different production pathways, i.e., hydrogen production technologies. The proposed policy framework, based on reliable qualitative data, aims to enhance the scientific underpinning in assigning colours, ensuring that hydrogen colour codes accurately reflect their environmental impact. By offering a clear and consistent classification, the proposed harmonized colour code system facilitates market access for businesses, it enables strategic decision-making, effective market positioning, and fosters consumer trust. It also supports businesses in differentiating their products based on environmental credentials.

Key words: green hydrogen, policy, harmonization, colour codes
J.E.L. classification: M10

1. Introduction

The global commitment to mitigate and adapt to climate change is enshrined in the Paris Agreement, a landmark international accord that seeks to limit global warming to „*well below 2°C above pre-industrial levels*" (UNFCCC, 2015, p.3). As part of this broader sustainability agenda, regional plans and initiatives have been established to accelerate the adoption of clean energy solutions. One such initiative is the *European Green Deal*, which sets ambitious targets for achieving climate neutrality and a sustainable economy within the European Union (European Commission, 2019).

In this context, the need to decarbonize the energy sector and reduce greenhouse gas emissions has led to a growing interest in hydrogen as a versatile energy carrier, which can be produced from renewable energy sources and other sources that emit fewer emissions than the fossil options. Hydrogen can play a vital role in the energy transition at global level by facilitating the integration of renewable energy sources into existent power grids, providing energy storage, and decarbonizing various sectors, such as transport or industry.

However, the use of hydrogen is not without challenges, particularly in terms of its production methods and the associated carbon dioxide emissions. To address this, various colour codes have been introduced to classify hydrogen based on its environmental impact, such as green, blue, grey, and others. Yet, the existing colour code framework lacks consistency and scientific underpinning, leading to confusion and misinterpretation (Ocenic and Tanțău, n.d.).

The aims of this paper are twofold: firstly, to redefine hydrogen colour codes based on carbon dioxide emissions associated with different production pathways, and secondly, to propose building blocks of a policy framework for harmonizing these colour codes. By aligning hydrogen colour codes with their environmental impact, the author seeks to provide a transparent and scientifically grounded approach to labelling hydrogen, supporting the objectives of the Paris Agreement and regional plans like the *European Green Deal* (European Commission, 2021).

Furthermore, the paper seeks to highlight the relevance of harmonized colour codes for businesses, emphasizing the potential for transparent market access and enhanced business competitiveness in the emerging hydrogen economy.

2. Literature review

The scientific literature on „*green*" hydrogen, colour codes for hydrogen, policy frameworks, and their relevance for businesses provides valuable insights into the development of sustainable hydrogen economies. Despite growing research, policy and business interest into „*green*" hydrogen, key questions – both socioeconomic and technical – remain unanswered.

While Nikolaidis and Poullikkas conducted a comprehensive study on hydrogen production processes (Nikolaidis and Poullikkas, 2017), the commonly used colours „*green*", „*blue*" and „*grey*" hydrogen have not received a lot of attention as to what these labels mean or convey (other than a technological processes).

There has been some initial work done proposing a lifecycle analysis (LCA) for hydrogen production technologies, looking into the environmental impact of various production methods (Mehmeti *et al.*, 2018). Since this work used several environmental criteria, including human toxicity potential, freshwater eutrophication potential and land use, among others, the study concluded with a lack of a single technological pathway that is environmentally friendly form the perspective of all studied variables.

The relevance of policy frameworks for harmonizing hydrogen colour codes and their impact on businesses have also received little scholarly research. However, besides academia, international organisations such as the International Renewable Energy Agency provide insights into policy frameworks and market design for „*green*" hydrogen, emphasizing the need for clear labelling and harmonized standards in driving market growth and attracting investments, including so-called „*guarantees of origin*" (IRENA, 2020, p.18).

Yet, literature lacks a standardized framework that accurately reflects carbon dioxide emissions in hydrogen production technologies, or a clear and consistent labelling or colour code that ensures transparency and facilitate market understanding.

In this context, the present research aims to advance the understanding of what is needed for a clear and consistent labelling system that enhances transparency and accuracy, ensuring that hydrogen colour codes accurately reflect their environmental impact, or at least reflect the carbon dioxide emitted in the production processes, as a minimum criteria.

Additionally, the study will investigate the direct implications of harmonized colour codes for businesses, exploring the potential benefits and challenges faced by companies operating in the hydrogen sector. It will examine how clear labelling enables informed decision-making, product differentiation, and competitive advantage in the emerging hydrogen economy. Furthermore, the research will assess the alignment of hydrogen colour codes with the objectives of the Paris Agreement and regional sustainability plans like the European Green Deal, determining if additional colour categories beyond „*green*" are necessary to fully comply with these frameworks.

By addressing these research gaps, the study seeks to provide practical insights that support the development of a transparent and informed hydrogen market while promoting business success and a sustainable energy transition.

3. Research methodology

The research methodology for this paper involves a literature review, data collection, data analysis, framework development, and conclusion with recommendations.

Firstly, a review of existing scientific articles, reports, policy documents, and industry publications will be conducted to gather relevant knowledge on green hydrogen, colour codes, policy frameworks, and their implications for businesses. The literature review helps identify research gaps and provided a comprehensive understanding of the subject matter.

For this paper, secondary data will be collected from reliable, public sources. This data includes hydrogen production methods, carbon dioxide emissions associated with different production pathways, existing colour codes, policy frameworks, and the impact on businesses. The collected data will be relevant to the research objectives and support the subsequent analysis.

A qualitative method will be employed for the analysis, which focuses on carbon dioxide emissions data related to various hydrogen production pathways, aiming to identify variations and inconsistencies in the existing colour codes. The qualitative analysis will examine policy frameworks and their implications for businesses, considering factors such as market access, competitiveness, and alignment with sustainability goals. By comparing and synthesizing the findings, research gaps will be identified and a comprehensive understanding of the topic can be further developed.

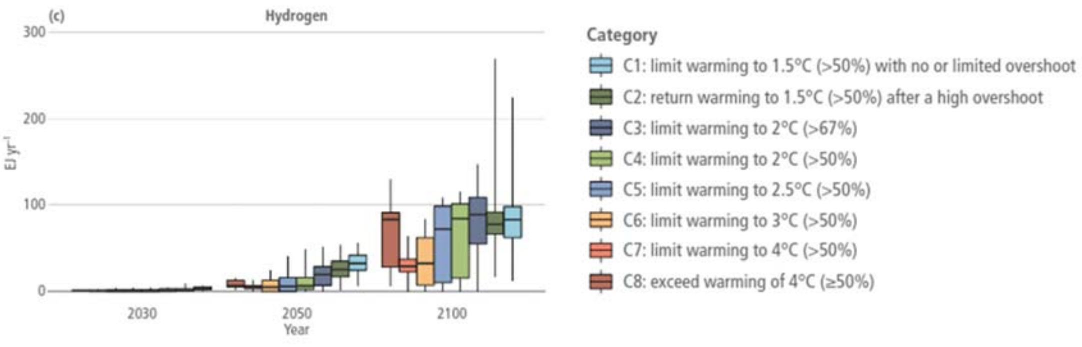
Based on the data analysis and identified research gaps, elements of a policy framework for harmonizing hydrogen colour codes can be put forward. The insights from the literature review and data analysis will inform the formulation of specific criteria and methodologies for assigning colour codes based on carbon dioxide emissions. The framework will address the challenges and inconsistencies in the existing system, promoting transparency, accuracy, and scientific basis for hydrogen colour codes. The relevance of the framework for businesses and its alignment with global and regional sustainability objectives will be considered.

4. Findings

4.1. Inconsistencies and gaps in labelling, despite huge importance of hydrogen in the long-term

Government plans including scenarios to reach low-emissions by mid-century or after mid-century are increasingly including hydrogen (IPCC, 2022, p.342). Figure no. 1 shows the hydrogen production across all studied scenarios by the IPCC and it illustrates that the current government plans take hydrogen technology into consideration rather after mid-century, if we consider the hydrogen contribution expressed as the energy per year that is included in such plans. Given the magnitude of the contribution of hydrogen to the future economy, this chart illustrates that, while consistent labelling might not be a matter of urgency, laying today the foundations for the creation of a future hydrogen market at global level, is a relevant policy, business and scientific topic.

Figure no. 1. Hydrogen production across studied scenarios by the IPCC



Source: (IPCC, 2022, 342)

However, the colour of the hydrogen used (i.e. the technology to produce the hydrogen depending on the source of energy input and the production process) reveals inconsistent approaches across policy, business and academia. Recent research argues that the current colour codes are „*misleading*” since colours like „*yellow*”, „*orange*” and „*turquoise*” – in addition to more commonly used ones like „*green*” and „*brown*” – are lacking a scientific underpinning (Ocenic and Tanțău, n.d.).

This finding illustrates a gap in reflecting the greenhouse gases – especially the carbon dioxide – emitted during the hydrogen production process. Similarly, (Cheng and Lee, 2022, p.23) argue that there is no „*environmental rigor*” in national and regional hydrogen strategies.

There is also no consensus regarding the hydrogen production technology, which is relevant towards the path of achieving the objectives of the Paris Agreement. If we analyse policy and programmatic documents or analytical reports released by international organisations, the lack of consistency is clear. While IPCC talks about „*low or zero-carbon hydrogen*”, acknowledging that „*there is no consensus on the hydrogen production spectrum*” (IPCC, 2022, p.657), IRENA favours the colour codes, using the label „*green*” for the hydrogen produced thanks to renewable power (IRENA, 2022, p.4). At the same time, the IEA considers „*low-emission hydrogen*”, which includes nuclear energy in addition to renewable energy sources and fossil fuels linked with carbon capture technologies (IEA, 2022, p.272).

Similarly, the hydrogen strategy of the European Union defines various technologies, including „*electricity-based hydrogen*”, „*renewable hydrogen*” (the same as „*clean hydrogen*”), „*fossil-based hydrogen*”, „*fossil-based hydrogen with carbon capture*”, while „*low-carbon hydrogen”* includes „*fossil-based hydrogen with carbon capture and electricity-based hydrogen*”. However, it does not explicitly include nuclear power – although „*electricity-based hydrogen*” could be produced thanks to nuclear power (European Commission, 2020, p.3-4), which can add to the confusion.

Therefore, the colour code or labelling at international level lack harmonization and agreement amongst the main stakeholders on the global scene.

4.2. Need for a standardized, scientifically grounded framework, using carbon dioxide emissions

Providing a standardized and scientifically grounded framework on carbon dioxide emissions for the hydrogen produced via various technologies will require a reliable methodology of accounting the emissions throughout the entire lifecycle or value chain of the production method, or at minimum, the carbon dioxide emitted in the production processes.

Table no. 2 provides the carbon intensity in kilogram (kg) of carbon dioxide equivalent (CO_2e) for each kg of hydrogen (H_2) produced. It is important to flag at this point there are no comprehensive comparative studies across various hydrogen technologies. While studies for individual technologies or few technologies in comparison can be found, the carbon intensity may be the outcome of different methodologies, so any comparison of the values indicated in Table no. 2 might be challenging without a deeper analysis. For example, some may include total greenhouse gas emissions, including other emissions other than carbon dioxide, while other may include carbon dioxide only.

IRENA has provided an illustration of the carbon dioxide emissions, which should be considered along the entire value chain, i.e. considering production, but also the required transport infrastructure and the final end-use applications of the hydrogen, as shown in Figure no. 2.

Providing government guarantees of origin for „*green*” or „*renewable*” or even „*low-carbon*” hydrogen will prove to be a challenging task unless clear definitions are put in place for a) technological pathways, b) colour labels and c) methodology for carbon intensity or footprint of hydrogen.

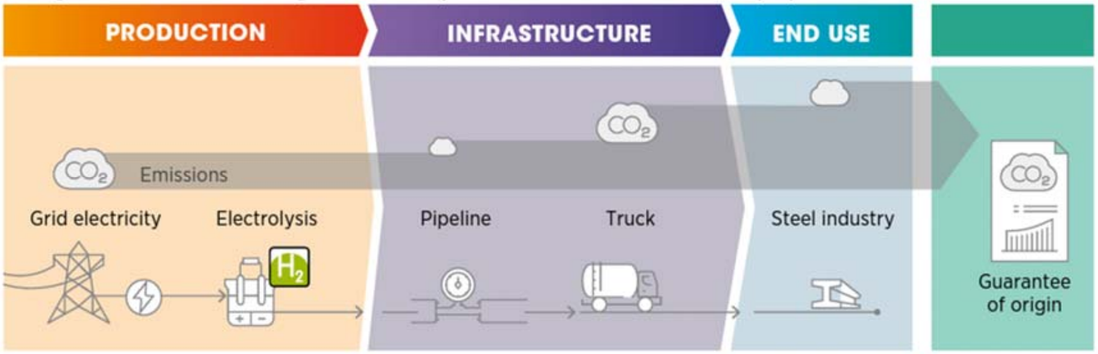
As such, there is a need to formulate a clear methodology to ensure transparency, accuracy, and meaningful differentiation of hydrogen colours, or any other label, which will be eventually used at international level to describe hydrogen produced via various means and techniques.

Table no. 2. Estimated carbon intensity per hydrogen production technology depending on the source

Selected technologies	**Colour label as per (Ocenic and Tanțău, n.d.)**	**Carbon intensity**	**Source**
Alkaline electrolysers with various sources	Yellow	15.4-43.01 kg CO_2e/kg H_2	(Aghakhani *et al.*, 2023, p.10)
Alkaline electrolysers with renewable electricity	Green	By convention, zero carbon intensity	(CertifHy, n.d.)
Polymer electrolyte membrane (PEM) with various sources	Yellow	13.15-38.1 kg CO_2e/kg H_2	(Aghakhani *et al.*, 2023, p.10)
Polymer electrolyte membrane (PEM) with renewable electricity	Green	By convention, zero carbon intensity 5–10 kg CO_2e/kg H_2 (by 2030)	(CertifHy, n.d.) (Aghakhani *et al.*, 2023, p.1)
Solid oxide electrolyser cell (SOEC) with renewable electricity	Green	By convention, zero carbon intensity	(CertifHy, n.d.)
Natural gas pyrolysis	Grey/turquoise	3.6-11.6 kg CO_2e/kg H2	(Okeke *et al.*, 2023, p.12592)
Natural gas pyrolysis with carbon capture	Blue/turquoise	1.8-4.6 kg CO_2e/kg H_2	(Okeke *et al.*, 2023, p.12592)
Steam methane reforming (SMR)	Grey	9-11.5 kg CO_2e/kg H_2	(Okeke *et al.*, 2023, p. 12582) (Valente *et al.*, 2020, p.4)
Steam methane reforming (SMR) with carbon capture	Grey/blue	9.35 kg CO_2e/kg H_2	(Cho *et al.*, 2022, p.13592)
Coal gasification	Black/brown/grey	21.60 kg CO_2e/kg H_2	(Li *et al.*, 2022, p.4)
Coal gasification with carbon capture	Black/brown/grey/blue	4.92–10.90 kg CO_2e/kg H_2	(Li *et al.*, 2022, p.9)
Hydrogen from biomass gasification including CCS	Green	Potentially negative emission	(Valente *et al.*, 2020, p.1)

Source: Author's own research results based on indicated sources

Figure no. 2. Schematic representation of carbon dioxide emissions in lifecycle assessments



Source: (IRENA, 2020, 30)

4.3. Need for comparable rules for businesses

Analysing closer the initiatives that seek to provide guarantees of origin for hydrogen, there are several relevant examples mainly in Europe. These include certification bodies like AFHYPAC, Low Carbon Fuel Standard, CertifHy, TÜV SÜD, Clean Energy Partnership, REDII, Technical Expert Group on Sustainable Finance that have already certification schemes in place, while others are being developed. However, only two of these focusing 100% on renewable power as input for the hydrogen production (AFHYPAC and Clean Energy Partnership) (IRENA, 2020, p.29).

Having such a mix of initiatives with various objectives, ranging from 100% renewable power input to a percentage point reduction in greenhouse gas emission in the hydrogen production process, or even a predefined carbon dioxide threshold can lead to market distortions for industry actors since there is no level playing field. At the same time, a level playing field with comparable, if not equal rules, is required for a truly global hydrogen market.

The benefits of harmonized colour codes for businesses operating in the hydrogen sector are manifold: a clear and transparent labelling enables informed decision-making, enhances market positioning, and supports product differentiation, providing businesses with a competitive advantage in the emerging hydrogen economy.

4.4. Alignment with sustainability goals

The extent to which „*green*” hydrogen is „*stringent*” i.e. the degree to which strategic and regulatory frameworks work towards achieving its objective has been studied in-depth (Cheng and Lee, 2022). Such work concludes that there is „*zero regulatory stringency*” in places like India, Norway and the United States. A strategy of „*scale-first-clean-later*” is adopted in most of the strategies studies around the world including Australia, the United Arab Emirates, the European Union or Japan. However, only one country seems to adopt the „*green-hydrogen now*” approach, i.e. without more carbon-intensive hydrogen production technologies as intermediary solutions ahead of meeting actual policy objectives. This exception is Portugal (Cheng and Lee, 2022, p.22).

Given this finding, corroborated with the fact that massive hydrogen adoption is likely taking place after mid-century, there is a need to define colour codes or labels in the nascent hydrogen market and to ensure that the adopted technologies are aligned with global climate objectives and more broadly with sustainability goals. However, since most strategies are aimed at economic scales, before environmental concerns (judged by stringency as defined above), there is a need to define what exactly „*green*” (or „*clean*”, „*renewable*”) hydrogen is, but also to define – more broadly speaking – the relevance of a technology in terms of contribution to limiting climate change. Therefore, it is relevant to which extent a hydrogen production technology contributes to the long-term climate and sustainably goals, as opposed to locking-in economic policy decisions which are counterproductive in terms of greenhouse gas emissions in the long term.

5. Conclusions

The current hydrogen colour code systems lack consistency and scientific underpinning, leading to confusion and misinterpretation among businesses and consumers. This is especially relevant since most of the existent hydrogen strategies aim at scaling the installed capacity of hydrogen production, before considering the environmental impact.

In order to harmonize hydrogen colour codes, developing guarantees of origin could provide they key towards a transparent and competitive global hydrogen market. Although there are several approaches and initiatives available and under development, the present article suggests that providing a carbon dioxide assessment for the hydrogen production process, followed by a corresponding colour code could perhaps be a more suitable solution in the absence of coherence and agreement on „*green*” hydrogen among policy, business, and academia. The main argument is that labels should accurately reflect the environmental impact of hydrogen if they are to contribute to the ultimate global policy objective of meeting the Paris Agreement and its underlying targets in terms of climate change mitigation. Colour codes are simple to be used, but to be useful these must have some scientific underpinning.

The discussion of harmonising colour codes is relevant for the private sector, including both large and small businesses since it facilitates their market access, enables strategic decision-making, supports effective market positioning, and can foster consumer trust. As such, businesses can differentiate their products based on environmental credentials while complying with sustainability goals.

However, as with any scientific endeavour, the present work has various limitations, which can be developed in subsequent work. First, it uses secondary data which – although sourced from reliable sources and contribute with valuable insights – limit its depth in the absence of primary empirical research. Second, the paper does not explicitly engage or consult stakeholders, like relevant industry actors, policymakers, or experts, which could validate these findings. Additional insights into the practical and feasible implementation of carbon dioxide assessments (or carbon footprint) as underpinning scale for labelling hydrogen depending on the technology and energy input used has yet to be analysed more closely.

6. References

- Aghakhani, A., Haque, N., Saccani, C., Pellegrini, M., Guzzini, A., 2023. Direct carbon footprint of hydrogen generation via PEM and alkaline electrolysers using various electrical energy sources and considering cell characteristics. *Int. J. Hydrog. Energy*. https://doi.org/10.1016/j.ijhydene.2023.04.083
- CertifHy, n.d. *GO LABELS. CERTIFHY*. URL https://www.certifhy.eu/go-labels/ (accessed 14.05.2023).
- Cheng, W., Lee, S., 2022. How Green Are the National Hydrogen Strategies? *Sustainability 14*, 1930. https://doi.org/10.3390/su14031930
- Cho, H.H., Strezov, V., Evans, T.J., 2022. Environmental impact assessment of hydrogen production via steam methane reforming based on emissions data. *Energy Rep. 8*, 13585–13595. https://doi.org/10.1016/j.egyr.2022.10.053
- European Commission, 2021. *A European Green Deal* [WWW Document]. URL https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (accessed 12.05.2023).
- European Commission, 2020. *A hydrogen strategy for a climate-neutral Europe* [WWW Document]. URL https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301 (accessed 12.05.2023).
- European Commission, 2019. *Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions - the European Green Deal*. [WWW Document]. URL https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF (accessed 23.05.2023).
- IEA, 2022. *Global Hydrogen Review 2022 – Analysis* [WWW Document]. IEA. URL https://www.iea.org/reports/global-hydrogen-review-2022 (accessed 12.05.2023).

- IPCC, 2022. *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, NY, USA. https://doi.org/10.1017/9781009157926
- IRENA, 2020. *Green hydrogen: A guide to policy making* [WWW Document]. URL https://www.irena.org/Publications/2020/Nov/Green-hydrogen (accessed 12.05.2023).
- Li, J., Wei, Y.-M., Liu, L., Li, X., Yan, R., 2022. The carbon footprint and cost of coal-based hydrogen production with and without carbon capture and storage technology in China. *J. Clean. Prod*. 362, 132514. https://doi.org/10.1016/j.jclepro.2022.132514
- Mehmeti, A., Angelis-Dimakis, A., Arampatzis, G., McPhail, S.J., Ulgiati, S., 2018. Life Cycle Assessment and Water Footprint of Hydrogen Production Methods: From Conventional to Emerging Technologies. *Environments* 5, 24. https://doi.org/10.3390/environments5020024
- Nikolaidis, P., Poullikkas, A., 2017. A comparative overview of hydrogen production processes. *Renew. Sustain. Energy Rev. 67*, 597–611. https://doi.org/10.1016/j.rser.2016.09.044
- Ocenic, E., Tanțău, A., n.d. Redefining the hydrogen “colours” based on carbon dioxide emissions: a new evidence-based colour code, in: *Proceedings of the International Conference on Business Excellence*. Presented at the Conference on Business Excellence, Bucharest.
- Okeke, I.J., Saville, B.A., MacLean, H.L., 2023. Low carbon hydrogen production in Canada via natural gas pyrolysis. *Int. J. Hydrog. Energy*. https://doi.org/10.1016/j.ijhydene.2022.12.169
- UNFCCC, 2015. *The Paris Agreement* [WWW Document]. URL https://unfccc.int/process-and-meetings/the-paris-agreement (accessed 12.05.2023).
- Valente, A., Iribarren, D., Dufour, J., 2020. Prospective carbon footprint comparison of hydrogen options. *Sci. Total Environ. 728*, 138212. https://doi.org/10.1016/j.scitotenv.2020.138212