Energy ecosystems layered over hydrogen valleys for sustainable smart communities. Strategic framework for the Green Deal Industrial Plan implementation in Romania

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Abstract
This research effort aims to obtain a clear and concise image of the organizational environment in Romania, currently operational in economic ecosystems built around host cities that sustain their societal dynamics based on corporative value chains. In order for cities to thrive, we propose the adoption of the continental framework for sustainable economies, having sufficient normative and regulatory elements to build a strategic analysis in support of a swift transition of industries and transportation, and the cities they influence, to sustainability. The research objectives are to analyse the main economic stakeholders organizational design and behaviour in their host communities, their relationship with the local and central public administration, and build new synergies based on opportunities to finance sustainable development, starting from renewable energy and green hydrogen as main catalysers for the transition. The research is an evolution of our prior "The Smart Community: Strategy Layers for a New Sustainable Continental Framework", a quantitative study of the European regulatory framework for sustainability, that now demands a thorough examination of the implementation methods in member states. The examination aims to obtain data regarding the organizational impact on the host community, and extended influences on the value chain, data to be used in a hypothetical optimization scenario based on renewable energy resources financed from power purchase agreements, a consolidated intra-industries demand for green hydrogen in industrial processes and transportation for a green energy demand forecast, the European, central and local governmental intervention in subsidizing the effort to build new resources and the social effects of a renewed approach to business administration. Considering the Paris Agreement and European Green Deal, several academic efforts are visible on defining the transition mechanisms to sustainable economies, providing sufficient information for best practices and successful implementation examples, studies to be used in a qualitative review of academic literature to sustain the concepts herein. The study and research result in a conceptual framework and strategy for industrial and value chain pivot to sustainable practices, based on a geographical segmentation of Romania into regions of interest selected due to specific infrastructure characteristics, energy resources, access to technology, access to human resources, etc. Implications for the academic sector and researchers abound, as this theoretical approach will include industrial sectors in defining a base-line for their legally mandated effort to comply with costly regulations, confronted with social tension regarding the effects of enterprises within communities they operate in, approach that translates into net value for governmental, corporative, academic and social stakeholders in our effort to clarify the benefits and hurdles implied by sustainability.

Keywords: sustainable development, renewable energy, economic ecosystems, organizational design, green hydrogen.

1. Introduction

In the face of escalating environmental challenges and the global imperative for sustainable development, Romania finds itself at a crossroads, tasked with the significant undertaking of transitioning its high-energy-consuming sectors towards more sustainable practices. This qualitative review aims to dissect the multifaceted economic climates within Romania, identifying sectors poised for sustainable transformation through the lens of financial and policy incentives. The study employs a comprehensive methodology, beginning with an exhaustive literature review to ground the research in the existing academic discourse. Following this, a PESTLE analysis offers a macro-environmental perspective on Romania's readiness for such a transition, complemented by an exploration of key Romanian regions and economic organizations pivotal in this ecosystem.

The final objective is to map the landscape of sustainable industries within Romania, providing a strategic blueprint for leveraging renewable energy and green hydrogen technologies. By bridging the gap between potential and practice, this research contributes valuable insights into the implementation methods within the EU framework, highlighting Romania's unique opportunities and challenges in navigating its sustainable development trajectory.

This study is meant to be revisited in 2025, the first year of mandatory non-financial disclosure for companies that are subject to comply with the Corporate Sustainability Reporting Directive of the European Union, that has been transposed and applied to the Romanian legislative system. Our ambition is to stimulate the growth of a sustainable economy from the energy resource that influences a Guarantee of Origin for sustainable products and services, that can then be assimilated into sustainable value chains.

Starting from energy ecosystems, we thus suggest preventive and pre-emptive compliance with green legislation by ensuring a clean value chain for economic agents that affect communities they employ from or sale to, fostering a synergic sustainable growth of organizations with sustainable designs and smart communities that thrive in progress. Pre-emptive compliance is suggested as a means to stimulate the new sustainable economies and generate ecosystems for Net 0 production. However, after the first non-financial reports will have been issued, carbon offset schemes may influence a new wave of sustainable finances, element that will be of interest for further academic research.

Hydrogen is, according to the Green Deal Industrial Plan, the main catalyser of this sustainable organization design, as it can be an emissions free energy resource, energy transportation vehicle or energy storage technology, all at the same time. With vast financial resources directed by both public and private organizations to the development of the “Hydrogen Economy”, our ambition is to find how hydrogen influences the growth of smart communities and sustainable organizations in Romania.

2. Literature Review

The transition towards sustainable development within economic ecosystems, especially in the context of host cities and corporative value chains, is a global imperative. The continental framework for sustainable economies offers a strategic approach for cities and

industries worldwide to embrace sustainability. This research effort, building on our earlier study "The Smart Community: Strategy Layers for a New Sustainable Continental Framework," seeks to explore the implementation of sustainable practices within the European Union member states, with a focus on Romania[1].

Renewable energy and clean hydrogen emerge as pivotal elements in the strategic analysis supporting the swift transition towards sustainability. The adoption of these sustainable solutions is essential for addressing environmental challenges and promoting economic growth within the framework of the European Green Deal and the Paris Agreement [2].

Renewable energy and clean hydrogen emerge as pivotal elements in the strategic analysis supporting the swift transition towards sustainability. The adoption of these sustainable solutions is essential for addressing environmental challenges and promoting economic growth within the framework of the European Green Deal and the Paris Agreement. The European Green Deal aims to transform the EU into a sustainable, climate-neutral economy by 2050, emphasizing the reduction of greenhouse gas emissions, increasing renewable energy use, and promoting circular economy principles [3], [4]. A focus on renewable energy sources is fundamental to achieving these objectives, as demonstrated by the development of the energy sector in the EU, which relies chiefly on renewables to ensure an environmentally friendly and health-conscious transition [5]

The implementation of Guarantees of Origin (GOs) serves as a crucial mechanism for assuring the renewability of electricity supplies and promoting upstream emission reduction. These certificates, however, face challenges in transparency and incentivizing renewable capacity investment. Blockchain technology offers potential solutions by enhancing transparency and simplifying processes, thereby supporting sustainability commitments, and facilitating the transition to renewable energy resources [6]. This approach aligns with European initiatives and the Green Deal industrial plan, underscoring the importance of pivoting industrial design towards renewable resources to achieve a sustainable and climate-neutral economy by mid-century.

The transition to renewable energy, supported by GOs and emission reduction strategies, is pivotal for sustainable organizational design. These measures are integral to the broader objectives of the European Green Deal, which seeks not only to mitigate environmental impact but also to foster economic growth and societal well-being within a sustainable framework.

2.1. Renewable energy and green hydrogen: a global perspective and focus on Romania

Renewable energy sources and green hydrogen are increasingly recognized as essential for achieving sustainable development goals (SDGs) and mitigating climate change impacts. Green hydrogen, in particular, offers opportunities for economic and social development by creating job opportunities and reducing greenhouse gas emissions. Its application across various industries, including agriculture, steel production, concrete, transportation, and energy, demonstrates its potential to contribute significantly to global sustainability efforts [7]. Clean hydrogen is increasingly recognized as vital to the decarbonization of Romanian energy systems and regional economic ecosystems. Local initiatives such as

hydrogen-natural gas blending in distribution systems have demonstrated significant potential for reducing greenhouse gas emissions, underscoring the techno-economic feasibility and environmental benefits of these approaches [8].

Romania is making significant strides in integrating green hydrogen into its energy landscape as part of its commitment to sustainable development and climate goals. The Ministry of Energy of Romania has published the first draft of its long-awaited Hydrogen Strategy and Action Plan for 2023-2030, indicating a substantial step towards incorporating hydrogen into the country's energy matrix. This strategy underlines the need for significant investments in hydrogen infrastructure to support the country's transition towards energy sustainability and economic growth through decarbonization [9].

In support of this strategy, Romania has unveiled a state aid scheme aiming to boost investments in green hydrogen production capacities, which are to be powered by solar, hydro, and wind resources. This move is highlighted by the plans for a national auction to fund at least 100MW of green hydrogen production, following the European Commission's approval to provide up to €149m ($152m) in public finance for this initiative. This scheme has encouraged the development of new green hydrogen production facilities, including extensions of existing capacities, with companies and research facilities being able to bid for direct grants of up to €50m per project [10]. A crucial aspect is that the company that stands to gain most from this financial facility is OMV Petrom, one of the largest players in the European hydrocarbon-based fuels sector [11], issue that is consistent with the global trend of Oil&Gas organisations pivoting to sustainable alternatives. Moreover, the Romanian minister of energy has launched a new modernization facility to subsidize green hydrogen projects at the beginning of 2024, which again stimulates the market to pivot to renewable solutions. With Romania being a strong backer of nuclear energy and pushing a common agenda for this resource to be considered sustainable, it is beginning to look like green hydrogen might have another advantage by the form of clean nuclear energy projects subsidized from the Innovation Fund [12]

2.2. Sustainable organizational design in the Hydrogen Economy

The global push towards sustainable consumer behaviour and digital adoption underscores the importance of agile adaptation by organizations. Sustainable practices and green business models are crucial for addressing the challenges of climate change and achieving environmental sustainability. The integration of digital solutions enhances the efficiency of these practices, promoting sustainable consumption and production patterns across different sectors [13]. The organizational environment in Romania is integral to the transition towards sustainable economies. Studies have highlighted major shifts in sustainable consumer behaviour and the agility of retailers in adapting to these changes, emphasizing the importance of green business practices and digital solutions [14]. Furthermore, the role of quality governance in reducing pollution and promoting sustainable development has been identified as crucial, with a focus on renewable energy consumption's impact on pollution levels [15].

Green hydrogen represents a transformative energy solution across various industries and transportation, including agriculture, to significantly reduce emissions and enhance

sustainability within communities[16]. This renewable energy source, produced through water electrolysis using electricity from renewable sources, offers a clean alternative to fossil fuels without generating polluting effects. Its application spans several sectors, demonstrating its versatility and potential in contributing to a sustainable and decarbonized future [17].

The transition to green steel production is a critical step in the global journey towards decarbonization, particularly in heavy industries like ironworks. Green hydrogen, produced through the electrolysis of water using electricity from renewable sources, plays a pivotal role in this transition, serving both as a reductant and as fuel. The steel industry, responsible for a significant share of global CO2 emissions, is under increasing pressure to reduce its carbon footprint. Utilizing green hydrogen as a clean energy source offers a pathway to achieving net-zero emissions in steel production, aligning with environmental goals and regulatory mandates.

One pathway towards decarbonizing the steelmaking process involves enhancing energy efficiency, incorporating low-carbon fuels, capturing carbon emissions, and ultimately, employing clean hydrogen as both a reductant and fuel. Short-term solutions for greener blast furnace processes are being explored, with direct reduced iron (DRI) production combined with carbon capture, utilizing gasified waste or biomass, emerging as a viable mid-term option at some steel mills. The development and scaling of hydrogen production technologies are crucial to this transition, encompassing challenges not only within the steel industry but also in the supply of renewable power and suitable iron ores. Strategic integration and consideration of geographical factors are essential for an effective transition to green steel production [18][19].

Moreover, the application of green hydrogen extends beyond reducing emissions in the steelmaking process. It also plays a role in the broader industrial sector, including oil refining and chemical production, where it can partially or fully decarbonize the production of commodities such as anode copper and pig iron. The chemical industry, for instance, can utilize green hydrogen to decarbonize ammonia production, which is pivotal for fertilizer manufacturing. This demonstrates the versatile role of green hydrogen in achieving industrial decarbonization across various sectors [20]

A cited technical review highlights that green hydrogen could serve as an appropriate substitute for carbon-intensive fuels in cement kilns, presenting a potential for comparatively smooth integration into, or replacement of, process heat systems based on fossil fuels. This shift could contribute significantly to the industry's efforts to lower its carbon footprint and move towards sustainable production practices. The review concludes that the use of hydrogen as a source of process heat in cement manufacturing can present a viable pathway to decarbonize the sector, although challenges related to the scalability, cost, and infrastructure for hydrogen supply need to be addressed [21]

Furthermore, the demand and cost comparison of green hydrogen across various industries in Germany identifies the cement industry as one of the sectors where green hydrogen can play a significant role in decarbonization. The study acknowledges the challenges and the short-term increase in costs associated with transitioning to green hydrogen but emphasizes its potential to contribute to the long-term sustainability of the industry [20].

Academic findings demonstrate that the CO2 avoided costs across multiple test scenarios are significantly lower than the conventional decarbonized cement production process (DCPP) cost. This reduction in cost is attributed to the valorised production of additional products (urea and methanol) from captured CO2, showcasing the economic benefits of integrating green hydrogen into cement manufacturing. Moreover, another scenario that employs the Cu-Cl thermochemical cycle and a partially green electricity grid for hydrogen and oxygen production, emerges as the most favourable, presenting the lowest renewable energy to power (RenE2P) cost and the highest efficiency in CO2 capture, highlighting the practical and financial feasibility of adopting green hydrogen for cement decarbonization.

Findings suggests that green hydrogen can play a pivotal role in reducing the cement industry's carbon footprint while maintaining economic competitiveness, marking a significant step towards sustainable cement production.[22]

In the agriculture and livestock sector, green hydrogen can revolutionize energy consumption patterns, providing a sustainable alternative to traditional fossil fuels. It can support the industrial revolution in agriculture, enhancing access to energy resources, improving energy security, and reducing greenhouse gas (GHG) emissions. The deployment of green hydrogen in this sector is still in its infancy, facing barriers to large-scale adoption. However, with appropriate policies and financial incentives, it can emerge as a profitable technology for the future, contributing to sustainable development goals (SDGs) [23].

Green ammonia production for fertilizers: Green ammonia, synthesized from green hydrogen, stands at the forefront of this revolution. Produced through renewable energy-powered electrochemical and thermal processes, green ammonia presents a viable replacement for fossil fuel-based ammonia commonly used in fertilizers. Its adoption in the fertilizer industry can significantly reduce the carbon footprint of agricultural practices, promoting a shift towards cleaner, renewable sources of essential nutrients[24]. The integration of green ammonia into fertilizers supports the transition to a sustainable energy system, offering new opportunities across the fertilizer, transportation, and energy industries.

Cellulose-based hydrogels for slow-release fertilizers: Another innovative approach is the development of cellulose-based hydrogels that incorporate green hydrogen. These hydrogels can regulate the release of nitrogen fertilizers, offering a slow, sustained release that aligns with the nutrient uptake patterns of crops. This method not only improves the efficiency of fertilizer use but also minimizes nutrient leaching and environmental pollution. The hydrogels exhibit excellent absorbance capacity and durability, highlighting their potential for widespread agricultural applications [25].

In the chemical industry, green hydrogen is pivotal for achieving net-zero emissions. The industry, responsible for a significant portion of CO2 emissions, can benefit from replacing fossil-derived hydrogen in the synthesis of key chemicals like ammonia, hydrogen peroxide, methanol, and aniline with green hydrogen. This substitution can disrupt traditional production methods, paving the way for a low-carbon economy and contributing to the environmental sustainability of the chemical sector [26].

In transportation, hydrogen serves as a clean fuel alternative, capable of being used in fuel-cell electric vehicles (FCEVs) or burnt in internal combustion engines. This transition is vital for reducing GHGs and other harmful emissions, offering a sustainable path forward for the sector. Various countries support the research and development of hydrogen-powered vehicles due to their environmental benefits, showcasing the global recognition of hydrogen's role in achieving a sustainable transportation system[27].

Green hydrogen plays a crucial role in enhancing the sustainability of the fuel industry by reducing the aromatic component of fossil fuels and contributing to the production of synthetic fuels, synthetic natural gases, biogases, and biological fuels. Its application in these areas is pivotal for achieving carbon neutrality and advancing towards a more sustainable and environmentally friendly energy landscape.

Reduction of aromatic components in fossil fuels – green hydrogen's potential in the hydrogenation of vegetable oils demonstrates its capacity to produce high-quality biodiesel and environmentally friendly diesel fuel. This process, which involves compounding green diesel with hydro-treated diesel fuel and incorporating bio-additives, leads to diesel engines' fuel with improved lubricating properties and reduced wear scar diameter. The production of three-component environmentally friendly diesel fuel aligns with standards such as EN 590: 2009, indicating its viability as a substitute for conventional fossil fuels [28]

Synthetic fuels, natural gases, and bio-gases production – green hydrogen can be blended with natural gas/biomethane for transportation in existing gas networks, highlighting its role in emission reduction in hard-to-decarbonize sectors such as transport applications and certain industrial processes. This blend supports the production of synthetic fuels, such as synthetic kerosene in aviation, by reacting carbon dioxide (CO_2) with hydrogen. Furthermore, hydrogen's environmental co-benefits, like the absence of air pollutant emissions when used as fuel, underscore its significance in the transition towards cleaner energy sources. Moreover, blending hydrogen with natural gas/biomethane for transportation in existing gas networks is a transitional strategy from fossil-based to renewable green hydrogen. Such blends, with hydrogen volumes of 5–20%, can be accommodated by most systems without significant infrastructure upgrades or appliance retrofits. This approach is gaining traction in Europe, aimed at decarbonizing natural gas grids, and promoting the European Hydrogen Backbone as a pivotal element in transitioning to renewable energy sources [29]

The generation of green hydrogen through biomass represents an environmentally friendly approach, with techniques aimed at enhancing conversion processes and leveraging Pressure Swing Adsorption (PSA) for cost-effective hydrogen extraction. This method, particularly when using pyrolysis, offers economic benefits due to the potential for valuable by-products. As such, biomass stands out as a promising source for the production of green hydrogen, paving the way for the creation of biogases and bio-based fuels. Additionally, the production of Sustainable Aviation Fuel (SAF) from biomass using methodologies like Fischer-Tropsch synthesis and Hydroprocessed Esters and Fatty Acids (HEFA) plays a pivotal role in the movement toward low-carbon aviation solutions. The introduction and expansion of SAF are pivotal for slashing aviation-related greenhouse gas emissions, aligning with international

efforts such as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to mitigate the environmental impact of aviation. This shift towards the adoption of synthetic hydrocarbon fuels underscores a global commitment to replacing traditional jet fuels with more sustainable options by the end of the century, despite facing hurdles in raw material availability and the evaluation of environmental impacts. [30]

The synthesis of Sustainable Aviation Fuel (SAF) via CO/CO2 hydrogenation presents a promising pathway for reducing carbon emissions in the aviation industry, aligning with goals for renewable energy assimilation. A thermodynamic investigation into the direct or indirect synthesis of SAFs from CO/CO2 hydrogenation has highlighted the temperature-dependent reduction in the reaction driving force for all products, emphasizing the thermodynamic favorability of various hydrocarbon products synthesized. This study reveals a thermodynamic preference for synthesizing SAF with a higher proportion of aromatic compounds, offering insights into potential pathways for optimizing fuel synthesis to improve efficiency. The findings underscore the importance of developing SAF with complex components to meet the standards set by the American Society for Testing and Materials (ASTM) D7566 and suggest a strategic approach to the synthesis process in industrial scenarios [31]

The incorporation of green hydrogen into the production of fuels and additives represents a significant advancement in the pursuit of carbon neutrality and environmental sustainability. By reducing the aromatic component of fossil fuels and facilitating the production of synthetic and bio-based fuels, green hydrogen not only contributes to the decarbonization of the energy sector but also promotes the development of cleaner and more sustainable fuel alternatives.

The integration of renewable-energy-based green hydrogen into the energy landscape supports the transition from fossil fuels to clean energy, optimizing the energy industry system and promoting strategic energy development transformations. This approach enhances energy security and aligns with global efforts to build a low-carbon, efficient, and clean energy structure [32].

District heating systems are pivotal in the transition to decarbonized energy systems, enhancing supply security. Despite the primary focus on electrification for decarbonization, green hydrogen emerges as a vital energy source for peak demand coverage, offering long-term storage in power-to-gas solutions and acting as a backup. The debate between utilizing pure hydrogen and building appropriate infrastructure versus employing hydrogen-derived synthetic gas, for which infrastructure already exists, is central to current research. Existing technological solutions and associated costs for utilizing either hydrogen or synthetic gas demonstrate the feasibility of integrating green hydrogen into district heating systems, offering a cleaner alternative to natural gas [33]

The technical and economic aspects of transitioning natural gas thermal power plants to green hydrogen also demonstrate the feasibility and benefits of such a shift. A case study in Nigeria highlighted the potential for significant CO2 emissions reduction and economic viability, with a return on investment within 4-5 years, emphasizing green hydrogen's role in decarbonizing the energy sector and contributing to global warming mitigation efforts [34].

The integration of green hydrogen technology into the energy framework of data centres represents a forward-looking approach to achieving sustainability in the IT industry. Green hydrogen can serve as a key to unlocking energy efficiency and reducing carbon emissions within these critical infrastructures. Optimizing the operation of microgrids for hydrogen-based heat supply through deep reinforcement learning demonstrates how green hydrogen can provide competitive production costs and act as a natural gas substitute for heating within the industry. This optimization paves the way for data centres to adopt green hydrogen for both electrical and thermal energy needs, significantly contributing to the decarbonization of the IT sector[35]. On the other hand, the role of artificial intelligence, data analytics, and optimization algorithms in advancing green hydrogen technologies for sustainable power supply within data centres emphasizes the synergistic relationship between green energy solutions and technological innovation[36].

As we navigate the complexities and challenges of transitioning towards a more sustainable and environmentally friendly industrial landscape within the European Union, the role of hydrogen as a versatile and clean energy vector under the Green Deal Industrial Plan becomes increasingly significant. With the backing of abundant financial resources and the proactive engagement of numerous companies in exploring its potential, hydrogen is steadily emerging as a pivotal element in the decarbonization of innovative industries. The dynamic nature of this exploration is underscored by the discovery of new uses for hydrogen on a daily basis, each offering a glimpse into a future where energy efficiency, sustainability, and economic growth coalesce. This continuous expansion of hydrogen's applicability not only exemplifies the ingenuity and resilience of European industries in the face of climate change but also reinforces the imperative to foster a collaborative, well-funded, and research-driven approach towards realizing the full spectrum of hydrogen's potential. As such, the exploration of hydrogen utilization in novel industrial sectors represents not only a testament to our current technological advancements but also a commitment to the sustainable development goals that define our collective aspirations for a greener, more resilient Europe.

2.3. Financing sustainable development globally

Financing mechanisms play a critical role in supporting the transition to sustainable development. The analysis of various funding sources, including European funds and green finance, highlights the importance of economic incentives in promoting sustainable practices. The entrepreneurial qualities of founders and the development of sustainable business models are essential for the economic sustainability of green initiatives [37]. The trajectory towards sustainable development has universally recognized the integration of finance with environmental, social, and governance (ESG) principles, placing sustainable finance at the forefront of efforts to foster greener economies. The European Union (EU), spearheading this transformation, has emerged as a paragon of sustainable finance, instituting a broad and strategic framework that serves as a global reference point. The EU’s leadership in this domain is supported by a well-established strategy and policy framework aimed at aligning the financial system with sustainable development goals, creating a more efficient and cohesive green finance market across Europe.

Global Consensus and EU Leadership – available academic research underscores the EU's vanguard position in sustainable finance, attributing it to its early origins, comprehensive

development experience, and a well-structured framework system. This assertion is complemented by the EU Action Plan: Financing Sustainable Development, which is highlighted as a pivotal initiative that stimulated regulatory action towards achieving sustainable development goals, significantly enhancing the efficiency of green finance within the interbank market. The plan's success in unifying European standards for green finance has facilitated an effective convergence among financial institutions [38].

Strategic Direction and Innovative Mechanisms – there is comprehensive research to shed light on the European Commission's 2018 action plan, detailing a strategy for the financial sector to support the transition towards a climate-neutral and inclusive economy [39] [40]. This strategy not only promotes financial stability but also endeavours to mobilize private capital, a crucial component in meeting the substantial investment requirements for sustainable development. Several research papers contribute to this discussion by exploring innovative financing mechanisms, such as sovereign green bonds and modifications to the European Central Bank's collateral framework, showcasing the EU's proactive approach in financing the sustainable development goals agenda [41] [42] [43].

The European Green Deal and Regulatory Framework – the EGD is designed as a roadmap to reduce carbon emissions by 55% by 2030 and achieve carbon neutrality by 2050, with a focus on solidarity, sustainable development, and environmental protection within the EU's constitutional framework [44]. private sector financing is crucial for the EGD, necessitating a regulatory framework to facilitate sustainable investments, with the EU Commission planning to invest EUR 1 trillion into the green transformation over the next decade [45]. EU sustainable finance policies, including the EU Taxonomy, have evolved, and accelerated in response to increasing awareness of the severity of climate and environmental crises, with the EGD being a key policy package [46].

The EGD outlines a plan for a resource-efficient economy, emphasizing the importance of a just and inclusive transition, efficient resource use, and the reduction of biodiversity loss and pollution [47]. Assessments of the EGD's ability to combine environmental, economic, and social objectives highlight the need for a just transition towards sustainable economies and societies, especially in light of the Covid-19 pandemic [48]. Sustainable finance is integral to the EGD, with regulatory tools such as the Taxonomy Regulation, Green Bond Standard, and Sustainable Finance Disclosure Regulation playing a significant role in directing private money towards sustainable investments. The EGD aims to make the EU economy sustainable and competitive by leveraging public funds and reorienting the financial system and private investments towards environmentally positive projects[49] [50].

The EU's sustainable finance framework is well-established, providing guidance and a unified standard for green finance business, influencing global green finance development. Critiques of the EGD include a lack of vision for a just, post-carbon economy, inadequate resources, and limited implementation tools, suggesting the need for broader green industrial policies. The discourse of sustainability within the EGD is questioned for potentially side-lining crucial environmental issues and reinforcing the political power of EU institutions [51] [52] [53].

2.4. Sustainable financing in Romania

The European Union (EU) is undergoing a significant transition towards sustainable finance, underscored by directives such as the Corporate Sustainability Reporting Directive (CSRD). This shift aims to integrate Environmental, Social, and Governance (ESG) considerations into financial decision-making processes, thereby funnelling investments towards sustainable development. Romania, as an EU member state, is part of this transformative movement. Sustainable finance in Romania involves redirecting investments to projects that consider ESG factors, aligning with the European Green Deal and the EU's sustainable finance agenda. The mechanism aims to mobilize private capital towards sustainable investments while ensuring the financial system's resilience to environmental risks. We reference academic findings to discuss the EU Green Deal's impact on sustainable finance, emphasizing the necessity of significant investments across major sectors and the pivotal role of the private sector in financing the green transformation. These insights are crucial for understanding the landscape of sustainable finance in Romania, as they reflect the broader EU policies influencing national financial strategies [54] [55]

The EU's regulatory landscape, including the EU Taxonomy and the Sustainable Finance Disclosure Regulation (SFDR), provides a structured approach to identifying and investing in sustainable economic activities. Well regarded critiques of the EU Sustainable Finance Strategy and its implementation challenges, such as the lack of standardized ESG metrics and inconsistencies in rule application have been documented in specific literature [56] [57]. These challenges are pertinent to Romania's adoption of sustainable finance practices, as they highlight the complexities of aligning financial strategies with sustainability objectives within the existing regulatory frameworks. Sustainable finance is reshaping investment landscapes and corporate strategies by emphasizing ESG considerations. Research includes a critical analysis of the EU Taxonomy, highlighting potential economic downsides and the risk of increased global emissions [58]. Conversely, we have detected articles that underscore the significance of National Development Banks in financing sustainable projects [59]. These discussions are relevant for Romania, showcasing the balance between regulatory expectations and market realities. The integration of sustainable finance into corporate strategies reflects a commitment to sustainability that can drive long-term economic and environmental benefits for the country.

In the context of Romania's transition towards a green and sustainable economy, the role of the EU's Resilience and Recovery Facility (RRF) and the Modernization Fund is paramount, particularly in financing green hydrogen projects. These mechanisms are not only pivotal for Romania but also align with the EU's wider environmental objectives. The RRF, a cornerstone of the NextGenerationEU program, is crafted to cushion the economic and social ramifications of the COVID-19 pandemic, thereby bolstering the resilience of EU economies, and promoting their green and digital transitions. For Romania, this translates into significant funding opportunities for hydrogen technology development, which is essential for decarbonizing industries and energy systems. Authors elaborate on how the RRF is integral in aiding the EU and its Member States to emerge stronger and more resilient from the crisis, highlighting the emphasis on green and digital transitions [60]. Similarly, another set of articles analyse the funding opportunities for Romania

through the National Recovery and Resilience Programme, underscoring the importance of efficient access and implementation of these support forms to enhance sustainable development efforts [61] [62] [63].

Parallelly, the Modernization Fund, aimed at EU member states with a GDP per capita below the EU average, supports investments in energy efficiency, renewable energy, and transitioning from coal. Hydrogen projects, especially those involving green hydrogen produced via electrolysis powered by renewable energy sources, are significantly advantaged by this fund. Financing the development and deployment of hydrogen technologies through the Modernization Fund aids Romania in reducing greenhouse gas emissions, modernizing its energy and industrial sectors, and bolstering energy security. Authors provide insights into the strategic importance of the RRF and the Modernization Fund in supporting the sustainable and resilient development of European economies, with a special focus on facilitating the green and digital transition[64] [65].

These financing mechanisms underscore the EU's commitment to assisting member states in their sustainable development endeavours. For Romania, the RRF and the Modernization Fund are critical in advancing its hydrogen economy, marking a significant stride towards realizing its sustainability and energy transition goals. This strategic emphasis on hydrogen within Romania's sustainable finance landscape signals the nation's potential to emerge as a leader in green hydrogen production and utilization, thereby contributing to the EU's collective efforts to mitigate climate change and transition towards a more sustainable future. The discussions nuanced in two of our academic findings highlight the instrumental role of these EU financial mechanisms in supporting Romania's sustainable development, underscoring the integrated approach towards achieving green and digital transitions in line with the EU's broader environmental goals [60] [61].

In aligning with the discourse on sustainable finance in Romania, the significance of the EU's Resilience and Recovery Facility (RRF) and the Modernization Fund in financing green hydrogen projects deserves emphasis. These financial tools are instrumental in Romania's shift toward a sustainable and green economy, reflecting the EU's broader environmental aspirations. The RRF, integral to the NextGenerationEU program, aims to alleviate the economic and social repercussions of the COVID-19 pandemic by bolstering the resilience of EU economies and promoting their green and digital transitions. For Romania, this represents a significant opportunity for funding the development of hydrogen technologies, a critical factor in decarbonizing industries and energy systems. The Modernization Fund, targeting EU member states with GDP per capita below the EU average, facilitates investments in energy efficiency, renewable energy, and the transition away from coal. Green hydrogen projects, especially those involving electrolysis powered by renewable energy sources, stand to gain substantially from this fund, assisting Romania in reducing greenhouse gas emissions, modernizing its energy and industrial sectors, and improving energy security.

These financing mechanisms underscore the EU's commitment to assisting member states in sustainable development pursuits. For Romania, the RRF and the Modernization Fund are crucial for advancing its hydrogen economy, signifying a major step toward meeting its

sustainability and energy transition goals. This strategic emphasis on hydrogen within Romania's sustainable finance landscape showcases the nation's potential as a leader in green hydrogen production and utilization, contributing to the EU's collective efforts to mitigate climate change and transition to a more sustainable future.

Supporting this narrative, [66] discuss the complexity of transitioning to carbon neutrality by 2050 in the EU, highlighting the need for changing the energy mix and the socioeconomic implications, especially in coal-mining regions like Romania. Their analysis offers scenarios for addressing these challenges, emphasizing the potential benefits of the RRF and the Modernization Fund in supporting a just transition. Similarly, [67] explores the effect of renewable energy consumption in Romania, highlighting the significant role of EU funding mechanisms in increasing renewable energy production and promoting green economic growth. These insights are pivotal for understanding the role of EU financial mechanisms in Romania's transition to a green economy, illustrating the intertwined paths of environmental sustainability and economic modernization.

Another mechanism that has taken shape in various forms throughout the European Union is the Important Projects of Common European Interest (IPCEI) framework, that embodies the European Union's strategic initiative to foster collaboration among EU Member States, supporting large-scale projects that significantly contribute to the EU economy, society, and environmental sustainability. These projects aim to tackle market failures in critical sectors and technologies, facilitating the development and deployment of innovative solutions vital for the EU's strategic objectives such as sustainability, industrial competitiveness, and digital transformation.

In the hydrogen sector, the IPCEI on Hydrogen represents a cornerstone effort under this framework, showcasing the EU's dedication to promoting a clean and innovative hydrogen economy. The “Hy2Use” project and the “HyDeal Ambition” are prime examples of such initiatives within the IPCEI on Hydrogen. They aim to upscale hydrogen production and utilization across various industrial sectors and to deliver green hydrogen throughout Europe at competitive prices via an integrated value chain, respectively. These projects span numerous applications, including hydrogen production through renewable energy sources, and the development of infrastructure for hydrogen storage, transportation, and distribution, as well as the application of hydrogen technologies in industries like steel manufacturing, chemical production, and transportation [17]. The collaboration fostered by IPCEIs on Hydrogen among Member States, companies, and research institutions is crucial for accelerating the EU's transition to a green economy, reducing carbon emissions, and achieving energy independence.

These initiatives are reflective of the EU's strategic approach to utilizing hydrogen as a fundamental element of its energy transition, aiming to establish a sustainable, efficient, and globally competitive hydrogen industry. Supporting the discussion on IPCEIs and their significance in the hydrogen sector, [68] provides an insightful analysis of the German National Hydrogen Strategy and its alignment with the EU's broader objectives, highlighting the importance of IPCEIs in advancing hydrogen goals. Furthermore, [69] describe existing and planned hydrogen production and consumption projects within the EU, emphasizing the pivotal role of low-emission hydrogen in transforming the transport and industrial sectors.

3. PESTLE Analysis of Romania

3.1. Political Analysis of Romania within the European Union

Romania's political landscape, especially in relation to its European Union (EU) membership, is multifaceted, reflecting both achievements and challenges. The nation's EU accession in 2007 was a landmark event, setting the stage for a complex interplay of compliance, governance reforms, and European integration dynamics.

EU Membership and Governance Challenges: Romania's EU membership was a significant milestone, heralding a period of substantial political and legislative transformation. However, this transition was not without its challenges. According to [70], [71], Romania's accession is depicted as a strenuous phase in the EU integration process, requiring intense efforts to align with EU norms, particularly in areas such as corruption, judiciary reform, and rule of law. Despite notable progress, Romania faced hurdles in democratic consolidation and combating political corruption, underscoring the nuanced impact of EU membership on governance practices. This narrative is supported by [72], who critically analyse the impact of EU membership on Bulgaria and Romania, highlighting the nuanced effects on national policies and the rule of law, indicating the complex dynamics of post-accession Europeanization.

The Journey Towards Europeanization: [73] offer insights into the negotiation dynamics preceding Romania's EU accession, emphasizing the country's efforts to meet the Copenhagen criteria. This examination sheds light on the negotiation processes, underscoring the critical role of acceleration and commitment in achieving exceptional outcomes in EU integration. In a similar vein, [74] delves into the compliance with EU law in Romania and Bulgaria, challenging the narrative of failed integration by showcasing Romania's adherence to EU legislation. This perspective highlights the importance of continuous monitoring and institutional support in fostering legal compliance and integration success.

Differentiated Integration and Economic Perspectives: [70] explores Romania's differentiated integration into the EU, evaluating the country's expectations, priorities, and achievements across various stages of EU membership. This analysis reveals a mixed record of progress and challenges, with Romania exhibiting strong support for EU integration despite remaining outside the Schengen area and eurozone. [75] discuss the economic aspects of Romania's EU membership, emphasizing the country's potential for economic growth and the critical role of investments in research and development. This economic perspective underscores the multifaceted benefits and challenges of EU integration, highlighting the importance of innovation and strategic investments in achieving long-term stability and growth.

Governance, Public Affairs, and Lobbying: the intersection of corporate governance, public affairs, and lobbying in Romania presents another layer of complexity in understanding the country's political landscape within the EU context. [76] outline the impact of public affairs and lobbying on corporate governance in Romania, suggesting that these elements are essential for developing sustainable business practices and macroeconomic growth strategies. This analysis highlights the evolving nature of Romania's governance and public policy landscape, emphasizing the need for ethical and effective engagement with democratic institutions and policymaking processes.

Global press impression of Romanian political environment: Romania's political landscape is marked by a coalition government aiming for stability ahead of the 2024 elections, amidst navigating policy differences within the coalition and addressing the need for reforms to unlock further tranches of European Union recovery funds. The coalition, formed by the leftist Social Democrats and the centre-right Liberals along with the ethnic Hungarian UDMR, is steering the country through a series of socio-economic challenges, including energy policies, healthcare reforms, and economic recovery post-pandemic. The Romanian President's move to appoint Marcel Ciolacu as the prime minister under a rotating premiership deal is a step towards ensuring political stability and continuity in governance. This move highlights the coalition's intent to prioritize long-term reforms and policy stability, addressing the complexities of governance while also managing Romania's position within the European Union, especially concerning recovery funds and fiscal policies. On the macro-policy front, Romania faces critical challenges in terms of economic growth, energy independence, and healthcare reforms, which are pivotal for its sustainable development and alignment with EU norms. The government's plans to extend energy support schemes and invest in new power production underline its focus on becoming energy-independent and addressing the inflationary pressures exacerbated by rising energy costs. Additionally, the upcoming electoral cycle with presidential, general, local, and European elections presents a crucial juncture for Romania to navigate its policy directions and political stability. These elections will be instrumental in determining the future course of Romania's domestic and foreign policies, including its commitment to European integration, fiscal discipline, and socio-economic reforms. The emphasis on political stability and continuity in governance reflects a strategic approach to address Romania's pressing challenges while ensuring alignment with broader European objectives, especially in light of the geopolitical developments in Eastern Europe and Romania's strategic position as an EU and NATO member [77], [78], [79].

As a result of synthesizing these insights, it becomes evident that Romania's political landscape, particularly in relation to its EU membership, is characterized by a blend of achievements, ongoing challenges, and strategic efforts towards Europeanization. The country's journey towards EU integration has been marked by significant strides in governance reforms, legal compliance, and economic development, albeit with notable obstacles in fully materializing its EU membership benefits. This nuanced narrative underscores the complexity of Romania's political and economic integration within the European Union, reflecting a broader trend of differentiated integration among member states.

3.2. Economic Growth and Diversification

Romania's economic landscape has experienced significant growth and diversification over the last two decades, contributing to catching up with advanced economies. A study on the economic complexity at the regional level is relevant in findings such that of areas with lower development levels that have been prone on experiencing the most notable shifts in economic complexity [80]. This indicates a broadening of industrial product diversification and an enhancement in the complexity of economic activities, especially in regions that were previously lagging behind.

Labour Market and Emigration: the labour market in Romania is uniquely affected by emigration, with a substantial portion of the workforce seeking opportunities abroad. This dynamic exerts pressure on the domestic labour supply and influences economic development strategies. Romania stands out in the European Union with the highest proportion of its GDP attributed to the agricultural sector, a testament to the sector's potential for significantly enhancing the nation's economic quality. Numerous studies and professional discussions emphasize agriculture's pivotal role, particularly considering Romania's extensive arable lands. This research delves into the distinctive characteristics of Romanian agriculture within the European context, outlining key strategies for rural development aimed at elevating work efficiency in this vital sector, illustrating the country's ongoing transition from an agriculture-based economy to one focused on services and industry, despite the decreasing contribution of agriculture to GDP [80], [81].

EU Structural and Investment Funds: EU funds play a crucial role in Romania's development, especially in addressing infrastructural gaps and fostering regional development. [82] examine the impact of foreign direct investment and other factors on economic growth, suggesting that the influx of foreign direct investment and the importation of goods and services are negatively influencing economic expansion in Romania. This complex relationship underscores the importance of strategic investment and the utilization of EU funds to stimulate sustainable economic growth and development.

Infrastructure and Development Challenges: despite economic growth, Romania faces challenges in infrastructure development, which is crucial for enhancing competitiveness and regional connectivity. Studies focusing on infrastructure investment and its impact on economic growth would provide insights into the specific areas where Romania needs to improve to sustain its economic development trajectory.

[83] highlight the evolution of road transport infrastructure in Romania and its economic implications, supporting the theory that the state of Romania's road infrastructure plays a crucial role in the economic growth of the nation and its capacity to engage in international commerce. Several authors have highlighted the importance of aligning Romania's essential infrastructures with European Union standards, pointing out the critical need to enhance and bolster the resilience of Romanian Critical Infrastructures for economic progression. This aligns with discussions on the strategic investments required in the national motorway network to foster economic growth [84]. The authors propose methodological improvements for assessing the criticality of infrastructures, particularly in the energy sector. Infrastructure research continues to assess the distribution and availability of urban blue infrastructure in Romanian cities, stressing the scarcity of blue infrastructure [85]. Their study suggests enhancing the multi-functionality of blue infrastructure to provide socio-ecological and economic benefits.
Large cities, and even the state capital, are confronted with urban challenges, as research finds and explores the role of spatial planning in addressing Bucharest's urban challenges. [86] argue that “innovative urban planning” is essential for transforming Bucharest into a more competitive and liveable European capital while [87] propose a digital tool for generating tailored solutions to promote sustainable development in rural areas of Romania. They identify depopulation as a key issue, suggesting that government support is crucial for implementing effective solutions.

Competitiveness and Innovation: the push towards competitiveness and innovation is vital for Romania's long-term economic resilience. Research exploring the role of education, innovation, and digital infrastructure in driving economic competitiveness would offer a comprehensive view of the strategies Romania needs to adopt to secure its position in the global economy. For Romania to secure its place in the global economy, a strategic focus on competitiveness and innovation is vital. Addressing infrastructure challenges is part of this strategy, alongside fostering a culture of innovation and technological advancement.

[88]discuss the dual nature of entrepreneurship in Romania as both an opportunity and a challenge. They underscore that Romania is positioned at the bottom among European Union countries in entrepreneurial development, stressing the necessity to diminish bureaucratic hurdles and enhance financing accessibility.[89] conduct a review on the green economy in Romania, identifying "incomplete legislation" as a major barrier to transitioning towards a green economy. This study underscores the potential for Romania to leverage its resources and EU incentives for green development. [90] investigate Romanian residents' attitudes towards transitioning to renewable energy sources. They identify dissatisfaction and slowdown in the adoption process, recommending "immediate strategic measures" for accelerating the transition. [91] assess the potential of artificial intelligence (AI) in Romania's healthcare system, noting significant promise but also "several ethical and logistical challenges". The study calls for responsible AI implementation strategies. [92] highlight the environmental impacts of infrastructure projects on wildlife in Romania. They suggest measures to mitigate negative effects, such as roadkill, due to infrastructure development.

Romania's economy demonstrated resilience in the face of global challenges, achieving a growth rate of 1.8% in 2023, despite a slowdown from the previous year's 4.7%. This deceleration reflects the impacts of high inflation and subdued private credit growth which, in tandem with weak external demand, constrained domestic consumption. However, this was partially offset by substantial EU-funded investments in public infrastructure, which contributed to gross fixed capital formation. The European Commission's economic forecast anticipates a rebound, with GDP growth expected to increase to 2.9% in 2024 and further to 3.2% by 2025. This recovery is supported by an improvement in real disposable incomes, fuelled by a resilient labour market and minimum wage increases. Moreover, inflation is projected to decelerate from 9.7% in 2023 to 5.8% in 2024, and further to 3.6% in 2025, reflecting easing monetary conditions and declining energy and food prices. Romania's economic advancement is closely tied to its vibrant private sector, particularly in the renewable energy, transportation, and finance sectors, as highlighted in a World Bank report. The country's burgeoning IT sector is a testament to its potential for services sector growth, which could be further amplified by enhancing digital skills. This emphasis on the private sector is crucial for bridging Romania's living standards gap with the EU and addressing regional and social disparities. Additionally, Romania's effective utilization of EU funds has been a cornerstone of its economic strategy, having already drawn down over €6 billion in grants and loans, with ambitions to tap more than €10 billion annually until 2027. This strategic use of funds, coupled with advancements in justice reforms, positions Romania as a potential model of good governance within the region [93],[94],[95].

By integrating these aspects into the economic section of a literature review, one can offer a nuanced understanding of Romania's economic situation, underpinned by recent academic findings. This approach provides a solid foundation for further research and policy formulation aimed at fostering economic growth and sustainable development in Romania.

3.3. Social Analysis of Romania: Demographics, Urban-Rural Divide, and Implications

Romania has been experiencing significant positive social developments, reflecting resilience and progress across various sectors. This literature review synthesizes recent academic findings to provide an optimistic outlook on Romania's economic, social, and entrepreneurial landscape. [96] highlights Romania's tailored models and strategies for rural development and agriculture, aligned with European Union standards, showcasing a commitment to sustainable growth. The adoption of corporate social responsibility (CSR) practices, as detailed by [97], has become a transformative force within the Romanian business environment, contributing to economic growth and job creation. [98] offers a comprehensive analysis of Romania's evolution, emphasizing improvements in public health and the medical system, showcasing robust responses to global challenges like the COVID-19 pandemic. [99] discuss entrepreneurship as a key driver for economic and social development, acknowledging the vibrant entrepreneurial ecosystem in Romania. [100] investigate the relationship between internal migration and economic growth, highlighting the positive impacts of migration on regional economies. This underscores the importance of adaptive public policies for sustainable development and economic prosperity.

The rural demographic resilience and territorial evolution in Romania reveal a multifaceted picture of depopulation, adaptation to transitions, and socioeconomic impacts on access to basic services. [101] offer an extensive analysis over a century, highlighting the dynamic and fragile areas that require targeted public policies for sustainable spatial planning and environmental management. [102] explores the social consequences of population ageing in rural Romania, emphasizing regional disparities and the urgency to address rural depopulation. The study calls for solutions to mitigate the socioeconomic repercussions of this phenomenon, particularly in rural areas heavily impacted by these demographic shifts. Lastly, [103] provides a broad perspective on the socio-demographic trends in Romania, highlighting the significant role of migration in shaping the population landscape. The transition to EU integration has introduced complex dynamics in international migration, with economic reasons largely driving the current trends. This analysis underscores the evolving nature of migration and its implications for Romania's demographic future.

3.4. Technological Advancements in Romania

The IT sector in Romania has seen remarkable growth, becoming a significant contributor to the country’s GDP. [104] highlights the industry's doubling in value from 2015 to 2022, underscoring the sector's role in economic development and innovation. The concentration of IT businesses in urban centres, particularly Bucharest, has fostered a dynamic ecosystem for technological advancement. Financing mechanisms, such as the Bucharest Stock Exchange, offer vital support for small and medium enterprises (SMEs) in the IT sector. [105] examine these opportunities, highlighting the importance of accessible financing for innovation and growth, particularly in the face of economic uncertainties.

Digitalization's impact on economic growth is further explored by [106], who finds positive effects from digital adoption and patenting activities. This research suggests that focused digitalization strategies can enhance Romania's economic resilience and. The Covid-19 pandemic accelerated the e-market's growth, as documented by [107]. Their analysis of the Romanian e-market's expansion during this period offers insights into the digital transformation's acceleration under crisis. Lastly, [108] address the implementation challenges of ICT solutions in customer service management. Their findings underscore the critical role of ICT in enhancing service efficiency and the need for continued investment in digital infrastructure and education.

The remarkable expansion of Romania's IT industry, with its value doubling from 4.6 billion euros in 2015 to over 9 billion euros in 2022, underscores the sector's pivotal role in economic development and innovation. This growth has made a substantial impact on Romania's GDP, accounting for 7%, with a notable concentration of IT businesses in urban centres like Bucharest [104]. This geographical clustering has fostered a dynamic ecosystem for technological advancement and innovation, positioning Romania as a significant player in the global IT landscape.

The availability of financing opportunities for small and medium enterprises (SMEs) in the IT sector through the Bucharest Stock Exchange is crucial for fostering growth and innovation, especially in the context of economic uncertainties and post-Covid challenges [105]. These financing avenues are instrumental in enabling SMEs to navigate the economic landscape and invest in innovative strategies, thereby contributing to the dynamism of Romania's market. Digitalization and patenting activities have been identified as key drivers of economic growth, modernization, and diversification in Romania [106]. The positive influence of these factors on the economy suggests that strategic digitalization efforts can enhance Romania's economic resilience and competitiveness on the global stage.

The Covid-19 pandemic has accelerated the growth of Romania's e-market, reflecting the broader digital transformation of the economy. This expansion highlights the potential of digital retailing and underscores the importance of adapting to digital trends to sustain economic growth [107]. The implementation of Information and Communication Technology (ICT) solutions, particularly in customer service management, faces various challenges. Despite these obstacles, the ICT industry's significance in Romania's economy is undeniable, representing approximately 5.5% of the country's GDP in 2019. The study underscores the critical role of digitization and automation in enhancing service efficiency [108] [109] explore Romania's digital divide, emphasizing the need to identify and manage deeper determinants of digital literacy to make Romania fit for the digital age. Their analysis suggests that addressing foundational competencies and basic skills is essential for improving DESI performance and closing the digital gap.

Technological Developments in Hydrogen Energy in Romania: Romania's commitment to transitioning towards a sustainable and modern energy sector is increasingly focused on harnessing hydrogen technology. This literature review explores recent technological advancements in hydrogen energy within Romania, emphasizing its significance in the broader context of energy transition and sustainability.

Hydrogen and Natural Gas Blending: [8] conducted a techno-economic study on blending hydrogen with natural gas in Romania's distribution networks, particularly in Bucharest. They investigated the implications of injecting 5%, 10%, and 20% hydrogen into the natural gas system, focusing on energy efficiency, economic viability, and environmental benefits. This approach is pivotal for decarbonization efforts, showcasing a significant stride towards reducing greenhouse gas emissions while ensuring energy resilience. Hydrogen blending with natural gas is being explored as a means to improve system performance and reduce greenhouse gas emissions. A study has shown that blending hydrogen with natural gas can increase combustion energy and exergy efficiencies significantly, with improvements observed from 84.8% to 94.8% and 62.5% to 70.2%, respectively, when hydrogen addition ranges from 0 to 20%. Similarly, ammonia-natural gas blends have also been investigated, showing increases in efficiencies [110].

Hydrogen's Economic and Environmental Impact: [111] highlights the essential role of hydrogen in achieving the European Union's climate neutrality goals by 2050. The paper discusses the hydrogen market's evolution amid the Covid-19 pandemic and the European Commission's Hydrogen Strategy for a climate-neutral Europe. It emphasizes green hydrogen's potential to lower energy costs and reduce dependency on fossil fuel imports, underlining Romania's renewable energy capacity to significantly contribute to hydrogen production. Fuel Cell Technologies: [112] review the progress in hydrogen fuel cell technologies, particularly proton-exchange membrane fuel cells (PEMFCs), suitable for automotive applications. This comprehensive analysis spans key components, thermal and water management, and infrastructure development for hydrogen generation, storage, and transportation. The review underscores the global and national strategies toward adopting hydrogen as a crucial energy carrier, marking a step forward in Romania's energy transition journey.

Green Hydrogen Production Analysis: [113] delve into green hydrogen production, addressing technological and economic aspects. The study evaluates various electrolysis methods, with a focus on solid oxide electrolyser cells (SOEC) for their economic viability. It discusses production costs, including storage, compression, and distribution challenges, and presents achievements in the EU and Romania, offering insights into future perspectives for the hydrogen industry.

Hydrogen for a Cleaner Future: [114] assess hydrogen fuel and fuel cell technology's role in promoting a cleaner future. This review emphasizes hydrogen's zero-emission profile and its application in transport, distributed heating, and energy storage systems. It addresses the transition from fossil-based fuels to hydrogen, highlighting the scientific and socio-economic barriers that need to be overcome.

3.5 Legal Analysis: Romania's Legislative Landscape for Sustainable Development

Romania's approach to hydrogen and renewable energies aligns with its commitment to environmental protection and the transition to non-polluting technologies. A notable advancement is the exploration of hydrogen-natural gas blending in distribution systems. [8] conducted a techno-economic study simulating annual consumptions for hydrogen production capacities to be used in mixtures with natural gas. This method, considered one of the most significant changes toward decarbonization, indicates the legal and economic readiness of Romania to adopt innovative energy solutions. Furthermore, [115] explore the

societal benefits convincing households to support renewable energy development, identifying job creation, increased national energy independence, and pollution reduction as key motivators. This study underscores the necessity for supportive legal frameworks to foster public backing for renewable energy initiatives.

Environmental Affairs: [111] addresses the hydrogen market's potential to support the EU's climate neutrality goal by 2050, emphasizing green hydrogen's role in reducing energy costs and fostering a green economy. This highlights the legal framework's adaptation to accommodate renewable energy sources and reduce dependency on imported fossil fuels. [116] provide an analysis of Romania's energy sector using the autoregressive distributed lag model (ARDL), revealing long-term and short-term impacts of renewable energy on economic growth. Their findings advocate for legal measures promoting renewable energy adoption and transitioning to a low-carbon economy. [117] offer a comprehensive overview of the Romanian renewable energy market, emphasizing the critical role of policy and regulatory landscapes in attracting investments and facilitating project diversification. This underscores the importance of stable and supportive legislation for the growth of renewable energy sources.

ESG and CSRD Considerations: [118] delve into the Corporate Sustainability Reporting Directive (CSRD), highlighting its role in transitioning towards a sustainable environment. The CSRD, set to replace the Non-Financial Reporting Directive (NFRD), expands the scope of companies subjected to sustainability reporting requirements. This legislative shift aims to encompass a broader array of companies within the sustainability reporting framework, thereby enhancing the green transition. The authors note that the CSRD is set to have a substantial effect on financial reporting, mandating that companies on the Bucharest Stock Exchange comply with new reporting standards.

[119] study on Regulation (EU) 2019/452 outlines the establishment of a framework for screening foreign direct investments (FDI) into the EU, touching upon Romania's preparation to adopt national legislation in line with this regulation. This movement signals Romania's efforts to ensure FDI aligns with the EU's sustainability goals. [120] evaluates the CSR reporting practices of Romanian companies, revealing a trend towards improved sustainability reporting. The research indicates a preference for the GRI framework and ISO 26000 standard, which align with the EU’s sustainability reporting requirements. Romania's commitment to GRI and ISO 26000 standards in CSR reporting showcases its conformity with global sustainability reporting guidelines, promoting a corporate environment that is more transparent and accountable [120].

A critical examination of the EU's ESG regulatory framework, juxtaposed against global standards such as GRI, SASB, and TCFD, underlines the intricacy of the EU's approach to ESG reporting and its capacity to pioneer global sustainability practices. Despite its complexity, the EU's ESG framework is poised to establish a worldwide standard for sustainability reporting, shaping how global companies engage in ESG disclosure. [121]

Incorporating the latest legislative developments: Romania has taken a significant step forward in integrating hydrogen energy into its industry and transport sectors with the recent adoption of the Hydrogen Law. The Hydrogen Law focuses on enhancing Romania's

energy production capacity and strengthening its energy security. It mandates fuel suppliers to include a minimum percentage of hydrogen from renewable sources in their fuel mixes used in Romania, setting explicit targets that escalate towards 2030. By 2030, fuel suppliers are required to ensure that the energy value from non-biological renewable fuels supplied for the transport sector equals at least 5% of the total energy content of all fuels supplied for consumption or market use within the country. Furthermore, the law establishes progressive targets for the inclusion of non-biological renewable fuels and electricity from renewable sources for electro-mobility in the transport sector from 2024 to 2029, starting with 0% in 2024 and increasing incrementally to 4.5% by 2029. Non-compliance with these targets will result in fines, calculated by multiplying each megajoule (MJ) of shortfall by a government-established minimum value [122].

Romania's Ministry of Energy has published a draft Hydrogen Strategy and Action Plan for 2023-2030, marking a significant commitment to developing a hydrogen economy as part of its decarbonization goals under the National Resilience and Recovery Plan with the EU. The strategy, open for public consultation until 20 June 2023, aims to establish comprehensive hydrogen infrastructure, embracing both renewable and low-carbon hydrogen to achieve ambitious production and usage targets by 2030 [9]. The Hydrogen Strategy is set to be delivered in 2024 by the Price Waterhouse Cooper's – Horvath consortium. The European Commission has just approved a €3 billion support scheme for solar and onshore wind projects in Romania. This funding aims to increase Romania's renewable energy production and reduce carbon emissions, aligning with the EU's green transition goals. The scheme is part of Romania's efforts to boost its energy independence and sustainability and will have direct results in PPAs for electrolysers and green hydrogen production [123]. The minister of energy continues to finance the overhaul of the Romanian energy system and is now utilizing EUR 640 million from the Modernization Fund to enhance its power grid, as announced by the Ministry. This financial injection will support 21 projects aimed at expanding and modernizing the country's electricity distribution infrastructure. The initiative represents a significant step towards improving energy efficiency and reliability in Romania[124].

3.6 Environmental Analysis of Romania

Romania's environmental strategy reflects a comprehensive approach towards sustainability, tackling various sectors from circular economy initiatives to renewable energy adoption. This literature review synthesizes findings from recent research, offering insights into Romania's environmental management and sustainability efforts.

Transitioning from Linear to Circular Economy: the shift from a linear to a circular economy is essential for mitigating environmental degradation in Romania, especially in its eastern regions plagued by pollution and resource misuse. Research by [125] emphasizes the adoption of circular economy practices as crucial for preserving material and water resources. They propose sustainable alternatives that include the reuse of solid waste, wastewater treatment, and the promotion of organic agriculture, alongside a transition to renewable energy sources. These strategies are particularly aimed at combating environmental challenges like those observed in the Pungesti shale gas incident, showcasing the need for a holistic approach to sustainability.

Climate Change Mitigation through Fiscal Policies: Romania's commitment to climate change mitigation is evident through its implementation of fiscal measures and government expenditures dedicated to environmental protection. [126] have identified a significant impact of these measures on reducing greenhouse gas emissions in the long run, illustrating the effectiveness of government spending and green taxes in fostering a sustainable economic development. This alignment with the European Union's objectives underscores Romania's efforts to balance economic growth with environmental conservation.

Challenges in Real Estate Sustainability: The real estate sector in Romania faces hurdles in adopting sustainable practices. According to [127], despite Romania's commitment to EU environmental policies since its accession in 2007, the implementation of sustainable conditions in real estate development has been slow. The lack of interest from both private and public sectors in using low-carbon materials and addressing issues like illegal deforestation and waste management inefficiencies highlights significant areas for improvement in achieving sustainability goals.

Regional Variations in Environmental Protection: Environmental protection perceptions and actions exhibit notable regional differences within Romania. [128] point out that regions like West and Bucharest-Ilfov show a higher concern towards environmental protection compared to others. This variation underscores the necessity for region-specific strategies that address local environmental challenges and leverage unique strengths, ensuring a more targeted and effective approach to sustainability.

Renewable Energy as a Path to Sustainability: The renewable energy sector is pivotal for Romania's sustainable development and carbon neutrality goals. [129] highlight Romania's progress in integrating renewable energy into its power system, stressing the need for continued policy support and infrastructure development. The focus on diversifying the energy mix through renewable sources not only addresses climate change challenges but also positions Romania as a key player in the global shift towards a sustainable and energy-efficient future.

GPP – Green Public Procurement: Within the environmental analysis of Romania, green public procurement (GPP) emerges as a crucial tool for steering the nation towards sustainable development, albeit with challenges in implementation and adoption. [130] identifies a critical gap in the utilization of GPP criteria among Romanian contracting authorities, pinpointing the absence of mandatory GPP requirements and targets as a significant impediment to leveraging GPP for environmental goals. This is corroborated by [131], who advocate for integrating innovative solutions like aquaponics into Romania's GPP network to enhance sustainability in agriculture and aquaculture. Consumer attitudes towards green products, as analysed by [132], further underscore the necessity for heightened awareness and education to bolster GPP and sustainability initiatives. [133] discuss the role of green innovation within Romanian mobile commerce companies, emphasizing the importance of green training and supplier development in promoting sustainable business practices. Additionally, [125] review the transition towards a green economy in Romania, highlighting the challenges posed by barriers and legislation gaps while recognizing the potential for growth in the green economy sector through EU incentives. Together, these studies underscore the critical role and challenges of GPP in Romania's

environmental strategy, emphasizing the need for strategic approaches, enhanced consumer education, and legislative support to advance sustainable development goals.

4. Methodology

Building on the foundational work of the qualitative study on hydrogen valleys, the future efforts aim to construct a detailed landscape of sustainable ecosystems underpinned by green energy sources. These ecosystems are envisioned to encompass a wide array of industries, ranging from green steel manufacturing to sustainable agriculture, connected through a seamless flow of clean energy, primarily hydrogen. This envisages a transformative shift towards sustainability, where the origins of products and services are authenticated through guarantees of origin, ensuring a verifiable pathway of sustainability from the ground up. Such a framework not only promises environmental benefits but also heralds economic growth grounded in sustainability principles, offering a competitive edge in the global market through clean, certified products and services.

The methodology for the current part of the study involves a comprehensive mapping and analysis of organizations that can pivot towards sustainable methods by incorporating hydrogen into their operations. This includes:

4.1. Identification and Categorization: Listing all relevant economic agents in the region of interest, categorized by their industry sector (e.g., energy, manufacturing, agriculture). This involves a meticulous examination of existing databases, industry reports, and sustainability disclosures to capture a broad spectrum of organizations.

4.2. Geographical Mapping: Placing these organizations on a geographical map, preferably using a tool like Google Earth, to visualize their distribution, proximity to hydrogen production facilities, and potential for forming sustainable clusters. This dynamic map will serve as a living document, constantly updated with new data, collaborations, and developments in hydrogen infrastructure.

4.3. Infrastructure and Logistics Analysis: Evaluating the existing infrastructure and logistics capabilities in the identified geographical regions to assess their readiness for adopting hydrogen-based operations. This involves an analysis of renewable energy sources availability (for green hydrogen production), existing hydrogen production facilities, transportation logistics, and storage capacities.

4.4. Stakeholder Engagement and Data Collection: Engaging with these organizations through a structured questionnaire to gather insights on their current energy use, sustainability practices, interest, and readiness for integrating hydrogen into their operations. This step aims to identify potential early adopters and partners for pilot projects.

4.5. Value Chain and Ecosystem Development: Analysing the potential links between different organizations' products or services and the input of others, to form hypothetical sustainable ecosystems. For example, linking renewable energy producers with hydrogen producers, who in turn supply to industries like steel manufacturing or agriculture, creating a closed-loop system of clean energy use.

4.6. Sustainability Assessment and Reporting: Developing a framework for continuously assessing the sustainability impact of these ecosystems, including the reduction in carbon emissions, energy efficiency improvements, and socio-economic benefits to the communities. This will involve setting up a PowerBI platform to integrate and visualize the data collected, including non-financial reporting by organizations, to track progress towards sustainability goals.

4.7. Collaboration and Policy Recommendations: Based on the analysis, recommending potential collaborations between organizations, and suggesting policy interventions needed to support the development of these sustainable ecosystems. This could include incentives for green hydrogen production, subsidies for organizations transitioning to hydrogen use, and regulations for certifying the sustainability of products and services.

The overarching goal of this methodology is to create a detailed blueprint for building sustainable ecosystems powered by hydrogen, aligning with the global objectives of the Paris Agreement and the European Green Deal. By fostering cross-sectoral collaborations and leveraging existing infrastructure and resources, this approach aims to catalyse the transition towards a sustainable economy with hydrogen at its core.
In concluding, it's paramount to acknowledge the inherent limitations within the current study's scope, primarily confined to establishing the foundational framework through points 1 to 5. This encapsulation allows for a detailed exploration of organizations' pivot potential towards hydrogen utilization and the initial sketching of sustainable ecosystems on a geographical map, alongside infrastructure and stakeholder readiness assessments.

However, the intricacies of fully developing and optimizing these ecosystems, including a thorough sustainability impact assessment, active policy advocacy, and the formulation of an interactive, multi-dimensional inventory of these ecosystems, are beyond this study's immediate reach. These aspects are designated for a subsequent study, which aims to build upon the groundwork laid here by incorporating a more nuanced, interactive approach. This forthcoming endeavour will engage more deeply with the dynamic interactions within the ecosystems, refine the sustainability assessments with real-world data, and evolve the PowerBI platform into a living, interactive inventory. Such progression acknowledges the complex, iterative nature of transitioning towards a fully sustainable economy, underscoring the study's phased, building-block approach to achieving long-term environmental, economic, and social sustainability goals.

4.8. Model Construction

Our research model is a bottom-up approach started from the final draft of the National Hydrogen Strategy and Action Plan, public legal proposal drafted by consultants and affiliated NGOs for the Romanian Ministry of Energy. The document covers a broad and ambitious set of goals and objectives for the development and implementation of hydrogen technology in Romania. The strategy draft outlines specific targets for hydrogen production, usage, and infrastructure development, aiming to significantly reduce CO2 emissions and facilitate the transition towards a cleaner, more sustainable energy sector by 2030 and beyond. Our consideration is that the strategy draft is a top-down analysis that is

concentrated on the needs of the state and regulators rather than the needs of market players, revealing several limitations, including but not limited to:

a) **Top-Down Approach:** The strategy primarily addresses the roles of state regulators and governing bodies, focusing on setting national targets and frameworks. While necessary, this approach may overlook the importance of grassroots initiatives and the innovation potential at the market and community levels. Engaging with and stimulating the bottom-up innovation from industries, research institutions, and local communities and businesses could uncover practical challenges and innovative solutions that a purely top-down strategy might miss.
b) **Market and Industry Needs Analysis:** There's an implicit acknowledgment of the need for infrastructure development and legislative frameworks to support the hydrogen economy. However, the strategy might not sufficiently emphasize the importance of in-depth market analysis, including the specific needs of active market players like steel mills, fertilizer plants, and petrochemical plants. A comprehensive understanding of these needs is crucial for developing targeted action plans that address the practical aspects of transitioning to hydrogen-based solutions.
c) **Economic Viability and Cost Considerations:** While the strategy includes cost estimations and potential financing sources, the economic viability of transitioning to a hydrogen-based economy is a significant challenge. The strategy might benefit from a more detailed analysis of the economic impacts on different sectors, including the competitiveness of hydrogen solutions compared to existing energy sources. This also involves considering the readiness of various industries to adopt hydrogen technology and the impact on jobs and local economies.
d) **Technological Maturity and Innovation:** The document outlines objectives for the development and implementation of hydrogen technologies. However, the rapid pace of technological innovation in this field means that strategies must remain flexible and adaptable to incorporate new advancements. There's a need for continuous evaluation of the technological landscape to ensure the strategy remains relevant and leverages the latest breakthroughs for efficient and cost-effective hydrogen production and usage.
e) **Stakeholder Engagement and Collaboration**: Effective implementation of the hydrogen strategy requires collaboration across a wide range of stakeholders, including government bodies, industry, academia, and civil society. The strategy could place more emphasis on mechanisms for stakeholder engagement, ensuring that all relevant parties are involved in the decision-making process and that their insights and concerns are adequately addressed.

An assessment of the strategy draft clearly delineates issues left unsolved for market players that have manifested interest in joining the hydrogen economy. This study and the proposed future evolutions of this study plan on addressing these limitations. An academic approach with mixed qualitative and quantitative data manipulation is to incorporate more dynamic, iterative processes for stakeholder engagement, market analysis, and technological assessment. This research effort and the proposed updates to this document

are to result in a strategy that remains responsive to the needs of the market and the latest technological developments, ultimately contributing to its success and sustainability.

5. Results and Discussion

The analysis takes shape by developing a visual inventory of the required components for sustainable ecosystems and hydrogen valleys. We have sketched the effort on Google Earth, taking into consideration the following information deemed crucial for sustainable value chains:

5.1. Geographical Overview

Sub-sections for Major Regions:

- Romania is sectioned by the Carpathian Mountains and infrastructure is still to be built to properly connect all ecosystems amongst each other, resulting in peak operational efficiency and minimum carbon emissions resulted from logistics.
- Climate and natural resources have a direct influence in the production of hydrogen, starting from the possibility of installing new renewable energy resources based on the regional climate and spanning to the availability of water for the electrolysis processes.
- Infrastructure and logistics capabilities are considered for hydrogen transportation to consumers, which is a complex and sensitive issue, and for the expansion of the sustainable ecosystem to encapsulate all economic activity on extended value chains.

5.2. Renewable Energy Potential

Solar Energy:

- Regions with high solar irradiance;
- Current solar projects and future potential;
- Grid connection permits and status.

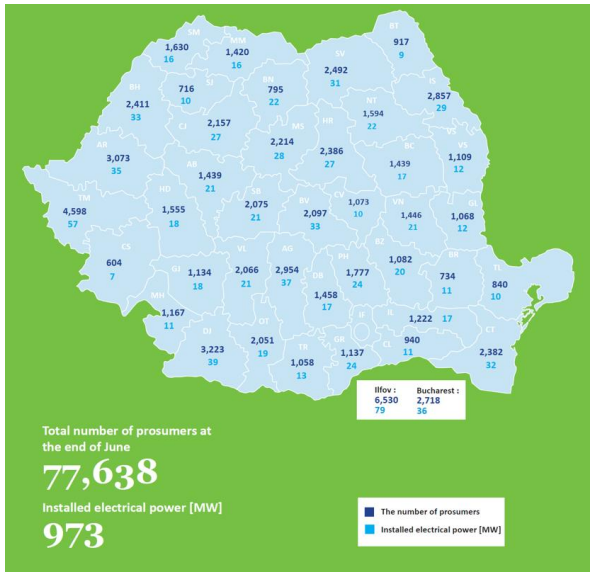
Wind Energy:

- Wind patterns and optimal locations for wind farms;
- Status of wind energy development;
- Grid connection permits and status.

At the time of elaborating this study, the market is highly restrictive and reactive against sharing information that reveals strategic development plans, investments, approved projects, or grid permitting status. The secrecy behind projects that otherwise would have been an efficient opportunity for CSR campaigns on behalf of investment consortiums has reasoning in the highly flawed and speculative nature of the grid connection permitting system in Romania, allowing malicious agents to reserve the entire bandwidth in a region where goodwill agents manifest intentions to invest.

We can, at the moment, obtain data about implemented projects that are operational and provide power to the grid, with prosumers passing the 1TW threshold, as visible in Fig.1 (a), and 4.5TW from solar and wind, as visible in Fig. 1 (b).

a.



b.

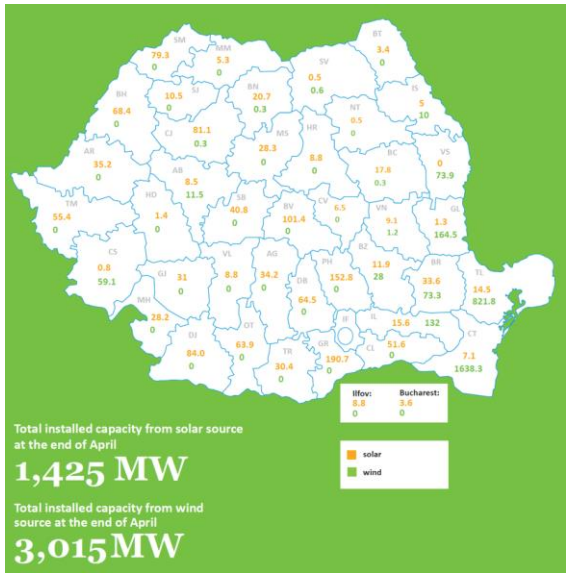
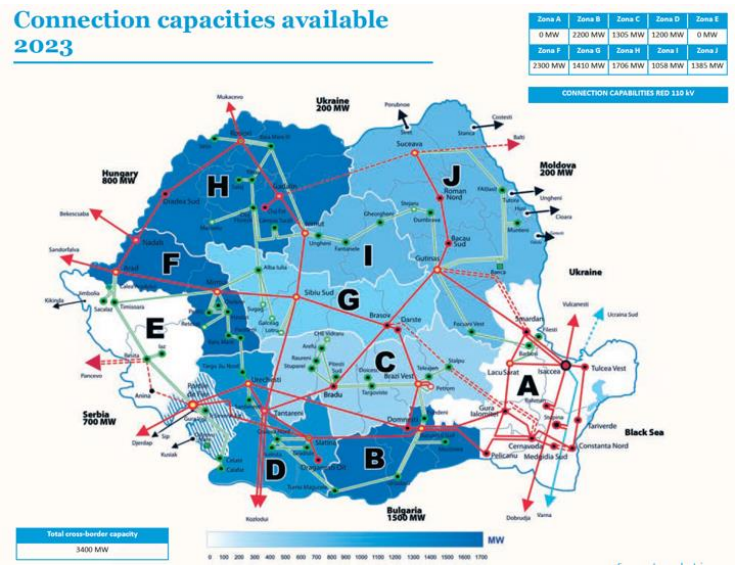


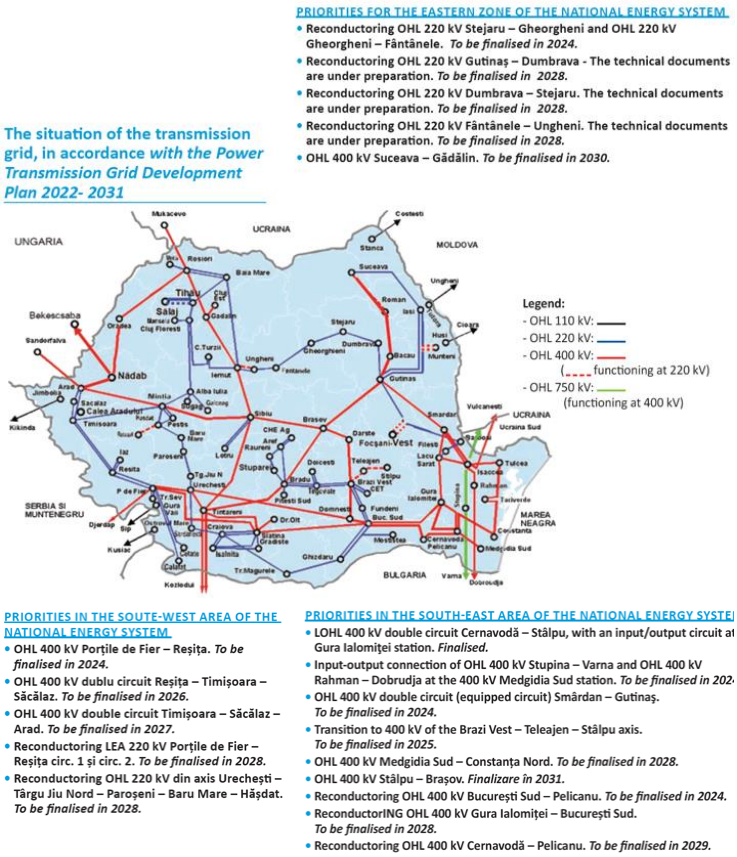
Fig. 1. (a) Map of Prosumers (Jun 2023); (b) Map of wind and Solar installed capacities (Apr 2023)
Source: Code of Good Practice for Renewable Energy in Romania 2023 – RWEA

However this practice is curbed by the introduction of new legislation, to come into effect in 2024, that requires a percentual investment guarantee escrow to be made available before the grid connection permit is issued. This is partially due to a cautious investment strategy on behalf of state infrastructure administrator (Transelectrica), as visible in Fig. 2.

a.



b.



PRIORITIES FOR THE EASTERN ZONE OF THE NATIONAL ENERGY SYSTEM

- Reconductoring OHL 220 kV Stejaru – Gheorgheni and OHL 220 kV Gheorgheni – Fântânele. *To be finalised in 2024.*
- Reconductoring OHL 220 kV Gutinaș – Dumbrava - The technical documents are under preparation. *To be finalised in 2028.*
- Reconductoring OHL 220 kV Dumbrava – Stejaru. The technical documents are under preparation. *To be finalised in 2028.*
- Reconductoring OHL 220 kV Fântânele – Ungheni. The technical documents are under preparation. *To be finalised in 2028.*
- OHL 400 kV Suceava – Gădălin. *To be finalised in 2030.*

PRIORITIES IN THE SOUTE-WEST AREA OF THE NATIONAL ENERGY SYSTEM

- OHL 400 kV Porțile de Fier – Reșița. *To be finalised in 2024.*
- OHL 400 kV dublu circuit Reșița – Timișoara – Săcălaz. *To be finalised in 2026.*
- OHL 400 kV double circuit Timișoara – Săcălaz – Arad. *To be finalised in 2027.*
- Reconductoring LEA 220 kV Porțile de Fier – Reșița circ. 1 și circ. 2. *To be finalised in 2028.*
- Reconductoring OHL 220 kV din axis Urechești – Târgu Jiu Nord – Paroșeni – Baru Mare – Hășdat. *To be finalised in 2028.*

PRIORITIES IN THE SOUTH-EAST AREA OF THE NATIONAL ENERGY SYSTE

- LOHL 400 kV double circuit Cernavodă – Stâlpu, with an input/output circuit at Gura Ialomiței station. *Finalised.*
- Input-output connection of OHL 400 kV Stupina – Varna and OHL 400 kV Rahman – Dobrudja at the 400 kV Medgidia Sud station. *To be finalised in 202*
- OHL 400 kV double circuit (equipped circuit) Smârdan – Gutinaș. *To be finalised in 2024.*
- Transition to 400 kV of the Brazi Vest – Teleajen – Stâlpu axis. *To be finalised in 2025.*
- OHL 400 kV Medgidia Sud – Constanța Nord. *To be finalised in 2028.*
- OHL 400 kV Stâlpu – Brașov. *Finalizare în 2031.*
- Reconductoring OHL 400 kV București Sud – Pelicanu. *To be finalised in 2024.*
- ReconductorING OHL 400 kV Gura Ialomiței – București Sud. *To be finalised in 2028.*
- Reconductoring OHL 400 kV Cernavodă – Pelicanu. *To be finalised in 2029.*

Fig. 2. (a) Romanian Grid Connection Capacities (2023); (b) power transmission grid development priorities
Source: Transelectrica – State Grid Administrator

The second part of our study will take full advantage of this legislation, having already contacted all renewable energy developers and raising the secrecy vale to have a clear and concise image of the developing renewable energy projects once legislation is in place to curb speculative behaviour.

Hydroelectric legacy:

- Hydroelectric power resources from dams on all rivers in Romania are a legacy left by the communist era in working condition, having been used to stabilize the grid in the past and now being used to generate clean power and contribute to a very attractive renewable energy mix evaluated at country level, as visible in Fig. 3.

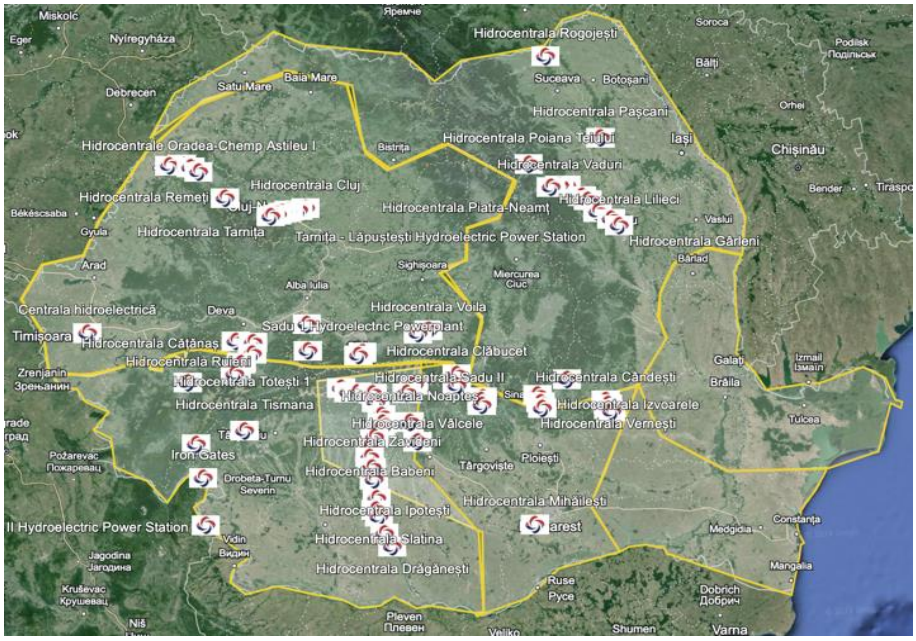


Fig. 3. Romanian Hydroelectric Dams (2023)
Source: Author's research and interpretation of data

- Hydroelectrica, the private/public enterprise that manages all of the hydroelectric resources has clear plans to continue investments in damming for new production capacities, despite environmental concern and NGO resilience.
- Hydroelectrica has acquired UCM Reșița, the main Romanian provider for hydro power technology.

Biomass Energy – biogenic Carbon and biological resources:

- Biomass sources for energy production that we have considered for the study are mainly relying on circular economy value chains. We have selected the landfills as primary resources, with the condition administrators start acquiring European funding for selective waste management and biological resources are transformed into energy resources based on available subsidies and schemes.

- Romsilva, the state agency for woodland management, that is also responsible for all the biospheres and natural reservations in Romania, has also been accounted for with the regional offices in every main city. However, they are represented in hundreds of locations, being a valuable asset in the management of biological resources.
- We have inventoried all wood mills, paper and cellulose mills, the F&B sector, and the main agriculture market players for our resources map, as visible in Fig. 4.

Fig. 4. Romanian Hydroelectric Dams (2023)
Source: Author's research and interpretation of data

All renewables are dependent on state transportation infrastructure. Where grid connection permits have reached a peak, the administrator of the electrical grid is following a cautious approach to grid modernization investments if the market does not show clear demand, especially after the industrial consumer downfall registered during the pandemic. Clean hydrogen production through electrolysis relies heavily on new wind and solar projects that can deliver power to the hydrogen plant.

Moreover, the transportation of hydrogen from plant to consumer is an issue that the industry needs to resolve with state implication and aid, as the required infrastructure and networks within the ecosystems must be a subject of political interest, accumulating multiple deciding factors from geographically linked territorial administrative institutions.

While Romania is abundant in hydroelectric power, the European philosophy around hydrogen tends to disqualify Hidroelectrica from providing power for "green" hydrogen production, as the E.U. stimulates the development of new energy resources. This

ultimately results in ignoring hydroelectric and nuclear capacities, until the Guarantee of Origin legislation will pass through Parliament.

However, opportunities abound in biomass and biological gasses, catching the attention of organizations that deal with biological residue. Considering biological waste now has a price, the waste management sector has newly invested interest in developing a circular economy ecosystem nation-wide, just estimating a need for sustainable transportation of said resources to incinerating facilities, for example.

Nuclear Energy:

- With nuclear energy being included into the EU Taxonomy Regulation as a clean energy resource, Romania is again in advantage as a clean energy provider, having two reactors operational at the Cernavodă plant and being the host country for the innovative SMR technology, via a Romania – US Memorandum of Understanding.

Microgrids:

- A concept that is being explored is the independent microgrid, resulted from a compromise between a pragmatic state administrator of the national grid, with a restrictive development strategy that is not attractive for potential investors in renewable capacities, and industrial sectors that rely on renewable resources for sustainable operations.
- The microgrid allows sustainable organizations to sign Power Purchase Agreements (PPAs) with renewable energy project developers, acting as guarantees for sustainable loan approval, working to the effect of financing the renewable energy project and to the benefit of the organization employing the energy resource into sustainable operations.
- The system functions similar to prosumer regulations, state grid only hosting direct delivery from energy supplier to industrial benefactor on restricted geographical areas, defined by the economic activity of the demanding organization(s).
- Moreover, the microgrid can act as a grid supplier if national systems fail.

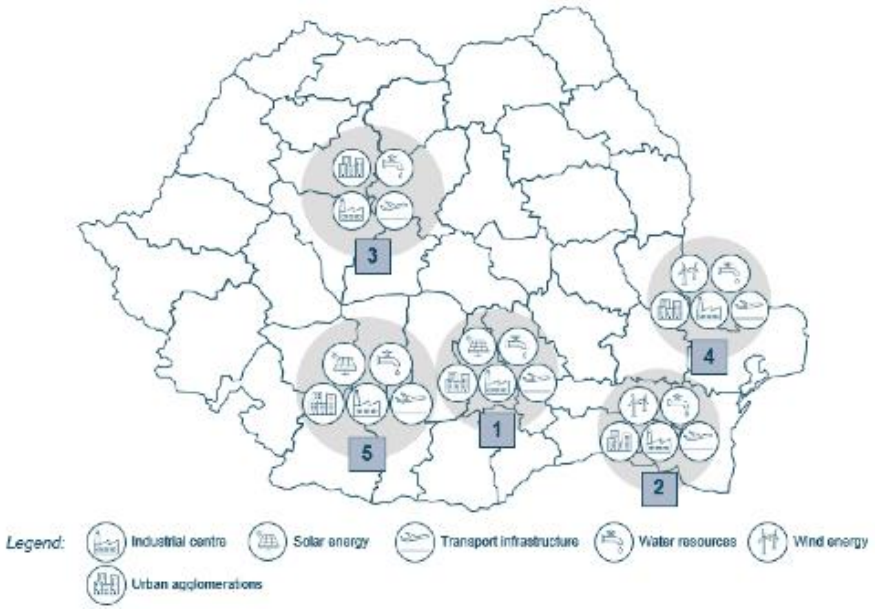
5.3. Hydrogen Opportunities

The concept of green hydrogen, produced through the electrolysis of water using electricity generated from renewable energy sources, holds significant promise for Romania's energy transition and environmental goals. As the country seeks to reduce its carbon footprint and enhance energy security, green hydrogen emerges as a key technology that can offer a sustainable alternative to fossil fuels across various sectors, including transportation, industry, and thermal services (central heating and cooling).

Given Romania's substantial potential for renewable energy, particularly from solar, wind, and hydroelectric power, the production and utilization of green hydrogen can play a pivotal role in achieving a low-carbon economy, driving innovation, and fostering economic growth within the region. This aligns with Romania's commitments under the European Green Deal and its own national strategies to embrace cleaner energy solutions and sustainable development.

The Romanian national hydrogen strategy is a programmatic document, required as a medium-term vision for the national authorities and European regulators, to negotiate investment budgets and aid schemes. The strategy is a requirement for the proper allocation of financial resources to feasible projects, with private and public institutions being stimulated to develop projects in the parameters of the programmatic documentation. However, as visible in Fig. 5, the current draft of the strategy is a very broad approach to a domain that requires granularity to the last detail, as the production of hydrogen requires consumers to immediately intake the production and generate a stable revenue stream, even with an intensive subsidies program backing the industry.

a.



b.

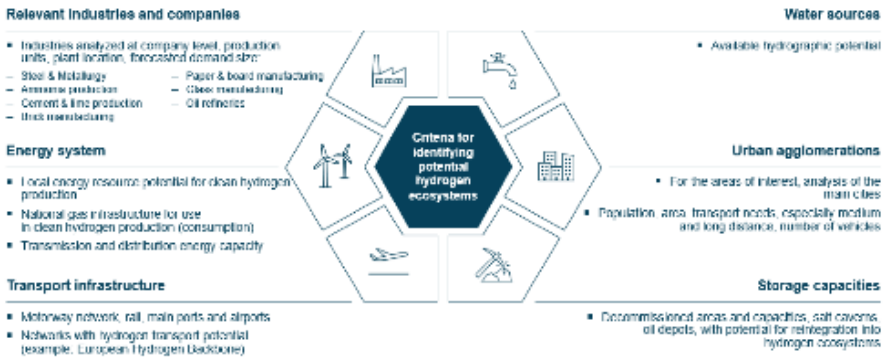


Fig. 5. (a) Prioritised hydrogen valleys based on multimodal demand ; (b) Legend of the selection criteria
Source: National Hydrogen Strategy November 2023 Draft – Ministry of Energy

The strategy is a very static and one-dimensional document. It rarely tackles issues upstream and downstream of hydrogen. This study and its evolutions resolve value chains

between energy providers, specific technology developers, hydrogen utilizers in the varied sectors with a direct approach to all the potential stakeholders that are active in the Romanian economy. Fig. 6 represents a summary of estimated green hydrogen and clean hydrogen consumption, by sectors expressed in percentages for the year 2030. Our ambition is to stimulate organizations to exploit the green financing mechanisms and increase these figures substantially, at least at a declarative level, after we have had concluded our quantitative analysis of the market following discussions with all the organizations identified on our Ecosystems Map.

Fig. 6. Hydrogen consumption / CO2 reduction
Source: National Hydrogen Strategy November 2023 Draft – Ministry of Energy

Throughout the year 2023, several opportunities came in effect for the hydrogen industry, to which the sector specific organizations have answered. An important opportunity has been the 100mw electrolysis projects tender, to which an overwhelming response from 19 companies has been received by the Ministry of Energy, as visible in Fig. 7. Four of these projects have actually been approved and financed from the Resilience Facility. However, a new call for projects has been issued by the Ministry of Energy, this time from the Modernization Fund, and all the rejected projects from 2023 are expected to be financed on this new axis.

Chimcomplex, Monsson Alma, OMV Petrom, SAPE, Frizon Holding, Intervenții Active în Atmosferă SA, Sudarec Romserv, Technomir, Copper Beech, Ground Investment, Elektra Power, Vermont Green, BPlus Advisory, Termoficare Oradea, Infra Expert, Alternative Green Project and Rohidrogen One are the 19 companies that have submitted projects on the Resilience Facility. Romania has ambitions for 2500MW electrolysis capacity installed by 2030, representing approx. 6% of the EU electrolysis capacity, according to the European Commission Hydrogen Strategy. That will result in a demand for roughly 5 new GW RES, basing the estimations while taking the additionality principle into account.

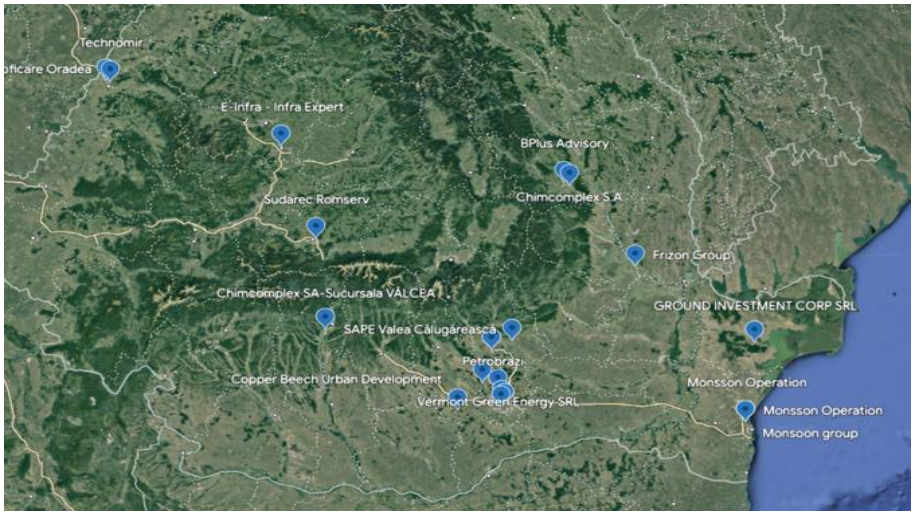


Fig. 7. Electrolysis projects submitted to Resilience Facility financing
Source: Author's research and interpretation of data

5.4. Industrial Ecosystems and Energy Transition

Our research outlines a detailed analysis focusing on specific regions in Romania identified for their potential in renewable energy integration and green hydrogen insertion, emphasizing their strategic importance in developing sustainable industrial ecosystems. Here's a summary of the key regions and their characteristics:

Ecosystem 1 centers around the regions of București, Ploiești, Târgoviște, Pitești, Vâlcea, Buzău, Oltenița, Giurgiu, and Turnu Măgurele, showcasing a robust foundation for renewable energy integration and green hydrogen production, underlined by their strategic importance for developing sustainable industrial ecosystems. Ecosystem 1 is visible for analysis in Fig. 8.

Fig. 8. Ecosystem 1
Source: Author's data inputs in Google Earth

Transportation and Logistics Access: this ecosystem enjoys exceptional multi-modal connectivity, including significant highways (A1, A2, A3), comprehensive railway networks, accessibility to Bucharest's airports, and Danube ports. Such infrastructure facilitates the seamless movement of goods and services across the region.

Biogenic Carbon Potential: the area is marked by high agricultural activity, forest resources, and a diversified industrial sector, including FMCG, tobacco, cement, steel, and chemicals. These features provide ample opportunities for carbon capture and sequestration initiatives, contributing to the reduction of carbon footprints.

Power Profile and Projects: hosting a considerable portion of Romania's photovoltaic (PV) projects, the region is at the forefront of renewable energy development, bolstered by European financing schemes. Plans for further expansion into renewable energy are well-supported, signifying a positive trajectory towards energy sustainability.
Hydrogen Prospects: with several electrolysis projects already receiving funding through the Resilience Program and plans for a hydrogen fuel-cell train network, the region is emerging as a pivotal area for hydrogen energy. This evolution represents a significant step towards achieving a low-carbon energy system.

Thermal Plants: the presence of thermal plants undergoing transitions to gas and potentially hydrogen signifies the region's move towards cleaner energy production. Efforts are underway, supported by modernization funds, to upgrade these facilities for enhanced efficiency and reduced environmental impact.

Specific Cities and Industrial Focus:

- **Bucharest and Ilfov**: Dominated by a diverse industry base including food processing, breweries, plastics, and textiles, with a significant focus on renewable energy and central heating system upgrades.
- **Ploiești – Câmpina**: Renowned as Romania's petroleum nucleus, this area is transitioning towards sustainable energy, housing refineries and FMCG producers.
- **Pitești – Argeș**: The site of the Automobile Dacia plant, presenting potential for green hydrogen utilization in automotive manufacturing and the petrochemical industry.
- **Vâlcea**: Acts as a center for chemical, petrochemical, agritech, and pharmaceutical industries, emphasizing hydrogen as a clean energy carrier.
- **Buzău**: This region is evolving its industrial output with opportunities in steel production, food and beverage, and renewable energy projects.

These regions collectively highlight strategic opportunities for the cultivation of sustainable ecosystems based on renewable energy and green hydrogen. Our analysis underscores the imperative for targeted investments, collaborative efforts among stakeholders, and infrastructure development to fully exploit these areas' potential, steering Romania towards a sustainable and competitive economic landscape.

Ecosystem 2: Constanța, Medgidia, Slobozia, and Călărași, presenting a promising landscape for renewable energy integration and green hydrogen production due to its strategic geographical advantages and natural resources. The map of Ecosystem 2 can be studied in Fig. 9.

Transportation and Logistics Access: the region boasts significant logistical advantages, including the only Black Sea ports in Romania capable of industrial operations due to favourable water depths. These ports, alongside Constanța's functional airport, which hosts a NATO base, and access to Danube ports in Medgidia and Călărași, provide excellent opportunities for the transportation of goods and services. Slobozia acts as a critical road intersection, offering distributed access to neighbouring ecosystems, with an efficient rail network for cargo operations.

Fig. 9. Ecosystem 2
Source: Author's data inputs in Google Earth

Biogenic Carbon Potential: this area is characterized by its rich agricultural activities, including abundant vineyards and mixed crops. The presence of industries under proactive private management across various sectors, from metallurgy to chemicals, alongside the two largest refineries in the country, contributes to its biogenic carbon potential. The Rompetrol – Midia Năvodari Refinery, subject to legislation enforcing green hydrogen production, highlights the region's focus on reducing the aromatic compounds in fuels. Moreover, the availability of algae from the Black Sea and the Danube Delta in the connected region is an advantage in biological resources management for this ecosystem.

Power Profile and Projects: wind power projects, despite facing grid access challenges, are prevalent in this region, which also hosts the Cernavodă Nuclear Plant. The overcrowded grid has led project owners to pivot towards energy storage in hydrogen, with a noticeable increase in demand for electrolysis plants. The region is at the forefront of renewable energy innovation, with Linde and Air Liquide already operating here, and Monsson's financed electrolysis system set to come online. The 1TW offshore wind project has been prepared for implementation, with government officials voting the specific legislation into effect and the EU allowing a 3 billion EUR grant for renewables contracts for difference, ensuring the viability and feasibility for this project, in particular.

Hydrogen Prospects: the strategic positioning for green hydrogen production is evident, with the region hosting several electrolysis projects. These projects, focusing on reducing greenhouse gas emissions, are supported by abundant renewable resources and legislative mandates for refineries to incorporate green hydrogen into their processes.

Thermal Plants and Renewable Energy Opportunities: with the presence of the Cernavodă nuclear plant and limited operational thermal plants, the region plans to modernize existing facilities for gas-to-power generation with hydrogen-ready technology. Although low photovoltaic opportunities are noted due to the prioritization of agricultural land, the region's excellent wind conditions support the feasibility of new wind power projects, especially offshore.

Industrial and Agricultural Profile: the ecosystem is home to a diverse range of industries, including the Petromidia Refinery, Monsoon Alma, Linde, Romcim, and various agriculture-intensive areas. The focus on clean production requires massive hydrogen production to support industries like cement, metal production, clean transportation, and green agriculture.

Ecosystem 2 embodies a dynamic blend of renewable energy potential, green hydrogen prospects, and strategic logistics and transportation access, setting a solid foundation for sustainable industrial development in Romania.

Ecosystem 3 encompasses the regions of Timișoara, Cluj-Napoca, Târgu Mureș, Făgăraș, Sibiu, Sebeș, Alba Iulia, and Hunedoara. It represents a densely populated industrial ecosystem with a vast network of road and rail connections facilitating efficient logistics. This ecosystem stands out for its abundant industrial resources, including a significant concentration of biological resources, offering a rich landscape for renewable energy and green hydrogen projects. The geography of Ecosystem 3 can be consulted in Fig. 10 bellow.

Transportation and Logistics Access: this ecosystem benefits from exceptional transportation and logistics access, including six operational international airports and extensive rail infrastructure undergoing modernization. The main A1 highway, which exits Romania at the Nădlac customs, along with the plan to connect Timișoara, Reșița, Semenic, and Orșova with a hydrogen-fuelled rail, underscores the region's commitment to sustainable transportation.

Fig. 10. Ecosystem 3
Source: Author's data inputs in Google Earth

Biogenic Carbon and Thermal Plants: intensive agricultural activity characterizes the region, alongside well-organized cooperatives between farmers and abundant chemical plants. The ecosystem houses several mills, factories, and industrial sites ready to enter the value chain for biogenic carbon. While most thermal plants have been conserved or sold to private operators for modernization with gas-to-power technology, there's a significant interest in installing electrolysers for green operations.

Power Profile and Projects: the ecosystem shows promise in renewable energy projects, particularly in wind and solar energy. Notably, the Reșița region is home to development projects exceeding 1000MW in mixed wind and solar capacities, taking advantage of optimal wind conditions in the mountainous areas. Despite the low wind and solar conditions within the central parts of the ecosystem, opportunities for renewable energy development are expanding, particularly towards the north and west. Reșița is the second city behind Cluj-Napoca, both in Ecosystem 3, to emit green bonds for sustainable long-term investments in public interest projects. Moreover, UCM Reșița, the industrial behemoth revitalised with Hidroelectrica finances is set to pivot to RES with a new investment strategy and the Green Public Procurement standards that have come into effect.

Hydrogen Prospects and Industrial Focus: with active operations by Linde and Air Liquide, and the approval of three electrolysis plants in Sibiu and Oradea, Messer presence in Reșița, the region is poised for significant advancements in green hydrogen production. Steel and cement mills are exploring the transition from hydrocarbon fuels to hydrogen, emphasizing the ecosystem's move towards sustainable industrial processes. The presence of ceramic producers and international airports mandated to integrate synthetic aviation fuels further highlight the ecosystem's diverse industrial base and its shift towards

sustainability. Timișoara is the Linde HQ in Romania, developing sustainable operations within this ecosystem and the whole country.

Regional Opportunities: Ecosystem 3 presents a unique combination of resource gathering potential, both biologic and non-biologic, and excellent rail-bound shipping capacities for processing plants in southern Romania. There are also numerous sustainability-optimization opportunities with industrial agents operating within this ecosystem, signifying a broader move towards compliance with sustainability standards.

This analysis of Ecosystem 3 underscores its strategic importance in Romania's transition towards a sustainable and competitive economy, focusing on renewable energy integration, green hydrogen production, and efficient transportation and logistics infrastructure.

Ecosystem 4, encompassing the regions of Galați, Brăila, and Tulcea, is poised as a strategic hub for sustainable industrial development, particularly in the metallurgical sector, with a high demand for hydrogen production. This ecosystem is characterized by its rich resources, strategic logistics access, and ongoing projects aimed at transitioning towards green energy and hydrogen use. A visual representation of the geographical positioning of Ecosystem 4 can be seen in Fig. 11 below.

Fig. 11. Ecosystem 4
Source: Author's data inputs in Google Earth

Transportation and Logistics Access: the regions enjoy comprehensive transportation and logistics access, including Danube cargo capabilities, partial highway access with modern or modernizing road infrastructure, rail cargo capabilities, and a significant airport project in Galați-Brăila. This infrastructure supports efficient movement and logistics, essential for the ecosystem's development and integration into wider economic activities.

Biogenic Carbon Potential: Ecosystem 4 is a rich agricultural area with abundant river vegetation and proximity to the seashore for potential algae extraction. The presence of intensive industries, including metallurgical, cement, and chemical sectors, further adds to the ecosystem's biogenic carbon potential, essential for sustainable development and green hydrogen production.

Power Profile and Projects: the region hosts wind power projects, although these face challenges due to grid access issues. The pivot towards energy storage in hydrogen signifies a strategic shift, aiming to circumvent the grid constraints with innovative solutions like hydrogen energy islands and offshore wind projects. Active operations by Linde and Air Liquide, including contracted electrolysers funded by resilience programs, underscore the move towards green hydrogen as a pivotal energy source for the area. The DAMEN shipyard situated in Galați, within Ecosystem 4, has just financed a re-technologization process for the entire factory, with the purpose to produce sustainable transportation vessels, fitted with biofuels, gaseous or hydrogen fuel cell technologies.

Thermal Plants and Modernization Needs: with thermal plants in the ecosystem having been conserved, there is a pressing need for modernization to gas-to-power and hydrogen-ready technologies. This transition is crucial for ensuring efficient public thermal services and aligning with sustainability goals.

Regional Opportunities and Industrial Focus: ecosystem 4 is recognized for its role as an education provider, industry host, and logistics hub, continuously evolving to meet the demands of sustainable development. The Liberty Steel Galați, undergoing modernization for green steel production, exemplifies the industrial shift towards green hydrogen, necessitating significant increases in power demand dedicated to hydrogen production. Other key players like ALRO Alum in Tulcea, recently selected as an aluminium provider for Airbus Industries, are actively pursuing emissions reduction, emphasizing the need for renewable energy and hydrogen in metallurgical processes.

Strategic Development and Sustainability: the establishment of the Galați-Brăila airport project, alongside the EU-funded suspension bridge connecting the three cities, enhances the ecosystem's logistics capabilities. This infrastructure development, combined with the region's industrial ambitions and renewable energy projects, positions Ecosystem 4 as a crucial area for Romania's transition to a sustainable and competitive economy, leveraging green hydrogen and renewable energy sources to fuel its industrial and agricultural sectors.

Ecosystem 5, covering areas including Craiova, Slatina, Târgu-Jiu, Reșița, Caraș-Severin, Drobeta Turnu-Severin, and Moldova Veche, is identified as a promising landscape for sustainable development, marked by significant industrial potential and renewable energy opportunities. A geographical representation of Ecosystem 5 can be found in Fig. 12.

Transportation and Logistics Access: this ecosystem benefits from an extensive transportation network, featuring two airports (Caransebeș Industrial and Craiova Passengers), multiple Danube ports ensuring robust internal logistics, and a comprehensive road network that includes ongoing highway development projects. These infrastructures facilitate multi-modal logistics capabilities, crucial for the ecosystem's industrial and renewable energy sectors.

Hydrogen Production and Demand: active participation from companies like Linde and Messer, particularly with Messer's headquarters in Reșița and operations by Linde in Chimcomplex Vâlcea, underscores the region's potential for hydrogen production. The ecosystem's industrial framework, including sectors such as steel production and automotive components, exhibits a growing demand for clean hydrogen, essential for modernizing operations and transitioning towards green steel production. Specific interest is manifested by the Banat Airport Caransebeș management for Synthetic Aviation Fuel production in this ecosystem, that requires clean hydrogen and biological carbon for refining. Remaining in the Caransebeș region, the recent acquisition and operationalisation of the "Oțelul Roșu" steel mill is an opportunity for the hydrogen industry, as the overhaul of this particular factory, to green steel standards produced with clean hydrogen, will influence a vast and ample value chain both upstream in infrastructure constructions and confections, and downstream in the regional RES and hydrogen sectors.

Fig. 12. Ecosystem 5
Source: Author's data inputs in Google Earth

Biogenic Carbon and Power Profile: despite the challenges posed by soil desertification in parts of the ecosystem, there remains a considerable potential for biogenic carbon resources, notably from ROMSILVA's forest administration. The region is also home to significant renewable energy projects, with over 1000MW development projects in wind and solar energy, highlighting a favourable environment for sustainable industrial production.

Thermal Plants and Renewable Energy: the ecosystem hosts several carbon-intensive gasses-to-power or coal-to-power plants. Governmental aid schemes from the Modernization Fund are set to update these facilities to embrace hydrogen and biological resources, signalling a shift towards cleaner energy production methods.

Regional Opportunities: Ecosystem 5 is uniquely positioned for intensive industrial development, benefiting from strategic connectivity to European destinations via the Danube and enhanced access to renewable energy resources. This connectivity, combined with the region's industrial and agricultural capabilities, presents a solid foundation for establishing Hydrogen Valley initiatives, aimed at fostering sustainable industrial ecosystems.

Industrial and Agricultural Focus: key cities within the ecosystem, such as Craiova and Drobeta-Turnu Severin, are noted for their industrial activities, including Ford OTOSAN and Holcim in Craiova and the Vrancart Cellulose and Paper Mill in Drobeta-Turnu Severin. These industries, alongside others in Slatina and Reșița, form the backbone of the ecosystem's economic potential, driving the demand for renewable energy and clean hydrogen for sustainable production processes.

Ecosystem 5 emerges as a critical area for Romania's industrial rejuvenation and transition towards sustainability. With its rich renewable energy prospects, significant demand for clean hydrogen, and robust transportation and logistics infrastructure, it is poised to contribute meaningfully to the country's sustainable development goals.

Ecosystem 6, as defined by the cities of Brașov, Miercurea Ciuc, Mureș, Satu Mare, Suceava, Botoșani, Iași, Roman, Bacău, Borzești, and Focșani, represents a diverse and dynamic region of Romania that spans from the heart of Transylvania, across the Moldavian plateau, to the eastern borders of the country. This ecosystem is characterized by a rich tapestry of natural landscapes, from the Carpathian Mountains to rolling hills and fertile plains, which provides a unique backdrop for both its ecological and energetic profiles.

Transportation and Logistics Access: Ecosystem 6, spanning strategic locations like Brașov and Iași, boasts a comprehensive transportation and logistics network essential for its diverse economic landscape. This includes an extensive road network with major national and European corridors, vital rail infrastructure supporting both freight and passenger services, and key airports facilitating domestic and international connections. The region's proximity to the Danube River enhances its logistics capabilities through river transport. Additionally, the presence of logistics centres and hubs streamlines the distribution of goods, underpinning industrial activities and agricultural output. Investments in infrastructure improvements and multimodal transport links are pivotal for enhancing regional economic growth and connectivity.

Hydrogen Production and Demand: enriched by industrial activities and a robust agricultural sector, this ecosystem presents significant opportunities for hydrogen production and demand. The presence of Chimcomplex, showing keen interest in hydrogen, underscores the region's potential as a hub for hydrogen energy development. The area's extensive agricultural industry, necessitating green fertilizers, complements this by driving demand for hydrogen as a key component in producing eco-friendly fertilizers. Given Romania's abundance of chemical and fertilizer plants, the region is poised to lead in the transition towards green hydrogen, leveraging its industrial and agricultural strengths

to fuel demand, support sustainability, and foster innovation in hydrogen technologies. This convergence of industrial need and green aspirations highlights Ecosystem 6's potential in shaping a sustainable energy and agricultural future.

Biogenic Carbon Potential: Ecosystem 6, characterized by its varied landscapes from the Carpathian Mountains to fertile plains, holds significant biogenic carbon potential. The region's extensive forests, managed by entities like ROMSILVA, offer vast resources for sustainable forestry and carbon sequestration efforts. Agricultural lands contribute through crop cultivation and potential for biomass energy production. Initiatives to harness biogenic resources, including agricultural waste and forest residues, for energy and material use could further enhance the region's sustainability and reduce carbon footprint. Optimizing these natural resources for bioenergy and eco-friendly products represents a key opportunity for Ecosystem 6 to advance its green economy.

Thermal Plants and Renewable Energy: thermal power plants are undergoing significant transitions to align with EU environmental directives, focusing on reducing emissions and securing environmental permits. Concurrently, there's a notable shift towards renewable energy sources, highlighted by solar and gas-powered projects, to foster a cleaner energy landscape. The region's industrial entities, especially those with a keen interest in hydrogen like Chimcomplex, mirror a broader national shift towards sustainability, emphasizing renewable energy and the phasing out of coal dependence.

Regional Opportunities: given the presence of significant industrial players across Ecosystem 6, including ArcelorMittal, Agrana, Holcim, Amazon, Autoliv, Vrancart, and many others within cities from Roman to Iași, Adjud, Onești, Brașov, Miercurea Ciuc, Suceava, Botoșani, and the Satu Mare region, the regional opportunities for development, innovation, and sustainability are vast and multifaceted:

- Industrial Synergy and Innovation: The diverse industrial base, from steel manufacturing (ArcelorMittal) to advanced technologies (Amazon Web Services) and automotive (Autoliv, Schaeffler), creates opportunities for synergies and collaborative innovation. Establishing research and development clusters can spur technological advancements and product innovations, driving economic growth.
- Agricultural Innovation and Bioeconomy: The presence of Agrana and Heineken Ciuc Brewery, alongside extensive agricultural lands, opens up opportunities for bioeconomy initiatives, leveraging agricultural by-products for energy production, and developing value-added agricultural products, enhancing the sustainability and profitability of the agricultural sector.
- Digital Transformation and IT Infrastructure Development: With technology companies like Amazon in the region, there's a significant opportunity to advance digital transformation across industries, improve IT infrastructure, and foster a digital economy that supports e-commerce, cloud computing, and remote working environments.
- Supply Chain Development and Logistics Enhancement: The geographical location and industrial diversity present opportunities to develop integrated supply chains, improve logistics and transportation infrastructure, and facilitate efficient distribution channels, both domestically and for export markets.

- Workforce Development and Education: Collaborations between industries and educational institutions can address workforce needs, providing specialized training and development programs in fields such as engineering, IT, and sustainable agriculture, ensuring a skilled workforce ready to meet future industry demands.
- Tourism and Cultural Heritage: Beyond industrial and agricultural development, the region's rich cultural heritage, natural landscapes, and historical sites offer opportunities for developing sustainable tourism, including cultural, eco-, and agro tourism, contributing to local economies and conservation efforts.

Ecosystem 6's blend of industrial activity, agricultural richness, and technological innovation, coupled with its natural and cultural assets, sets the stage for a dynamic regional development trajectory focused on sustainability, innovation, and cross-sector collaboration.

Socioeconomic Context: the region encompasses a mix of urban centres, such as the historic cities of Brașov and Iași, and rural areas with economies based on agriculture, forestry, and increasingly, tourism. The diverse economic activities, combined with cultural and historical richness, provide a solid foundation for sustainable development initiatives.

5.5. Industries of Immediate Interest and Priority

Energy (Refineries and Thermal Power Plants): This sector emerges as a top priority due to its substantial energy demand and significant potential for emissions reduction through the integration of green hydrogen. The analysis points to several key refineries and thermal plants, such as OMV Petrom and Electrica Furnizare, underscoring the critical need for transitioning to cleaner energy sources.

Synthetic fuels and gasses production: This sector as critical as it is innovative, with mandatory quotas for Sustainable Aviation Fuels being introduced and gradually growing, but with no supplier for this resource on the entire continent. This particular element is synthetized with clean hydrogen and captured carbon. Cleaning gases produced by the pyrolysis of biological waste requires clean hydrogen.

Steel Production: The steel industry, represented by companies like Liberty Steel and ArcelorMittal, is identified as another critical area for renewable energy integration. The sector's high carbon footprint and energy intensity make it a prime candidate for adopting green hydrogen technologies to reduce emissions and improve energy efficiency.

Chemical and Petrochemical: The document highlights the chemical and petrochemical sectors, including Chimcomplex and Oltchim, as essential for sustainable transformation. These industries stand to benefit from green hydrogen as a feedstock, reducing reliance on fossil fuels and decreasing carbon emissions in the production of chemicals and fertilizers.

Cement Manufacturing: With players like Holcim Romania and Heidelberg Materials, the cement industry's energy-intensive processes and significant CO2 emissions are

spotlighted. The adoption of green hydrogen and renewable energy sources could revolutionize this sector, lowering its environmental impact while maintaining production efficiency.

5.6. Challenges and Opportunities

Romania's trajectory towards a hydrogen-based economy underpins a spectrum of challenges and opportunities across infrastructural, regulatory, and collaborative dimensions, each intertwined with the broader objectives of sustainable development and energy transition.

Infrastructure Needs and Investment Opportunities: Romania faces substantial infrastructure needs to foster a hydrogen economy, from production facilities to storage and distribution networks. This challenge, however, opens up vast investment opportunities. The development of dedicated hydrogen pipelines, electrolysis plants powered by renewable energy sources, and the enhancement of existing gas networks to accommodate hydrogen blending are critical steps. These initiatives not only require significant capital investment but also present opportunities for public-private partnerships, drawing in expertise and funding from various sectors. Moreover, the divided and inconsistent political environment is unaware of several financing opportunities and responds with difficulty to proposals such as the development of a Romanian IPCEI for hydrogen (Important Projects for Common European Interest)

Regulatory and Policy Environment: Navigating the regulatory landscape presents a challenge, with the need for a coherent framework that supports hydrogen production, utilization, and market development. The opportunity lies in crafting forward-looking policies that incentivize renewable energy investments, streamline permits for hydrogen projects, and establish clear standards for clean hydrogen, thus creating a conducive environment for growth. Embracing EU directives and integrating them into national law can expedite this process, positioning Romania as a leader in hydrogen innovation within the region. Romania requires legislation for the Guarantees of Origin (GO) for hydrogen, specific legislation for Hydrogen Contracts for Difference in order to support the production, distribution and utilisation of hydrogen aided by subsidies. Moreover, specific legislation for type certification of hydrogen machinery is required in order to evaluate procurement tenders by means of European quality and safety standards, excluding off the market those components that cannot be accounted for in sustainability reports.

Collaboration between Government, Industry, and Academia: The complexity of transitioning to a hydrogen economy necessitates a collaborative approach among government bodies, industry stakeholders, and academic institutions. The challenge is to synchronize efforts, align objectives, and share knowledge and resources. The opportunity arises in leveraging this tripartite collaboration to drive innovation, research, and development in hydrogen technologies, ensuring a workforce skilled in new energy sectors, and piloting projects that demonstrate the viability and benefits of hydrogen solutions. Such collaborative platforms can also play a crucial role in public education and acceptance of hydrogen technologies, laying the groundwork for a sustainable energy future.

In addressing these challenges and capitalizing on the opportunities, Romania can advance its green agenda, fostering a sustainable and resilient energy ecosystem that contributes to its economic growth and environmental goals.

6. Case Studies

Examples of Successful Renewable Energy or Green Hydrogen Projects

Ørsted's Transition to Renewable Energy: Ørsted, originally a traditional fossil-fuel company, successfully transitioned to become the world's largest producer of offshore wind energy. The company strategically focused on wind power, leveraging early-stage projects in Denmark and the United Kingdom and significant in-house expertise in renewable energy. Ørsted's transformation was marked by adopting a serial production approach to offshore wind projects, moving away from highly customized, infrequent projects to more standardized, frequent developments. This shift required strong partnerships, particularly for turbine installation and supply, and led to innovative financing models, like the "farm down" model, which attracted significant investment for European projects .

Germany's Kopernikus Projects for Renewable Energy Research: Germany launched the Kopernikus Projects, the nation's largest renewable energy research initiative, with a €400 million investment aimed at advancing energy storage, developing renewable-centric power networks, adapting industrial processes to renewable sources, and integrating conventional and renewable energy production. This initiative is distinguished by its collaborative approach, involving research institutions, industrial companies, and civil-society bodies to work on complex challenges like converting intermittent renewable electricity into hydrogen. This reflects a holistic strategy to ensure public buy-in and address socioeconomic impacts alongside technological advancements.

Lessons Learned and Best Practices

Emphasis on Strategic Vision and In-House Expertise: Ørsted's successful pivot to renewable energy highlights the importance of having a clear strategic vision that identifies future growth areas based on existing competencies and market differentiation opportunities. Equally crucial is the presence of substantial in-house expertise to navigate the technological and operational shifts required for transitioning to renewable energy sources.

Collaborative and Interdisciplinary Approach: The Kopernikus Projects underscore the value of collaboration across disciplines and sectors to address the multifaceted challenges of renewable energy transition. Involving a wide array of stakeholders from the onset ensures diverse perspectives and expertise contribute to holistic solutions, enhancing project viability and public acceptance.

Innovative Financing and Business Models: Developing new financing models, such as Ørsted's "farm down" approach, can be pivotal in attracting the necessary capital for large-scale renewable projects. These models must balance investor interests with project risks, facilitating investment in the sector while enabling project developers to maintain strategic control and operational expertise.

Adaptability and Continuous Improvement: As the renewable energy landscape evolves, successful projects demonstrate the importance of being adaptable and continuously seeking improvements in technology, operations, and business strategies. This includes everything from streamlining production processes to exploring new market opportunities and technological frontiers, such as green hydrogen.

7. Conclusion and Recommendations

The investigation into Romania's transition towards sustainable development, emphasizing renewable energy and green hydrogen, has unearthed a multifaceted landscape brimming with both challenges and opportunities. This comprehensive study, underpinned by a detailed review of the academic discourse, PESTLE analysis, and strategic frameworks, has highlighted the pivotal role of renewable energy and green hydrogen in Romania's endeavour to align with the European Green Deal and the Paris Agreement.

Summary of Key Findings:

- Romania exhibits a significant potential for renewable energy expansion, especially in solar, wind, and hydroelectric power, which forms the backbone for a robust clean and green hydrogen production capacity.
- The exploration of hydrogen-natural gas blending and the burgeoning interest in green hydrogen from industrial sectors underscore the readiness and eagerness of the Romanian market to transition towards cleaner energy alternatives.
- Legislative advancements, particularly the Hydrogen Law and EU-backed financial schemes, lay a solid foundation for fostering a conducive environment for renewable energy investments and green hydrogen initiatives.

Strategic Recommendations for Leveraging Romania's Renewable Energy and Green Hydrogen Potential:

- Infrastructure Development and Investment:
    a) Accelerate investments in renewable energy infrastructure, focusing on enhancing grid capacity and resilience to facilitate the integration of solar, wind, and hydroelectric power at a larger scale.
    b) Prioritize the establishment of hydrogen production, storage, and distribution facilities to support the burgeoning hydrogen economy, ensuring that these infrastructures are strategically located to maximize efficiency and accessibility.
- Regulatory and Policy Framework Enhancements:
    a) Continue refining and expanding the legislative framework to support renewable energy and green hydrogen, including incentives for investment, streamlined permitting processes, and clear guidelines for green hydrogen certification.
    b) Implement and enforce a comprehensive national strategy for green hydrogen, aligning with EU directives and focusing on both production and consumption across various sectors.
    c) Define clear and concise parameters for technology certification and accreditation in the EU, especially for machinery under pressure and hydrogen industrial components that can present extreme risks if fabricated superficially.

- Fostering Collaborations and Partnerships:
    a) Encourage public-private partnerships to leverage expertise, resources, and funding from both governmental and private entities. Such collaborations could accelerate the deployment of renewable energy projects and green hydrogen production facilities.
    b) Encourage the development of sustainable consortia between private organizations with common ESG goals and value chain compatibility, for Upstream Emission Reduction in operations.
    c) Strengthen collaboration between academic institutions, research centres, and industries to spur innovation in green technologies and hydrogen applications, ensuring a continuous flow of skilled professionals and cutting-edge solutions.
- Market Development and Public Engagement:
    a) Develop market mechanisms to promote the adoption of green hydrogen across different sectors, including transportation, industrial processes, and residential heating and cooling, through incentives, tax breaks, and subsidies.
    b) Launch comprehensive public engagement campaigns to raise awareness about the benefits of renewable energy and green hydrogen, fostering a societal shift towards sustainable energy consumption patterns.
- CSRD Compliance
    a) Hydrogen is a vehicle for energy to reach production in several key industries, respectively the precise industrial sectors that produce the critical raw materials required for the upstream fabrication of thousands of products derived from steel, aluminium, chemicals, fertilizers, plastics.
    b) Clean/green hydrogen with a guarantee of origin utilization in the upstream manufacturing of products or services, resulting in preventive compliance with emissions quotas, accumulating the minimum amount of carbon in the non-financial report.
    c) With sufficient skills and transparency on behalf of the organization, the products an/or services sold by US and EU based companies can absorb the guarantee of origin, being themselves hunted on the market for their value. Their Net 0 value.

This holistic approach to harnessing Romania's renewable energy and green hydrogen potential not only paves the way for achieving national sustainability goals but also contributes significantly to the global effort to combat climate change. By strategically leveraging its natural resources, legislative advancements, and collaborative spirit, Romania can position itself as a leader in the green energy transition, inspiring other nations and fostering a sustainable future for generations to come. A quantitative completion of this study is programmed to begin soon, probing the organisations gathered in our first study, finding their compliance level with CSRD to establish a sustainability baseline for Romanian organizations, later conversing with deciding factors regarding a swift implementation of pre-defined quality assurance mechanisms for a sustainable organization design in the era of smart communities.

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