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Sustainable locations in the world for the green hydrogen economy of tomorrow:
technical, economic and social analyses of the development of a global sustainable hydrogen atlas

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Towards a Green H_2 Economy: Costa Rica Country Report

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Abstract

The future of Costa Rica's green hydrogen (GH2) economy is uncertain despite significant natural and human-made advantages. The country has a history of pioneering environmental initiatives and nearly 100% renewable energy, positioning it well for GH2 development. Recent momentum includes a GH2 strategy approved by the Ministry of Environment and Energy (MINAE) and a presidential decree favoring hydrogen investments. However, the government's reluctance to invest public funds and uncertainties at both national and international levels pose challenges. Private sector pioneers and international cooperation, particularly with Germany, are crucial in advancing the GH2 sector. Experts foresee a phased development, focusing initially on research and pilot projects, with significant scaling and exports of hydrogen derivatives expected post-2030. Continued support from Germany in pilot projects and capacity building is vital, and Costa Rica could become a regional knowledge hub for the hydrogen economy.

Keywords: Green Hydrogen (H2), Green H2 Knowledge Hub, Costa Rica, Energy Transition, International Cooperation,

Key Messages

As of the time of publication, the fate of the GH2 economy in Costa Rica is unclear. On the one hand, the country has very good natural (hydro- and geothermal power, water availability) and manmade advantages (high education level, a broadly anchored social and environmental consensus). On the other hand, a series of internal and external uncertainties prevent dynamic developments in the GH2 sector.

Costa Rica has been pioneering innovative solutions to environmental challenges of the Central American region and beyond, since the 1970s, when the government declared large parts of the country National Parks, providing them with a highly protected status. By the mid-1990s, Costa Rica reversed deforestation and in 1997 an innovative protection scheme was introduced, known as Payment for Ecosystem Services. Thus, it is not surprising that the country recognized early on that green hydrogen opens up opportunities to combine environmental and climate protection with new possibilities for value creation.

For some years now, nearly 100% renewable energy sources have fed Costa Rica's electricity system. This might allow the country to "kick-start" a green hydrogen economy. Potential importers, like Germany, may insist on proof that hydrogen production for export does not impede the energy transition in producing countries. Indeed, the GH2 discourse in Costa Rica has gained momentum in the past three to four years. A GH2 strategy has been developed in a broad multi-stakeholder process. After some delays due to the change in Government in the year 2022, the line ministry MINAE approved the strategy and published it in 2023. In December 2023, a presidential decree declared investments in infrastructure, business, and alliances related to hydrogen as of public interest, which may lower the uncertainties that stakeholders perceive about the emerging GH2 economy. Still, the government does not seem to be willing to invest significant amounts of public money to advance the hydrogen economy.

Ad Astra Rocket, the Costa Rican branch of an aeronautics company headquartered in Houston, Texas, is among the pioneers in the private sector. Its CEO is a former NASA astronaut of Costa Rican origin. Another company worth mentioning is Cavendish S.A. the "green technologies branch" of Purdy Motors, the sole importer of Toyota vehicles to Costa Rica. GIZ is one of the international actors committed to promoting the GH2 economy in the country. In close cooperation with MINAE, GIZ has submitted a project proposal to the NAMA Facility seeking funding for GH2-related actions. At the time of writing, it is unclear what role the relevant state-owned companies can and shall play in the GH2 economy, above all the electricity utility ICE. Under previous governments, ICE was considered an important driver of change in the country's energy system. Its role appears to have been diminished and called into question after the change in the Costa Rica's government in 2022.

Uncertainties not only arise at national policy level, but also at international level. Even if exports of GH2 or derivatives are not the priority for Costa Rican stakeholders, joint investments in export-oriented projects for the domestic market could lower capital costs and make projects easier to finance. There is at least one Australian company, which has presented ambitious plans for export-oriented hydrogen projects in Costa Rica. However, some experts and observers doubt that GH2 produced in Costa Rica could find absorptive international markets. The country would have to compete with other locations, which may offer bigger land areas for larger projects and lower production costs. On the domestic market, GH2 might

contribute to de-carbonizing the transport sector, especially heavy cargo transport. Costa Rica has a very small business sector that could be considered a "hard to abate" industry, not accessible for direct electrification as a means of decarbonization. An interesting option could be the establishment of a fertilizer industry that uses GH2 to produce ammonia and nitrogen fertilizers. Indeed, in early 2023 Cavendish established a joint venture with a British company to develop green ammonia projects in the Central American region.

Given the diagnosed uncertainties, experts and observers assume that the Costa Rican hydrogen economy will have to develop over several phases and many years. The focus will initially be on applied research- and pilot projects as well as the development of competence and capacity before significant scaling can take place. Exports of hydrogen derivatives are not expected until well after 2030.

In this context, Germany should continue supporting pilot measures, e.g. in the transport and fertilizer sectors. Building on decades of bilateral cooperation, the political foundations can, for example, help strengthen the country's foresight and planning capacities, which may be crucial to making well-founded decisions in a fast-changing field, such as the emerging hydrogen economy. Similarly, scientific cooperation, which already has a long tradition between Costa Rica and Germany, should be intensified and expanded. Costa Rica might be considered to host a regional think tank for the hydrogen economy, which could attend to the knowledge needs of Central American stakeholders.

1 Country background

Costa Rica is one of seven countries that form Central America. It borders Nicaragua to the north and Panama to the south. Since the country gained independence from Spanish colonialism in 1821, it has undergone a socio-economic development vastly different from other countries of the region. At the time of independence, Costa Rica's central region was a sparsely populated area, inhabited mainly by smallholder, subsistent farmers, most of them descendants of Spanish immigrants. Several groups of indigenous peoples lived spatially separated from them.

With an economy that is historically strongly based on agricultural exports (coffee, non-traditional goods), Costa Rica is a latecomer in terms of urbanization. In 1990, only half the population was living in areas classified as urban compared to, for instance, 83% of Chileans living in urban areas. [1]Today, Costa Rica's population is concentrated in urban areas; over 80% of Costa Rica's 5.2 million inhabitants live in cities (on par with the average in Latin America, which is 81%).

In 2011, Costa Rica's national ethnicities were predominantly White or Mestizo, accounting for over 80% of the population. Mestizo refers to individuals with a mixed European and Indigenous heritage. Mulatto and Indigenous people comprised 6.7% and 2.4% of the population, respectively. Costa Rica has eight groups of Indigenous communities: Huetar, Maleku, Bribri, Cabécar, Brunka, Ngäbe, Bröran, and Chorotega (Mamo, 2022, p. 383). The Indigenous Law, Ley Indígena No. 6172, recognizes these groups as "pre-Columbian civilizations" and acknowledges their distinct tribal identities (Vaage, 2011, p. 12). Since the 1970s, Costa Rica's northern neighbor Nicaragua went through a series of partially violent conflicts and long phases of political repression which led to official and informal immigration into Costa Rica. Today, approximately 300,000 Nicaraguans are permanent residents of Costa Rica and thousands more migrate seasonally between the two countries for work. More recently, migration flows have come from Venezuela and Colombia. While some migrants enter Costa Rica to stay as residents, others use it as a transit route from South America to the United States.

From 1830, coffee became the first successful cash crop, transforming a subsistence to a commercial society. Due to the given social structures (mainly small to medium-sized farmers), the coffee economy allowed for broad-based growth and a bourgeois institutional setting while in other countries polarized feudal structures emerged. In the last quarter of the 19th century, banana was added as the second dominant cash crop. While coffee mainly occupied large parts of the mountain regions, banana was produced on large estates, often internationally owned, in the Caribbean lowlands. Over the following decades, the society consolidated as a bourgeois one, with a dominating middle class and a presidential republic. In 1889, the government established free and compulsory primary education. As a result, literacy rates rose dramatically, from 10.9% in 1864 to 67.2% in 1927. The first university was founded even earlier, in 1843.

[1] Urban population | Data (worldbank.org)

After a short civil war in 1948, the government adopted a rather interventionist governance regime, with strong public institutions to assure social welfare and public control over the main patterns of economic development. The abolition of the army in 1948 helped to finance a social security and welfare system, exceptional in the context of the Central American region. The social-democratic as well as the more conservative political movements of Costa Rica supported this social contract. From 1959 until the early 1980s, Costa Rica followed a model of import-substituting industrialization, as part of efforts to create a Central American Common Market. The policy achieved moderate success until the mid-1970s but led to highly volatile developments afterward. The debt crisis from the early 1980s triggered a fundamental change in development policies, from import substitution to an outward-oriented model. The main drivers of the subsequent growth were non-traditional agrarian exports, the contract-processing industry (textile and garment, medical equipment), and business service centres. During this time, international tourism developed into another cornerstone of Costa Rica's bold economic growth..

Based on the above-mentioned social contract, Costa Rica also demonstrated a stable democratic governance system for several decades since 1948. For a long time, the political power alternated between two parties, the social democratic *Partido Liberación Nacional* (PLN) and the conservative *Partido Unidad Social Cristiana* (PUSC). However, since the 2000s, the political stability of Costa Rica has been called into question increasingly. In 2000, dissidents of the two traditionally ruling parties formed a new party, *Partido Acción Ciudadana* (PAC), and won the election in 2014 placing the first-ever president not belonging to PLN or PUSC in power. While PAC can still be seen as fitting under the umbrella of the "green social contract" (Araya 2020), the 2018 elections brought a different political movement to the national scene: *Restauración Nacional*, a populist, right-wing and anti-liberal party was able to collect a significant number of votes by lobbying against women's rights and same-sex marriage. Finally, the 2022 elections introduced a significant change to Costa Rica's political system by installing Rodrigo Chaves Robles from the *Partido Progreso Social Democrático* (PPSD) as the new president of the country. PPSD, a centre-right party founded in 2018, received 15% of the votes in the 2022 election and only 10 of 57 MPs are members of this party. In a political system not used to forming coalitions, this implies difficult decision-making processes.

The increasing political instability is at least partially a reflection of decreasing social and territorial cohesion. Income inequality was relatively low for many decades. Since the beginning of the century, the country's Gini co-efficient increased from 45.3 in 1990 to 48.7 in 2021. As the region's traditionally very unequal societies (El Salvador, Honduras) have seen their Gini coefficient decrease, Costa Rica is now one of the most unequal societies in Latin America, topped only by Brazil and Panama. This is reflected in spatial patterns of inequality: While the Central Valley hosts many of the sectors that generate decent incomes (coffee, non-traditional export crops, industrial parks), the coastal areas at the Pacific and Caribbean side of the country are rather impoverished and only host few income generating activities, e.g. tourism resorts along the beach fronts. Indeed, it can be shown that the population in the Central Valley has continued to vote for "green social contract" parties in past elections, while people in the coastal lowlands preferred the populist right (Araya, 2020).

The main drivers of the social and territorial polarization in Costa Rica are locational and urbanization advantages. Many of the activities that have driven Costa Rica's growth in past decades have found the best locations in the Central Valley, where e.g. the availability of labor and business-related services is given. For international investors, the industrial parks are

attractive locations and these are mainly located in the Central Valley; often close to the main International Airport (Juan Santamaría). Once industries and service sectors are located in a preferred region, this leads to processes of mutual re-enforcements, as entities offering training or business consultancies will locate close to growing sectors, etc.

Costa Rica is widely recognized for its strong commitment to environmental conservation and ecotourism (Miller, 2006, p. 359). It is known internationally for its peaceful and democratic tradition, along with its ambitious conservation agenda (Girot et al., 1998, p. 1). The country's environmental policies are widely regarded as particularly ambitious, taking biodiversity seriously by boasting one of the most aspiring legislative regulations worldwide (John & Derakhshi, 2022, pp. 71-77). The nation acknowledges the importance of its ecosystems to the national economy, which has been reflected in its policymaking in the past (Miller, 2006, p. 359). Environmental protection is included in the country's "green social contract" (Araya, 2020) highlighted by the number and spread of Costa Rica's national parks, which cover around 25% of the country's surface. By the mid-1990s Costa Rica reversed deforestation. The land surface covered by forest started to grow by 2010 and is today at 59% (World Bank, n.d.-c). In 1997, Payment for Ecosystem Services was introduced, a financial mechanism of the State to the owners and holders of forests and forest plantations, for the environmental services they provide. In the 2000s, environmentally difficult projects in the mining sector were stopped by a coalition of policymakers, experts, and activists. In 2002, Costa Rica banned fossil fuel exploration and extraction, a decision that subsequent governments reinforced by extending the ban (García Sánchez & Avendaño Leadem, 2018, p. 268). However, with the change of government in 2022, Costa Rica's strong commitment to carbon neutrality might be in question with the environmental minister suggesting that lifting the ban might be an option (Madriz, 2022).

Table 1: Factsheet: Basic development indicators of Costa Rica

Indicator	Value	Year of reference
Area	51.100 km2	
Population	5.1 Mio)	2021
Population growth	0.6%	2021
Per capita income	12,472 US$ (Upper Middle Income Country)	2021
Exports (value)	24,036 Mio US-$	2021
Exports (goods and services)	coffee, medical instruments, bananas, pineapples, orthopedic appliances	
Main trading partners (exports)	United States, Netherlands, Belgium, Guatemala, and Panama	2019
Human Development Index	58 of 191 countries (very high human development)	2021
Gender Equality Index	60 of 191 countries	2021
Unemployment	11.5%	2022
Youth unemployment	30.4%	2022 (% of people between 15 and 24 years)
Corruption Perception Index	48 of 180 countries	

2 Introduction and Methodology

2.1 Introduction

This country report was developed in the context of the Hypat-project, financed by the German Ministry of Education and Research *(Bundesministerium für Bildung und Forschung, BMBF*). The main objective of Hypat is to map out the potential of different world regions and countries to (a) produce green hydrogen (GH2) and, (b) potentially export GH2 or derivatives to Germany and Europe. Hypat works under the assumption that the export potential of partner countries cannot be calculated solely from the potential of the exporting countries for renewable energies. Rather, mapping out the potential of different world regions and countries requires a complex understanding of specific national and regional socio-economic, technical, and socio-political contexts.

Developing countries frame their GH2 strategies and roadmaps with multiple purposes, often linking envisaged export potentials with options to use the emerging GH2 economy for their sustainable development. What role can GH2 play in the decarbonization of local businesses and do options exist for green industrialisation and/or a more sustainable transport sector? How can the required capacities of renewable energies (RE) for producing large quantities of GH2 be built and which conflicts may arise in land use and the use of clean water capacities? Which role can the export of GH2 and derivatives play in the near and longer-term future? Which uncertainties and risks are perceived about international GH2 trade?

The Hypat country reports are based on an extensive review of published and "gray" literature as well as interviews with stakeholders and experts in Germany's and Europe's (potential) partners in the ramp-up of a GH2 economy. The objective is to contribute to a better understanding of the starting conditions for the emerging global GH2 economy in several mainly developing countries. Based on the analyses, policy recommendations are derived.

2.2 Methodology

Seven countries were selected for in-depth studies, based on a combination of an extensive analysis of available indicators and a focus group discussion involving experts from various research groups at German institutes. These seven countries share an above-average potential to produce large quantities of hydrogen with electrolysis based on renewable energies and a reasonably good position to export hydrogen or derivatives to Europe. Developing countries with no significant potential for wind-, solar- or geothermal energy but good access to international maritime transport were not considered, e.g. Belize. The same applies to land-locked countries with excellent solar radiation (e.g. Chad). Beyond these two common denominators (RE potential, access to international maritime transport), the countries selected for the qualitative in-depth studies cover a range of different situations, e.g. from large countries with complex industries (Brazil) to small countries with a mainly rural economy. An extensive literature research was conducted for the Costa Rica case study, , followed by an initial country visit in November 2022 and a follow-up visit in July 2023. A series of stakeholder interviews were conducted, most of them in physical meetings during the field visits, some additional online.

2.3 Hydrogen strategies and roadmaps

2.3.1 National Green Hydrogen Strategy (NGHS)[2]

In November 2022, MINAE (Ministerio de Ambiente y Energía, Ministry for Environment and Energy) Minister Franz Tattenbach presented the „National Green Hydrogen Strategy"(NGHS). It was developed under the guidance of MINAE under the previous government led by PAC, a political party, which belongs to the tradition of Costa Rica's "green social contract". The NGHS was officially published on the Ministry's website only in August 2023 - several months after its formal announcement in 2022 (MINAE, 2022a).

2.3.1.1 Summarized content of NGHS

Costa Rica's NGHS aims to deploy green hydrogen as an energy vector in Costa Rica, contributing to the goal of zero net emissions by 2050. This goal is set out in the update of Costa Rica's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement. The National Decarbonization Plan 2018-2050 (see chapter 2.4) also includes as one of its objectives the promotion and development of hydrogen in the country. The NGHS sees potential risks and promises that

"Efforts will be made at all times to ensure that the environmental and social costs of electricity production with domestic renewable sources for hydrogen production are balanced with the benefits of hydrogen projects, about the achievement of decarbonization commitments." (NGHS 2022: 9, own translation from Spanish)

Costa Rica has a unique situation with a highly renewable energy matrix close to 100%, which could be used for the first phase of adoption and production of green hydrogen from grid electricity, using potential surpluses with values between 2 and 4 USD/kg H_2, while dedicated renewable energy plant projects are developed in the country. The levelized cost of hydrogen from wind and solar PV is expected to decrease over the decades and could reach values between 2 and 3 USD/kg H_2 by 2030. Competition between electricity demand for hydrogen production and that required for electrification of other uses (electric mobility and electrification of industry) shall be avoided through the creation of new renewable electricity generation capacity.

The NGHS identifies the transport sector in Costa Rica as a key field of application for green hydrogen in the country and as a lever to activate its demand. The sector constitutes the biggest polluter at the national level (especially in cargo trucks and long-distance buses). Green hydrogen is also foreseen to contribute to the progressive replacement of fossil fuels in hard-to-abate industry sectors, which today use often LPG and bunker gas. A national demand of 18 to 20 kton H_2/year is projected for 2030, which could reach 420 kton H_2/year by 2050, with the transport sector being the main demander.

[2] To date the strategy is only in Spanish version. To facilitate researchers the search the English name and acronym are used.

Based on the production and demand projections and the country's strengths identified while drafting the document, a long-term vision of the country is envisioned as the basis for the National Green Hydrogen Strategy:

"*Costa Rica produces green hydrogen competitively by taking advantage of its renewable electricity matrix, contributing to the decarbonization of the transport and industry sectors, energy independence, and economic growth, and positions itself as a regional hub of knowledge and technology*". (MINAE, 2022, p. 53, *own translation from Spanish*)

The vision for 2030 foresees an installed capacity of electrolyzers and projects under development between 0.2 GW and 1 GW and a series of milestones in the industrial and transport sectors. This would require mobilizing potential investments estimated at US$ 2.5 billion over the period 2022-2030 and might imply the creation of 30,000 jobs. In terms of greenhouse gas emissions, the NGHS assumes that the adoption of green hydrogen in the country could represent a reduction of up to 2,600 ktons of CO_2 equivalent.

Green Hydrogen Strategy Action Plan. The NGHS includes an action plan to boost the initial phase of hydrogen adoption in the country to achieve the proposed decarbonization targets for 2030. The action plan encompasses 77 actions grouped into 16 lines of action that are distributed in three axes aligned to the country's hydrogen vision and a fourth, transversal axis, which contains the enabling actions for the hydrogen market in Costa Rica, as follows:

- Enabling conditions: aims to establish the necessary bases for the development of green hydrogen, along the value chain, to be safe, competitive, consistent, and reliable in the long term.
- Decarbonization of the transport and high-energy intensive industry sectors: aims to achieve the integration of green hydrogen and its derivatives in the transport and industry sectors, to mitigate greenhouse gas emissions at the national level through financing, integration of hydrogen in production, transport, distribution, and demand promotion plans.
- Development of a technological hub: its objective is to trigger actions that will turn the country into a technological hub by attracting commercial and technological partners for the development of hydrogen-related enterprises, businesses, innovation, and jobs to enable the exploitation and development of competitive advantages at the national level and in the region.
- Hydrogen exports: this block proposes actions to develop strategic alliances, international agreements, guarantees of origin, and attraction of foreign investment, which will allow Costa Rica to enter the international green hydrogen market.

It is noteworthy to mention that current estimates project that Costa Rica will be one of the less competitive players in the global green hydrogen market due to its high energy costs. Currently, Costa Rica's energy matrix is dominated by two relatively expensive renewables, hydro and geothermal power. Hinicio and GIZ (2021) calculate that by 2050 the Levelized Costs of Hydrogen (LCOH) would be 5.1 US$/kg based on geothermal energy and 3.4 US$/kg based on hydroelectric energy. The future is seen in wind (which would reduce costs to 1.24 US$/kg) and solar PV (1.68 US$/kg). It follows that Costa Rica may reasonably and in the first phases focus on the domestic use of hydrogen and not so much on exports.

2.3.1.2 International Support of NGHS

The GIZ, the Interamerican Development Bank (IADB), and the World Bank have supported the development of the NGHS in various ways. Most significant was a technical cooperation project approved by IADB in 2018, titled "*Camino a la Descarbonización: Promoviendo la Economía de Hidrógeno en Costa Rica*" (Towards Decarbonization: Promoting the Green Hydrogen Economy in Costa Rica", own translation). This project triggered the formation of the "Hydrogen Alliance", a public-private entity to develop business cases around green hydrogen. IADB also financed three important studies:

- In 2020, an environmental Life Cycle Analysis (LCA) of non-emitting vehicles (hydrogen and battery-electric), found that the GHG emission of both technologies are in the same range along the whole life cycle, implying that both are relevant for the decarbonization of the transport sector in Costa Rica.
- Also in 2020, an analysis of the total cost of ownership of non-emitting vehicles (hydrogen and battery-electric) and scenarios for market penetration were published. This document found that the heavy-duty transport segment might be dominated by fuel cell electric vehicles (FCEV) and that for the busses, a combination of battery technology and FCEV is likely to happen (the choice of technology will depend on the autonomy needs of the busses). GH2 will be most adequate for long-distance transport (>350 km/day).
- In 2021, a market study was carried out to identify the potential in Costa Rica for the adoption and production of hydrogen and its macroeconomic impact. The data generated in this study were taken as reference information for the NGHS.

The IADB also supported the elaboration of the NGHS itself. As this included the participation of 125 stakeholders from different groups, it was a lengthy and resource-absorbing process.

The GIZ, in close cooperation with MINAE, submitted a substantial proposal to the NAMA facility to catalyze the GH2 economy. The project is based on a financing model through national and international banks with credits and subsidies, as well as a package of complementary technical assistance measures. This is intended to ensure that those, who want to produce green hydrogen, buy fuel cell electric vehicle (FCEV) trucks, or adapt their industry to the use of green hydrogen, can do so by accessing funds and becoming early movers.

2.4 Other Relevant Sector Policies

Four policy documents of the past years are relevant to analyse the framework in which a green hydrogen economy may unfold in Costa Rica, the goals that are being pursued, and the measures that could be taken in this context:

- In 2015, the Ministry of the Environment and Energy (*Ministerio de Ambiente y Energía, MINAE*) presented the Seventh National Energy Plan 2015-2030 (NEP 7).
- At the beginning of 2019, the Government presented the National Decarbonization Plan (NDP) with a vision up to the year 2050 (*Plan Nacional de Descarbonzación*).
- In April 2022, the National Strategic Plan of Costa Rica 2050 (Plan Estratégico Nacional 2050, PEN), elaborated by the Ministry of National Planning and Economic Policy (MIDEPLAN 2022) was presented.

- In November 2022, the National Green Hydrogen Strategy (*Estrategia Nacional de Hidrógeno verde de Costa Rica*) was presented by MINAE.

Before presenting the papers in some detail, it should be mentioned that all four documents were initiated and elaborated under the administrations led by PAC and largely supported by other political actors of the "green social contract". After PPSD took over the presidency in May 2022, it seems less clear whether the new government will make strong efforts to implement the strategies and plans, at least regarding the "green elements". We will come back to this further down when we discuss the deliberations around the Green Hydrogen Law.

Seventh National Energy Plan 2015-2030 (NEP 7)

The vision of the NEP 7 is described as achieving energy sustainability with low emissions. This overall orientation is broken down into the three dimensions of sustainability:

In the ***economic dimension***, the first challenge is seen as contributing to the country's industrial competitiveness by increasing the efficiency of the electricity system in the generation, transport, and supply of electricity. The second is to reduce the costs of the national economy associated with the transport of people and goods. The third challenge is that energy policy must favor macroeconomic balance by reducing the oil bill and the fourth is that it must provide an adequate level of energy security, both for production and consumption activities.

In the ***social dimension***, energy efforts shall be geared towards a sustained increase in the quality of life of the population. Six action lines are defined: The first is to increase the quality of electricity services. The second is to increase the supply of electricity capable of meeting the expansion of residential demand for electricity; the third is to reduce travel times by public and private means of transport; the fourth is to reduce the pollution associated with the use of different sources of energy; the fifth is to protect the environment. The fifth pathway to social welfare is to protect existing sources of employment and promote the creation of new jobs based on sufficient energy supply and the contribution of the energy sector to industrial competitiveness. Finally, the sixth action line is to mitigate the negative impacts of large energy sector projects on the populations located in their vicinity.

In the **environmental dimension**, the country's energy sector shall be geared toward an economic development increasingly low in greenhouse gas emissions. Emissions, recognizing that the energy sector produces about 80 % of the country's total greenhouse gas emissions. With the successful decarbonization of its energy sector, the country could set an example for other countries and strengthen the country's position in international climate negotiation.

The plan defines a series of axes for two subsectors: electricity and transport.

<u>In electricity:</u>

1) The axis "On the path to energy efficiency" focuses on achieving a higher level of efficiency of the current electricity matrix.
2) The axis "In pursuit of optimal distributed generation" aims at opening up real conditions for residential and business electricity consumers to participate in small-scale electricity generation.
3) The axis "On the road to the sustainability of the electricity matrix" is oriented towards provoking changes in the current electricity matrix, to increase the overall efficiency of the

National Electricity System and, at the same time, contribute to the achievement of the environmental and social objectives of the National Energy Plan.

4) The axis "Around the sustainability of electricity development" aims to improve the institutional capacity required to address the environmental aspects of the energy sector.

In transport:

5) The axis "Towards a more environmentally friendly vehicle fleet" includes actions aimed at the renewal of the vehicle fleet to incorporate lower emission technologies, the improvement of emission control regulations, and the promotion of efficient driving and fuel-saving practices.
6) The axis "Towards sustainable public transport" promotes the increased use and efficiency of public transport and the development of non-motorized transport.
7) The axis "On the road to cleaner fuels" includes actions to improve the quality of fuels to reduce emissions derived from their use, develop the biofuels industry and alternative fuels such as biodiesel or hydrogen, and make the necessary regulatory changes for their incorporation into the national energy matrix.

It is remarkable, that already in a policy paper from 2015 green hydrogen is mentioned as an option for decarbonizing the energy sector of the country, related both to the transport sector and as a possible option for storing energy. Moreover, already in 2015, around 99% of Costa Rica's electricity came from renewable systems. Unlike in many other countries, the bulk of renewables comes from hydropower and geothermal energy, two energy sources with low volatility. Thus, in the current NEP, the storage issue is not very crucial. This might change in the future if additional renewable energy sources are based on wind and solar energy.

National Decarbonization Plan (NDP)

In the NDP, approved in early 2019, Costa Rica commits to becoming a decarbonized economy with net-zero emissions by 2050. This vision is the long-term goal underlying the plan. The government at that time saw the plan as consistent and aligned with the Paris Agreement and the goal of limiting the increase in temperature to a range between 1.5°C and 2°C. Due to its long commitment to development in line with the protection of the environment, it also sees Costa Rica well positioned to take an internationally leading role in its aspirations to be a modern, green, and emission-free economy.

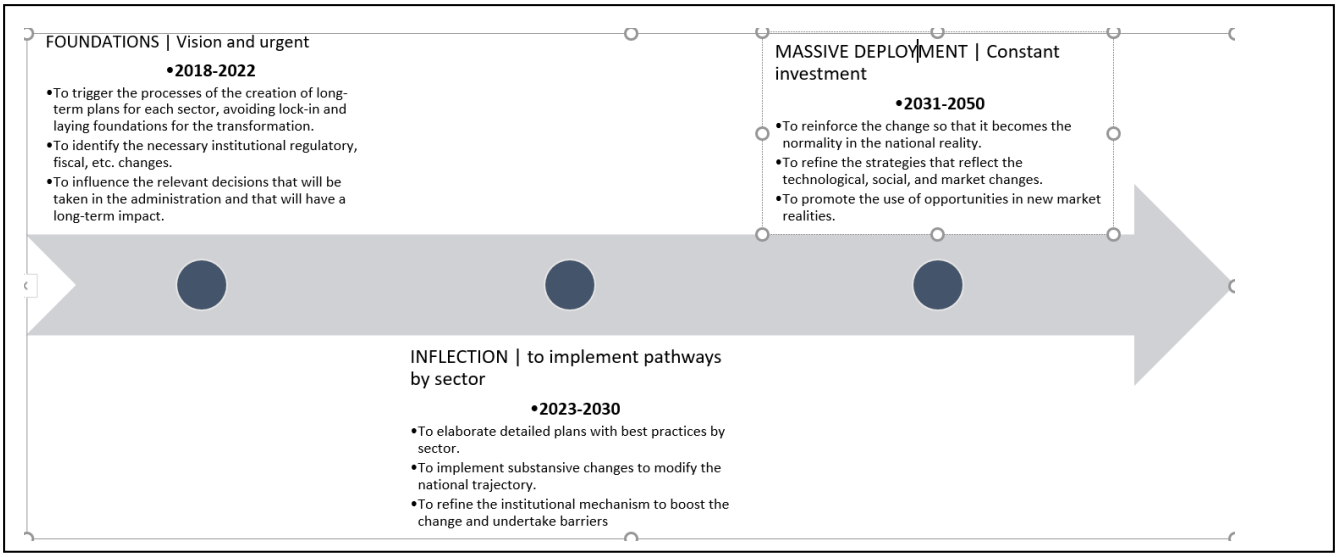
The document describes a strategic planning effort, based on a long-term vision, but structured around actions in several stages. Developing a decarbonization plan requires new planning methodologies to achieve transformational changes. Bringing GHG emissions to zero, while still looking for economic growth and improved social welfare requires deep decarbonization. This cannot be achieved through incremental adjustments alone but will require substantive technological, institutional, and economic changes. For instance, most of the energy and transport sector activities, among others, must be carried out with technologies different from the ones currently in use. This exemplifies the scale of the planning challenge that underlies a decarbonization strategy and the need to implement new methodologies of development planning. Decarbonization planning requires establishing clear long-term goals making it possible to identify a general pathway and then deduce the necessary actions in the short- and medium-term to reach the goal. Based on this, the work begins by determining what changes - institutional, market, price, and regulatory, among others - must be realized to fulfil the

trajectory. Simultaneously, just transition measures must be implemented so that people, communities, and businesses that have to reorient their activities have the necessary support to do so.

The actions sketched in the NDP are presented in three stages (see Figure 1): foundations (2018-2022), inflection (2023-2030), and massive deployment (2031-2050), each with different levels of detail.

- The first stage of foundations (2018-2022) contains urgent and foundational actions, necessary not only for their immediate impacts but also for generating conditions for a substantive transformation.
- The second stage of inflection (2023-2030) covers the period for the pathway change towards transformation. The interdependencies between different sectors shall be carefully examined. With this knowledge and support, decisive interventions that will redirect the markets toward zero emissions will be completed. In addition, deep institutional changes shall be implemented to reduce the barriers to change.
- For the third stage of normalization of the change or mass deployment (2031-2050), the goals and planned activities are much less detailed than in stages one and two, as the knowledge about the concrete situation in the world is limited. The plan assumes, however, that action implementation will be easier to appropriately execute as old assets, for example, equipment and facilities that have ended their usable lifespan and will be replaced with new ones that will already be equipped with decarbonized technologies.

Figure 1: Actions undertaken in NDP



The NDP analyses the four main remaining sources of GHG emissions in Costa Rica:

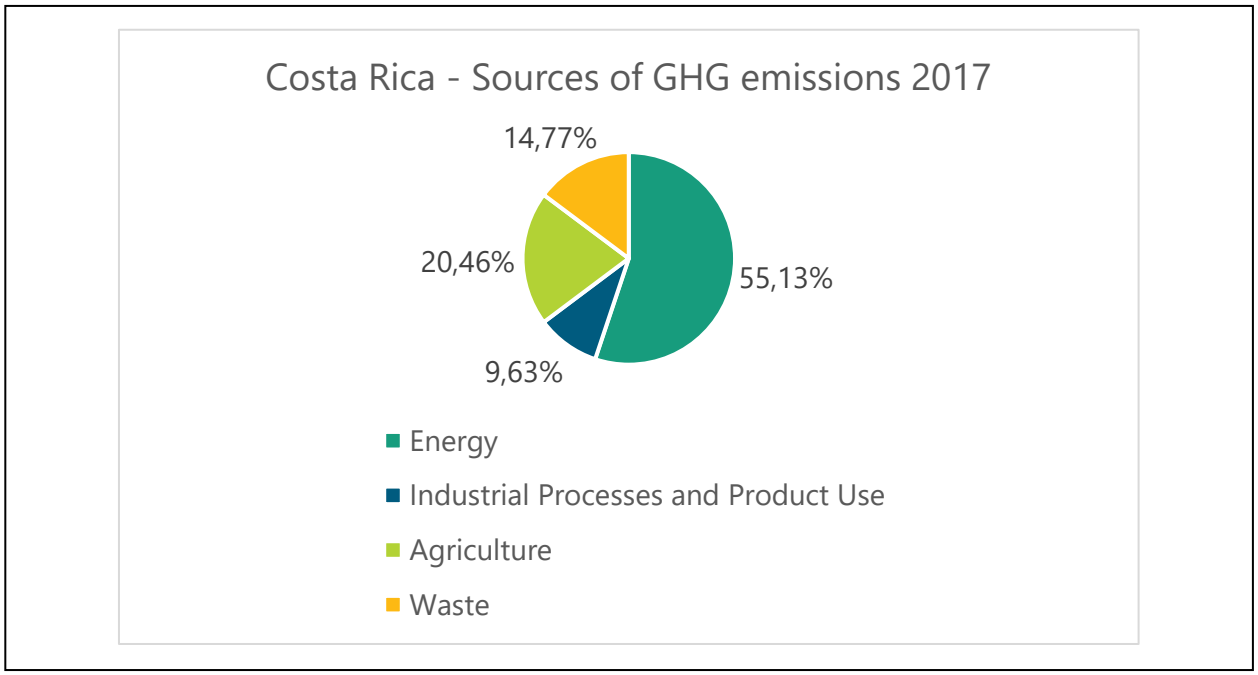
- Energy: mainly fuels used in private and public transport of passengers and cargo, while the electricity system has been fed by nearly 100% by renewable energies for a couple of years.
- Industry: Costa Rica has few GHG-intensive industries. The NDP mentions cement production as relevant. It does not mention fertilizers. While Costa Rica hosts a strong player in

the fertilizer business (Fertica), the carbon-intensive steps (e.g. Haber-Bosch process for ammonia synthesis) happen outside of the country and are not counted as GHG emissions of Costa Rica.

- Waste: Landfills in Costa Rica produce methane, which is a very powerful GHG.
- Agriculture, Forestry, and Other Land Uses (AFOLU): In the agricultural sector, greenhouse gas emissions mainly come from four productive activities: coffee, sugarcane, and musaceas (predominantly bananas) in relation to nitrous oxide emissions; and rice cultivation, for methane emissions. In the livestock sector, greenhouse gas emissions stem from enteric fermentation and excreta handling, and this corresponds to methane emissions.

The NDP has a clear focus on the transport sector, three of the ten intervention axes relate to public and private passenger transport and freight transport. This reflects the fact that transport is the main sector standing for the remaining GHG emissions of Costa Rica.

Figure 2: Costa Rica - Sources of GHG emissions 2017

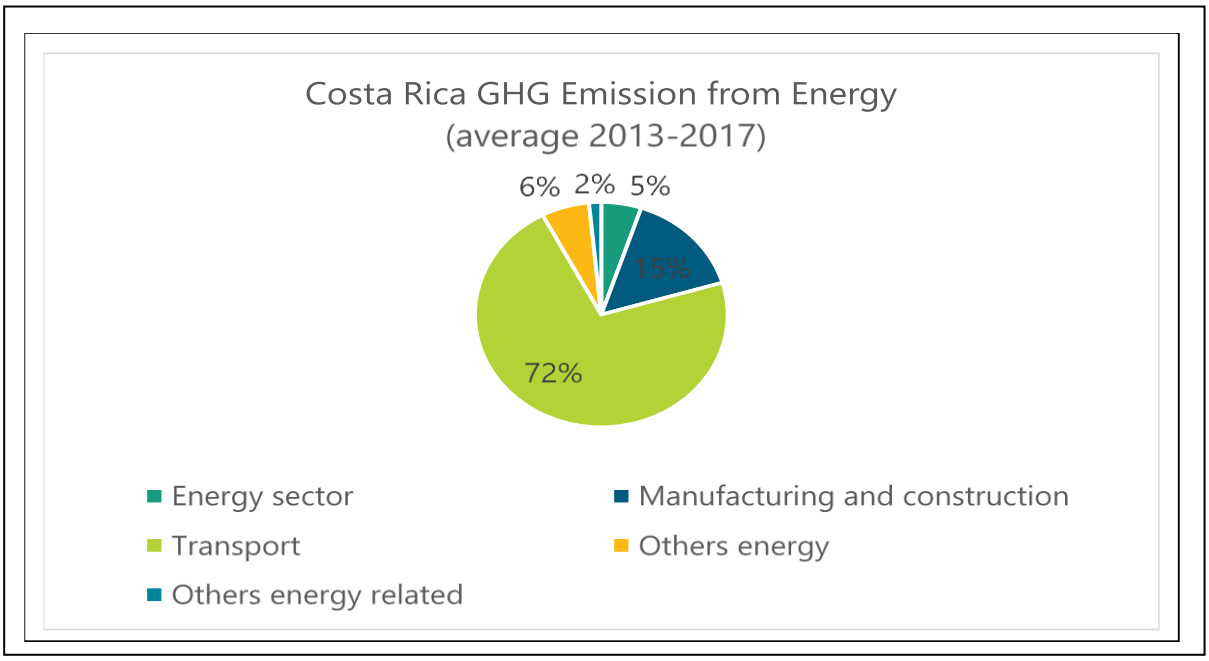


Source: Own calculations based on MINAE / IMN 2021

In Figure 2, we can see that overall, the energy sector stands for 55% of all GHG emissions in 2017.[3]

[3] Calculated without the negative emissions from Forestry and Other Land Use, which are negative in case of Costa Rica, due to significant afforestation efforts.

Figure 3: Costa Rica GHG Emission from Energy (average 2013 – 2017)



Source: Own calculations based on MINAE / IMN 2021

Within the field of energy, the transport sector is dominating the emission field, with 72% of all energy-related emissions, compared to 15% for the manufacturing industry and the construction sector (see Figure 3).

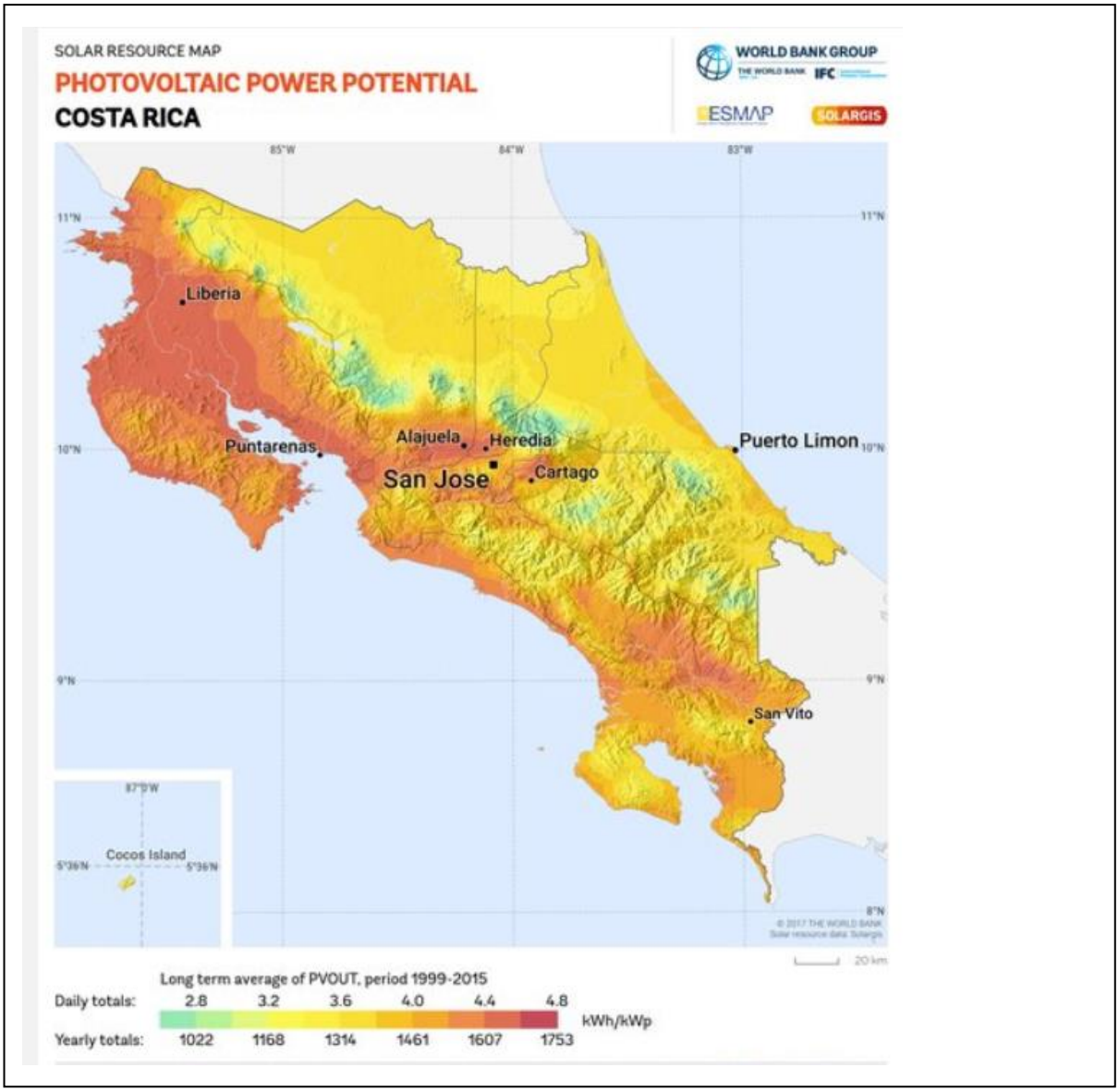
National Strategic Plan of Costa Rica 2050 (PEN)

In April 2022 (a few days before the transition of the government from PAC to PPSD), the Ministry of National Planning and Economic Policy (*Ministerio de Planificación Nacional y Política Económica*, Ministry for National Planning and Economic Policy, MIDEPLAN) presented the National Strategic Plan of Costa Rica 2050 (*Plan Estratégico Nacional*, PEN). The document is a long-term planning instrument that outlines a path for achieving a vision of sustainable development in Costa Rica. MIDEPLAN prepared the document with the support of the institutions, sectors, and subsystems of the National Planning System (SNP). Citizen participation was also a part of the planning process.

The National Strategic Plan of Costa Rica 2050 aims to build a more prosperous nation through sustained growth and equity with equality of opportunities. The vision is a "3D society" (decentralized, digitalized, decarbonized). The document also seeks to prepare Costa Rica for global changes and challenges. Specifically, it aims to make the nation resilient to climate change and decarbonize the nation's economy. When it comes to the decarbonization dimension of 3D development, PEN refers to NDP and mainly breaks it down to opportunities and challenges on the regional level. The main concern of the NEP is to increase social and territorial coherence of development and strengthen regions, which have been bypassed by many of the economic and social developments of the past two to three decades (see Chapter 1). The PEN contains 109 specific prescriptions that propose investments involving infrastructure projects, public policy initiatives, plans, and social programs to achieve these objectives. These are organized into five strategic theme areas: Social Inclusion, Human Capital and Innovation, Infrastructure and Connectivity, Economic Development, and Decarbonization.

For the options to implement a green hydrogen strategy, the PEN is relevant for several reasons: The coastal areas along the Pacific coast will play an important role in scaling up renewable energy generation, required for large-scale GH2 production. The North-Western province of Guanacaste and parts of the central Pacific region have by far the best photovoltaic power potential. In addition, large-scale electrolysers would most likely be located close to the two international ports, which are Limón on the Caribbean and Puntarenas on the Pacific coast. In the best case, international money coming to Costa Rica from GH2 investment could meet the major financial needs identified in the PEN specifically for coastal regions.

Figure 4: Costa Rica's Photovoltaic Power Potential



On the other hand, as the past two elections indicate, there is a great deal of frustration and mistrust among the population of the coastal regions. It is therefore important to avoid raising expectations that are ultimately not fulfilled. On the positive side, successful and labour-intensive GH2 projects could make an important contribution to Costa Rica's territorial and social cohesion.

2.5 Quality of policy formulation

In the process of policy formulation for the NGHS, the high level of stakeholder consultation and participation is remarkable. The governance tradition in Latin America is more of a top-down policy making with the government and its agencies defining goals, priorities, and actions to be implemented. 125 national (91) and international (34) GH2 stakeholders were identified, 57 from the private sector, 28 associations, 9 representatives of academia, 18 from the national government, 4 from other governments, 3 international associations, and 6 multilateral banks. Public hearings, participatory workshops, and individual interviews were conducted to gather information and raise and form opinions.

In more general terms, until the national elections in 2022, policymaking in Costa Rica was at an exceptional level in the regional (Latin American) context. The political parties, which dominated policymaking over many decades until 2022, were committed to a relatively broad consensus, as shown through the "green social contract". Thus, during previous changes of government, from PUSC to PLN or vice versa, strategies and road maps in important policy fields were not abolished as is quite common in other countries in Central and South America. Similarly, when PAC - as a new party - gained power in 2014, policy pathways and strategies largely remained the same. PAC is also committed to the "green social contract".

However, with the 2022 elections, policymaking became a more difficult undertaking. President Chaves belongs to the *Partido Progreso Social Democrático* (PPSD). After the election campaign and the first year in office, it can be assessed that President Chaves and his party do not see themselves as part of the "green social contract". This is indicated by the fact that Costa Rica, after a few months in office, decided to discontinue the leadership (together with Denmark) of the international "Beyond Oil and Gas Alliance" (Rodriguez, 2022). Interestingly, in February 2023, a member of the Costa Rican parliament (Asamblea Legislativa), who belongs to President Chavez's Parliamentary group presented an initiative of a law to "declare Costa Rica a country free from oil and gas exploration and exploitation". This may be seen as a sign, that the 2022 shift in government does not imply a radical departure from the "green social contract".

3 Stakeholders of the GH2 mission, interests, and policy goals interests

3.1 GH2 Stakeholders and their Interests

A variety of actors, predominantly from government and industry, have been active in the development of a green hydrogen economy in Costa Rica. In the following, we outline the identified interests of key stakeholders in this process as it has unfolded until now. We particularly focus on potential similarities and differences between stakeholder positions. Through this focus, we highlight coalitions in support of the developing green hydrogen economy, potential hydrogen exports in the future, and actors and standpoints that could present a barrier to these developments.

The line ministry for drafting the NGHS has been MINAE. Combining energy and environment in its mission and competencies can be seen as both a challenge and a big opportunity in policymaking for green hydrogen, which is both an energy carrier and also an option for further lowering GHG emissions. The development of the country's hydrogen roadmap was assisted by the Ministry of National Planning and Economic Policy *(MIDEPLAN)* as well as other ministries, such as the Ministry of Public Works and Transport *(MOPT) and the* Ministry of Treasure *(MH)*. It is noteworthy to repeat that the MINAE leadership changed after the 2022 election and that the new minister, Franz Tattenbach, represents a more distant stance towards green hydrogen and the NGHS than previous administrations.

A similar observation can be made about the Green Hydrogen Bill, which also was drafted under the PAC administration. The bill was passed in the first reading before the change in government. However, before the second reading scheduled for August 2022 could take place, eleven members of parliament presented an appeal to the constitutional court, as they saw the law violating the constitution. In November 2022, the court ruled that no parts of the law significantly violate the constitution. However, the legislative process has been stopped and has not been taken up again by the time of writing this report. Experts and observers interviewed in 2022 and 2023 argue that the opposition to the hydrogen law, by the President and the parties backing him in parliament, should not be seen per se as a disagreement with the general idea of promoting green hydrogen as a decarbonisation technology for Costa Rica. Rather, there seem to be aspects related to the proposed institutional setting and the fiscal incentives, which drive many of the actors to oppose the law. They mention, for instance, the preferences given to state-owned enterprises, such as ICE and RECOPE over private companies in the production of green hydrogen and the very high financial incentives proposed, which might exacerbate the problems with the already high fiscal deficit.

To conclude, while green hydrogen development was seen as a priority to decarbonize under the previous administration in Costa Rica, the current government appears more hesitant and sceptical while still advancing the country's path towards decarbonization efforts with more liberal market orientations.

A second core actor in the green hydrogen field is Costa Rica's ***Institute of Electricity (ICE***). The government-owned electricity provider holds a monopoly over the country's electricity generation and distribution. This allows ICE to control the transmission lines and decide

whether private producers can access their grid. The institution also determines the amount of renewable energy, including green hydrogen, which can be produced in the country through its allocation of permitted capacity. In some regions, ICE has granted concessions to municipal and cooperative companies to generate electricity, e.g. by small hydropower plants, and distribute it to the regional population. Any investor wishing to buy electricity from the national grid has to negotiate the conditions with ICE. The exception would be if investors aim at establishing green hydrogen plants exclusively with their generation capacities and without being connected to the grid. Such a hydrogen "enclave" would, however, imply not using all of the potential advantages Costa Rica might have: With an electricity system nearly 100% based on renewables, buying electricity from the grid could significantly reduce the lead time for starting the production of GH2. Generation capacities could then be expanded gradually, to the extent that the electrolysis would require increasing amounts of electricity. Having backup by a renewable electricity system fed by permanent supplies (hydro and geothermal power) could significantly increase the full load hour of electrolysers, contributing to cost reduction.

Third, Costa Rica's utility regulator **ARESEP** (*La Autoridad Reguladora de los Servicios Públicos*) has the mission to provide publicly regulated services at optimal access, cost, quality, and variety and will play an important role in regulating and monitoring the country's already high electricity rates compared to other countries in the region.

A final relevant stakeholder in the category of public entities and state-owned enterprises is **RECOPE** (Costa Rican Petroleum Refinery S.A), a petroleum refinery, whose interests might diverge slightly from the previously listed government and public institutions. Currently, RECOPE is not allowed to produce or sell hydrogen even though they have established infrastructure to store and transport fuels. With the Green Hydrogen Law, Costa Rica's former government had planned to allow RECOPE to enter the hydrogen market but this change did not happen before the change of government in 2022. It remains to be seen how the country's current government will view this development as fossil fuels are projected to still be needed to transition in the short- and medium-term and for some sectors in the long term (A government stakeholder, personal communication, November 2022).

Industry stakeholders:

The objectives of industry stakeholders are multifaceted although a large majority appears to be in favour of green hydrogen development. Some emphasize the importance of focusing on national development and the use of green hydrogen and highlight the need to establish appropriate infrastructure as well as regulation (for example to obtain permits for RE-Sites and other required infrastructure promptly). Others emphasized the development of Costa Rica as a technology hub for green hydrogen or potential export options in the medium- to long-term. Two green hydrogen pioneers in the private sector can be identified:

- **Ad Astra Rocket** is a US-Costa Rican spaceflight technology company headquartered in Houston, Texas, dedicated to the development of advanced plasma rocket propulsion. It was founded by former NASA astronaut, Costa Rica-born Franklin Chang. Since 2007, the Costa Rican branch has been located in the Western province of Guanacaste. In 2009 the company changed its mission towards developing renewable energy solutions, with a focus on green hydrogen. In 2011, it established the first GH2 project in Costa Rica: A small electrolyzer to produce green hydrogen to fuel a fuel cell bus providing services to up-market

rental cars in the region of Guanacaste, which is an important destination for international tourists.

- **Cavendish S.A.** is part of the *Grupo Purdy*, which is the main importer of Toyota cars to Costa Rica. Cavendish is named after Henry Cavendish, who - in the 18th century - was the first scientist to describe the chemical properties of hydrogen. Cavendish's mission is to promote and develop projects in Costa Rica and the Central American region related to green hydrogen. In early 2023, Cavendish signed an agreement with Atome Energy from Great Britain to develop projects in the field of green ammonia and fertilizers in Central America.

To date, no other companies in Costa Rica have made a clear commitment to the green hydrogen economy. This may be partly attributed to Costa Rica's relatively small steel and cement industry compared to other Latin American countries. While green hydrogen has been identified to potentially increase the capacity of the country's steel industry, the most important domestic sector for hydrogen application is seen in long-distance and heavy-duty transport. Interestingly though, particularly considering the incipient status of the green hydrogen cluster in Costa Rica, there are two umbrella organizations for the sector: **The Costa Rican Hydrogen Association**,[4] and the **Hydrogen Alliance.**[5] Both have similar missions by pursuing the development of hydrogen technologies as energy vectors in the country and overlapping memberships, mostly consisting of public and industry entities. Both have published important technical documents, which may help targeted policymaking related to green hydrogen.

Agriculture constitutes another relevant sector in the development of green hydrogen in Costa Rica. The agricultural lobby is quite influential and can constitute an important player either in favour or as a challenger of a green hydrogen economy depending on land-use competition as a potential obstacle or the use of green hydrogen for the production of fertilizer.

Other *intermediate actors* include the Cámara de Comercio e Industria Costarricense Alemana (AHK Costa Rica), representing German industry interests in the region, the German Corporation for International Cooperation (GIZ) the Inter-American Development Bank (IADB), and the Costa Rica United States Foundation for Cooperation (CRUSA). These actors play an important role in ongoing studies and assessment of a potential green hydrogen market in and for Costa Rica. The latter two worked under the request of MINAE and were key stakeholders in the development of the country's national hydrogen strategy (see also section 2.3.1.2*)*.

Civil society concerns are partly covered by the environmental sector as a stakeholder in the country's energy development. In Costa Rica, NGOs, biologists, and national park managers, often in cooperation with the country's important eco-tourism sector have a major influence on conservation policy. Indigenous communities as a distinct and relevant group of stakeholders find official representation through the state-introduced *Asociaciones de Desarrollo Integral Indígena (Indigenous Association of Integrated Development)* whose legitimacy is, however, questioned by many indigenous groups (Wallbott & Florian-Rivero, 2018). More legitimized and accepted representation of indigenous interests is reported for the *Mesa Nacional Indígena* (National Indigenous Board; Mamo, 2022; Miller, 2006).

4 Asociación Costarricense de Hidrógeno: http://ach2.org/

5 Alianza por Hidrógeno: https://alianzaporelhidrogeno.cr/

Additionally, there are tribe-specific associations relevant to participatory processes in the regional development project of renewable energy (Mamo, 2022).

Moreover, civil society in Costa Rica is also partly represented through a strong labor union, which in the past has often been in support of renewable energy policies and activities of the government and ICE. It remains to be seen how this will develop with the emergence of new political parties in recent years and the rise to power of the center-right *PPSD*. Additionally, some perspectives see labor rights as somehow lacking in Costa Rica as only 2% of all workers are members of a union (Martens et al., 2018).

Finally, **universities**, such as *Universidad de Costa Rica* and *Universidad Técnica Nacional*, play an important role in the development of a Costa Rican green hydrogen economy by conducting research into green hydrogen technologies. However, their lack of involvement in the development of current strategies and planning is a point of contention among policy and industry stakeholders in the country.

3.2 Policy Goals and Stakeholder Interests

Currently, it seems impossible to assess, whether or not Costa Rica keeps committed to a "green social contract". On the one hand, the government repeats its commitment to biodiversity conservation and climate protection. On the other hand, it is clear that under its ruling the country will not sacrifice goals of productivity enhancement and growth to environmental objectives. There are, however, signs that this "deviation" from the green social contract of the country will not last beyond the next elections, the latest in 2026. Cracks in the ruling coalition are becoming increasingly evident. For instance, in August 2023, MINAE Minister Tattenbach with the support of President Chavez decided that they would react positively to a request by UCCAEP, the umbrella organisation of Costa Rica's chambers and business association, to make an inventory of the natural gas reservoirs on Costa Rica's territory, which could be seen as a first step away from the ban on exploration and exploitation of fossil fuels. At the same time, a MoP belonging to Chavez' party PPSD presented a bill to the Legislative Assembly under the title "Law to declare Costa Rica as a country free of oil and gas exploration and exploitation".[6] It should be noted that the "green hydrogen vision" is rather incipient in Costa Rica, implying that there is not a lot of knowledge and information among civil society actors to form clear positions in favour or critical of the green hydrogen economy. Similarly, except for some hydrogen pioneers, clear commitment to the green hydrogen economy from industry actors in the country is so far missing. This will most likely change, once concrete projects are formulated and impacts may be assessed regarding e.g. the generation of employment opportunities in different regions or possible conflicts around land-use issues.

[6] Asamblea Legislativa de la República de Costa Rica: Proyecto de Ley. Ley para Declarar Costa Rica Como País Libre de Exploración y Explotación de Petróleo y Gas. Expediente No. 23.579, San José, Asamblea: Expediente 23579 - Delfino.cr Asamblea: Expediente 23579 - Delfino.cr

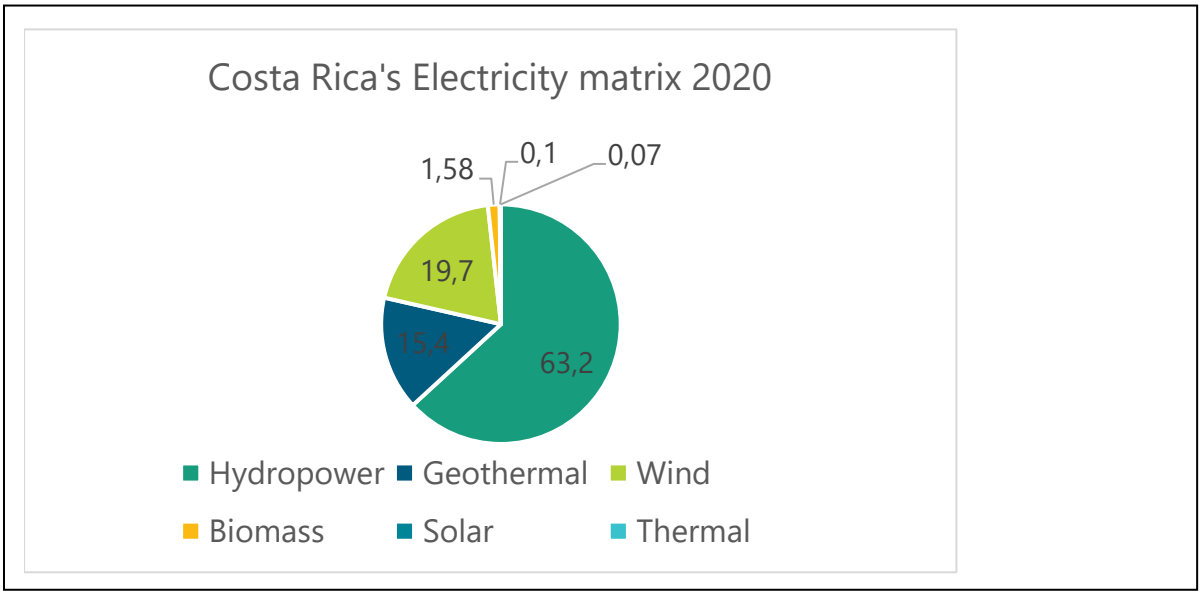
4 Opportunities and Challenges

4.1 Natural and Production Capital

4.1.1 Natural and Energy Resources

Costa Rica has very favourable conditions for the generation and usage of renewable energies. During the past couple of years, the contribution of renewable energies to all the electricity generated was around 98%. In 2020, thermal energy generation was only 0.7%. The most important power source was the 33 hydropower plants, which together produce 63% of all electricity consumed in the country. ICE estimates a theoretical technical potential (technically exploitable with currently available technologies) of 33 TWh/year (7137 MW of installed capacity) for hydroelectric energy and 5.3 TWh/year (875 MW of installed capacity) of geothermal energy.

Figure 5: Costa Rica's Electricity Matrix 2020



As a volcanic country, Costa Rica offers exceptionally good conditions for the generation of geothermal energy, which the country started to exploit in the 1990s. Its pronounced geomorphology also allows the use of hydropower without having to submerge large areas of land. Since 1996, the country has been enjoying the benefits of wind power, and wind energy currently covers about 5% of the country's needs. The seasonality of wind is complemented by hydroelectric production since the strongest winds occur in the dry season. Solar energy is the least developed energy form in the country. Today less than 0.1% of the electricity matrix is covered by solar energy. It is here where the largest potential for expansion of energy generation is expected.

The Colombian consultancy Hinicio, in the year 2021, calculated that by the year 2030, Costa Rica has the potential to produce 207 TWh of solar and wind energy within the price range of 20 US$/MWh and 25 US$/MWh (Hinicio & GIZ, 2021). This amount of energy is 20 times the

electricity consumption of Costa Rica in 2018. Installing all renewable solar and wind power plants in Costa Rica to produce the 207 TWh/year of the chosen percentiles for hydrogen production, would mean devoting 5% of the national territory to the installation of photovoltaic parks and a further 1% to wind farms, deployed mainly in the northwest region of the country.

The renewable potential of the four sources hydro, geothermal, wind, and solar would allow a total of 244 TWh, which significantly exceeds ICE's projected demand for electricity in Costa Rica, which could be around 20 TWh/year, in the decades to come. These estimates indicate that it is possible to advance the use of renewable energy for the production of green hydrogen without compromising electricity generation for Costa Rica's national electric system (Hinicio & GIZ, 2021).

4.1.2 Water

In the context of analysing opportunities for large-scale production of green hydrogen, water is of relevance for two reasons:

- In countries with huge water stress, the mere availability of water for hydrogen production (10 liters per kg) may be questionable if conflicts with the drinking water supply of the population and the needs of agriculture are to be avoided.
- In countries with no severe water stress but dependent on the generation of electricity with hydropower, sufficient rainfall is needed to refill the reservoirs.

The first challenge constitutes no risks in the case of Costa Rica. With 2926 mm of annual precipitation on average, Costa Rica is among the countries in the world with the highest absolute rainfall. However, the high dependence of Costa Rica on hydropower may lead to challenges with global warming and more irregular rainfall patterns. In the wake of El Niño Southern Oscillation (ENSO), affecting the region in 2023, there are first indications that the country might have to rely more than expected on fossil fuels, as the refilling of Arenal Lake, Costa Rica´s largest reservoir lake might not happen at the required speed to keep up the full energy harvest.

4.1.3 Built infrastructure

Costa Rica's economy has been open to the world market since the 1980s and has, thus, a solid infrastructure for importing and exporting goods, both in the country's East (Puerto de Moín, Limón) and the West (Caldera, Puntarenas). Puerto Limón is the largest port with nearly 2500 vessels visiting per year, followed by its direct neighbor Moín (898 vessels in 2022). Many fewer ships visit the Pacific Ports Caldera (117) and Puntarenas (30). Cruising ships are one important category of vessels, as well as container, bulk ships, and fishing vessels. For the context of a possible hydrogen future, it is important to know that in Puerto Moín, close to "Pier 5" (for imports of crude oil and oil products) the state-owned RECOPE has a refinery, which has been enlarged and modernized since 2007/08 forming a joint venture with a Chinese company. Since 1967, RECOPE has started the construction, enlargement, and modernization of a "poliducto" a network of pipelines connecting Moín, through the Central Valley (main urbanized area) and down to Puntarenas on the Pacific side of the country. The former government planned to re-construct a railway for cargo transports between Limón and San José, but the current government has put the project on hold.

4.2 Human and social capital

As outlined in Chapter 1, Costa Rica invested in free and universal education as early as 1869. Thus, it does not come as a surprise that the literacy rate was 98% in 2021 and that in 2016 (last available data) 93% of all pupils reached the final grade of primary (97% of female pupils). In 2018, 82% of all people in the relevant cohort were enrolled in secondary education, compared to 78% in the region LAC.

In the 2022 Global Innovation Index (GII), Costa Rica ranks in place 68 of 132 assessed countries, and is ranked seventh among Latin American countries; this is a modest performance for the ambitions of the country because the countries joined the OECD in 2021.

4.2.1 Human resources

If we look at the sub-indices of the GII, Costa Rica fares quite well in "Education" (rank 45). What stands out are the rankings in "Expenditure on education" (10 of 132) and School life expectancy in years (23 of 132). In terms of tertiary education, Costa Rica underperforms and ranks only 89 of 132 countries. This is mainly due to a low percentage of graduates in science and engineering (90 of 132) and tertiary inbound mobility (87). This implies that the percentage of students in innovation-related faculties is too low and that Costa Rican universities are not very attractive to foreign students.

A strength of Costa Rica's innovation system is the fact that brain drain is not a real issue. In general, emigration is low, and Costa Rica is among the few developing countries with a positive net migration rate, meaning that immigration is higher than emigration. Among younger people, brain circulation is much more the norm than brain drain. After finishing undergraduate or graduate studies at a Costa Rican university, people go abroad for a Master's and/or a PhD. Most of them will afterward return to Costa Rica to take up knowledge-intensive employment.

The GII does not cover the performance of countries in technical and vocational education and training (TVET). However, it is evident that for establishing a GH2 economy in Costa Rica, technical and vocational skills ("below" an academic degree) are going to be in high demand. The quality of technical and vocational training (TVET) in Costa Rica is internationally recognized. The National Training Institute (*Instituto Nacional de Apprendizaje*) is well known for quality assurance and is permanently updating its curriculum of dual and virtual courses. However, data from UNESCO-UNEVOC[7] indicate that the percentage of young people enrolled in vocational training might be insufficient. The most recent numbers for Costa Rica are 109,000 people enrolled in TVET courses, 7.7% of the youth. Compared to the regional good performers in the GII, the percentage in Colombia is 8.7%, in Uruguay 10.7%, and in Mexico 12.4%. Only in Peru (0.8%) and Brazil (3.5%) the vocational training participation rates are below Costa Rica. Whether the data are completely comparable or whether methodological issues distort the picture cannot be discussed here. It seems reasonable to assume that in Costa Rica the willingness to enroll in a TVET program might be lower than in other countries, as free university

[7] https://unevoc.unesco.org/home/Dynamic+TVET+Country+Profiles/country=CRI

education attracts many young people to an academic career and subsequent, well-remunerated white-collar jobs.

4.2.2 R&D institutions, incubators

Two macro indicators can help to map the efforts of countries in promoting science, technology, and innovation: a) the total spending of society in research and experimental development and b) the percentage of researchers in the overall labor force. Table 2 shows the relevant data for the seven "top performers" in the GII:

Table 2: Seven "Top Performers" in the GII

Country	R&D spending as a percentage of GDP (2018)	Researcher per million in the labor force (2018)
Costa Rica	0.37%	345
Brazil	1.17%	n.d.
Chile	0.37%	524
Colombia	0.31%	88 (2017)
Mexico	0.31%	311
Peru	0.31%	n.d.
Uruguay	0.51%	n.d.

Source: UNESCO Institute for Statistics (n.d.)

The numbers indicate that Costa Rica is performing relatively well in both indicators. However, it should be noted, that none of the countries in Table 2 has managed to improve regarding the R&D spending in the last decade, most managed to maintain the (relatively low) level, and in Brazil and Costa Rica the percentage tends to decrease. The main reason is the tight budgets in most Latin American countries. This implies, however, that the global gap in innovation capacities is widening, as most countries in the Global North (e.g. Germany, South Korea) are continuously increasing their R&D spending in absolute terms and as a percentage of GDP (see Stamm 2022).

Table 3: Data on the performance of Universities in Costa Rica

	Univer-sidad de Costa Rica	**Universidad Nacional de Costa Rica**	**Universdidad Estatal a Distancia**	**Instituto Tecnologico de Costa Rica**	**Universidad Tecnica Nacional**
Budget for research	CRC 39 billion (USD 70 million)	CRC 8,6 billion (USD 15 million)	CRC 1,2 billion* (USD 2 million)	CRC 4,3 billion* (USD 8 million)	CRC 861 million (USD 1,6
Number of researchers	1496	138*	123*	266**	23
Number of research papers	328 (0,2 per researcher)	93 (0,7 per researcher)	68* (0,5 per researcher)	158* (0,6 per researcher)	2 (0,08 per researcher)
Technological transfer office budget	CRC 95 million (USD 170 000)	n.a	No technological transfer office established	CRC 4,3 million (USD 10 000)	Technological transfer office under development
Technological transfer office personnel	9	12	No technological transfer office established	8	Technological transfer office under development

Notes: CRC: Costa Rican Colones (currency). *Data for 2014, **Data for 2016
Source: Data provided by public universities.

Source: OECD 2017

Most of the R&D in Costa Rica (around 70%) is funded by the government and executed in public universities.

Table 3 indicates that the largest university in terms of enrolment, Universidad de *Costa Rica (UCR)* (around 40.000 students), is also the undisputed number one in research, both in terms of funding and personnel. More recent data indicate that in 2021, the five public universities spent around 113 Mio EUR in R&D, more than 60% (69 Mio. EUR) UCR alone (Semanario Universidad 2021)[8] At UCR there is a small research team in the department CELEQ, working on options to use geothermal energy for the production of green hydrogen.

Two smaller universities are also relevant for applied research in energy and hydrogen: *Instituto Tecnológico de Costa Rica* (ITCR), one of the four traditional public universities in Costa Rica. A younger university with a technological focus in education and research is *Universidad Técnica Nacional*. Two of the 12 business incubators listed by the Ministry of Economy and Industry

[8] https://semanariouniversidad.com/universitarias/universidades-publicas-invierten-en-investigacion-y-desarrollo-mas-de-%e2%82%a170-000-millones-por-ano

(MEIC) are institutionally and spatially attached to ITCR and one to UTN.[9] As we can see in Table 3, the budgets for technology transfer from public universities are very low.

4.2.3 Implementing capacities

During the past three decades, Costa Rica has managed to take advantage of several windows of opportunity, which have opened up on the international markets and have allowed first-mover advantages. Examples are non-traditional agricultural exports, manufacturing of medical and orthopedic devices, eco-tourism, IT-enabled services, and the attraction of a large INTEL facility for testing of semiconductors. This has to do with both natural (climate and fertile soils) and human-driven (quality of human resources) locational advantages. In addition, the institutional system is effective. For the opportunities to establish a green hydrogen economy, three institutions (beyond those responsible for human resource development (Universities, INA) can be mentioned:

- *Promotora del Comercio Exterior* (PROCOMER) is the export promotion office. It hosts divisions for market intelligence and channels public support programs for the export sector.
- CINDE is a publicly funded institution for the promotion of international investments in Costa Rica. It has been praised for attracting international investors and companies in various fields, for instance, large business service facilities for companies, such as Hewlett-Packard and Procter and Gamble. Costa Rica's current government recently decided to terminate the public support to CINDE and transfer the competencies for investment promotion to Procomer.
- *Instituto Costarricense de Electricidad* (ICE) is Costa Rica's utility and has a monopoly on electricity generation and transmission. In addition, ICE is also in charge of landline telephone services and provides internet services through its subsidiary RACSA. In the past often considered a typical state-owned enterprise, slow in responding to consumers' demands and changes in the environment, ICE has gone through several institutional reforms and is today a rather agile company. The current corporate strategy (2023-2027) sees ICE contributing to a triple win (economic, social and environmental benefits).

4.3 Availability of funds for RDI

Costa Rica is committed to science-based sustainable development. However, national funding for RD&I does not live up to this commitment. The country is attractive for potential research partners from the Global North, but without stronger efforts "at home," international cooperation options are not taken advantage of.

4.3.1 National level

Costa Rica claims to be committed to science, technology, and innovation, but this is not reflected in public spending. In the year 2018, the ratio of gross expenditure on R&D (GERD)

[9] https://meic.go.cr/web/671/pymes/red-nacional-de-incubacion-y-aceleracion.php

and GDP was 0.37%, down from 0.54 % five years earlier (2013). In the same year, GERD was 0.66% on the average of the countries in Latin America and the Caribbean, and Brazil at 1.21%.

Table 4: Research, development, and innovation: Budget of MICITT 2019-2023

Budget of the Ministry of Science, Innovation, Technology, and Telecommunication (Ministerio de ciencia, innovación, tecnología y telecommunicaciones)				
Year	2019	2020	2021	2022
Total (in Million CRC)	8104	8378	8374	8792
Promotion of scientific and technological development (in Million CRC)	6129	6325	6303	6621
Total in (Million EUR)	12.32	12.84	12.83	12.08
Promotion of scientific and technological development (in Million EUR)	9.25	8.60	8.58	9.19

Source: https://www.crhoy.com/wp-content/uploads/2023/09/SIGYD_D_2023015694.pdf

From 2019, the MICITT budget shows a slight nominal increase but shrinks when converted into EUR. The MICITT dedicates around 75% to promoting scientific and technological development, and the remaining 25% is for telecommunication, which is part of the MICITT's mandate. The budget indicates that RD&I is not high on the agenda of Costa Rican policy. As a comparison: MINAE had a budget of nearly 43.000 Million Colones (57 Million EUR) in 2022.

4.3.2 International level

There is no institutionalized international funding to support RD&I in Costa Rica. There have been and still are international organizations active in Costa Rica and funding RD&I activities. Fundación CRUSA was founded in 1996 and is dedicated to promoting sustainable development. In August and September 2023, Fundación CRUSA announced several new projects with components of human resource development and RD&I:

- In the context of the project: "Accelerating the transition to electric public transportation in the Greater Metropolitan Area of Costa Rica" (2021-2025), Fundación CRUSA will provide six electric taxis to circulate in the Greater Metropolitan Area, whose performance will be monitored and evaluated. In this project, Fundación CRUSA cooperates with MINAE, UNDP, and the GEF:
- In cooperation with EON Reality, 5,750 students and lecturers will be trained, over five years, in artificial intelligence.
- In cooperation with the export promotion office PROCOMER, and the National Learning Institute (INA), the program Greentech funds SMEs (less than 100 employees) that develop and market green products and technical solutions.

The German Academic Exchange Service (DAAD) has its office for Central America in San José. Students and lecturers may receive scholarships to study or do a PhD in Germany. Other programs bring German lecturers to Costa Rican universities for shorter or longer stays.

Costa Rica is, in general, eligible to partner with European research institutions in projects of the Horizon Europe program. However, with relatively low levels of domestic funding, most RD&I in the country remains under the radar of potential European partners.

4.4 Greening the business sector

Costa Rica's industrial sector is relatively small. More so, when we look at subsectors that require a high amount of process heat. By 2050, hydrogen could represent between 6% and 10% of industrial energy demand, replacing up to 35% of LPG and bunker at the national level in activities such as wood production, paper, chemicals, and other industries such as steel or cement. The sector's hydrogen demand in 2030 could reach 2 kton H_2/year by 2050. It could rise to 25 kton H_2/year.

4.4.1 Metal industry (iron and steel. aluminum) and glass

Compared to other Latin American countries, Costa Rica has a small steel industry. Costa Rica has manufacturing, wire drawing, and steel rolling processes. An opportunity has been identified to increase the capacity of the country's steel industry through the use of green hydrogen in existing or new processes. However, there are no clear plans to expand iron and steel production based on this opportunity.

Costa Rica has glass factories that produce bottles for local and regional Central American consumption. It could take advantage of the availability of renewable hydrogen to participate in the flat/float glass market.

4.4.2 Mineral industry (cement)

Costa Rica produces and consumes roughly between 1.200 and 1.400 tons of cement per year on a largely closed market. Foreign trade is negligible. Calculating 0.5 to 0.9 kg of CO2 per kg of cement, results in either 600,000-700,000 tons or 1,080,000- 1260,000 tons of CO_2 emissions depending on the production level and the carbon intensity of the processes. The National Decarbonisation Plan 2018 speaks of 11.2 million tons of CO_2-equivalent GHG emissions. This would imply that cement production corresponds to somewhere between 5.3% (low production. low emissions per unit) and 11.25% (high production. high emissions per unit) of Costa Rica's total emissions. This corresponds to the global average of 7% to 8% of CO_2 emissions from cement production. Costa Rica's industrial cement sector consists of only two companies:

- Cementos Progreso Holdings. S.L. a company with roots in Guatemala and which took over activities of the Mexican Company CEMEX at the end of 2022.
- Holcim (Costa Rica) is a company with a majority shareholder (65%) based in Switzerland. Holcim actively declares its ambitions to become a Net Zero company and has – as the first company in the construction materials sector – signed the "Business Ambition for 1.5 °C" of the UN Global Compact. Holcim (Costa Rica) is a member of the Hydrogen Alliance.

Figure 6: Cement Production in Costa Rica

Cement production in Costa Rica

Year	Prod. (thousand of tons)	Consumption (thousand of tons)	Pro capita consumption (Kg hab.)
2016	1.220	1.290	263
2017	1.364	1.375	278
2018	1.340	1.350	270
2019	1.220	1.200	238

Source: ICCYC

https://cementproducts.com/2021/02/15/country-report-costa-rica/

4.4.3 Chemical industry (ammonia and fertilizer)

Fertilizantes de Centroamérica Limitada (FERTICA) is a Central American company producing and marketing fertilizers in the region. In Costa Rica, it is the main supplier of fertilizers to the agricultural sector. However, there is no local production - at least not in its CO2-intensive phases. Rather, Costa Rica imports fertilizers e.g. from Russia (28% in 2021), China, the USA, and Canada. With the war of Russia against the Ukraine, fertilizer prices soared leading to food crises in different Central American countries (Flores et al., 2022). A possibility to create an alternative supply for nitrogen fertilizer is the usage of green hydrogen as a feedstock for the Haber Bosch process. An option that international fertilizer companies like Yara (Norway) and Fertiberia (Spain) are starting to implement. The British company Atome Energy PLC approached Cavendish (see Chapter 3.1) to explore opportunities to produce fertilizers in Central America using green hydrogen as feedstock. In December 2022, the two companies formed National Ammonia Corporation S.A. to develop projects in Central America in this line of action.

4.4.4 Transport (heavy road and rail. aeronautics. maritime)

With a small carbon-intensive industry and a nearly 100% renewable electricity grid, the transport sector is the main entry point for decarbonization in Costa Rica, which constitutes -- - at the same time a real challenge. The National Decarbonization Plan of 2018 expects that without determined action, emissions will increase by 60% by 2030 and by 132% by 2050 reaching a level of 29.6 million tons of CO2 equivalent. This is mainly due to still unrestrained growth in road transport in the wake of a growing economy. The country went from 418,048 units of vehicles in 1994 to 1,347,000 in 2015 of which 834,000 were private/ light-duty vehicles (Government of Costa Rica, 2019, p. 11). In addition, there is a relevant cargo transport sector, which - although representing only 15% of the vehicle fleet - consumes 36.5% of all fuels used in the country. In addition, the NDP mentions 1,842 buses circulating in the Great Metropolitan

Area, the urbanized Centre of Costa Rica. The vehicle fleet (private passenger cars, busses, cargo trailers) is old: In 2017, the average age of trailers and semi-trailers in technical inspections was older than 25 years, trucks were older than 20 years, and cars older than 15 years (Government of Costa Rica, 2019, p. 12).

The number of zero-emission vehicles in Costa Rica is still very low but growing: A total of 2,375 electric vehicles were newly registered in the first six months of 2023 bringing the total number of registered zero-emission vehicles to 8875 (Herrera, 2023). This implies that around 1% of the vehicle fleet is electrified. Electrification of public transport is also part of the decarbonization efforts: The plans as formulated in the NDP aim that until 2035 30% of public buses and taxis should be free of emissions. Until 2050, 85% of public transport fleet is supposed to operate free of fossil fuels. To support the country's government in this endeavor, the German Federal Ministry of Environment, Nature Protection and Nuclear Safety (BMU) donated three electric buses and subsequently commissioned the GIZ-led project MiTransporte to implement a pilot project on the introduction of electric buses in Costa Rica. This includes purchasing the units, facilitating operation and monitoring as well and removing barriers in the transition towards electric buses (Schloenvoigt, n.d.). Currently, the only hydrogen bus in the country is operated by Ad Astra Rocket in the Western province of Guanacaste (see section 3.1). There is a project in the pipeline in the context of the NAMA-Facility, seeking international climate financing to import more GH2-busses and start establishing a fuelling infrastructure in the Central Valley (Meneses, 2022).

The main challenge for decarbonizing the transport sector is the high costs of low-carbon vehicles. Currently, the least expensive hybrid passenger car offered by Toyota Costa Rica has a unit price of 34,900 US$ while an equivalent car with an internal combustion engine costs 10,000 US$ less. Used passenger cars with hybrid propulsion are only starting to enter the market. The situation is also complicated regarding cargo transport and buses. Electric trucks may cost between US$ 257K and US$457K and a fuel cell truck between US$765K and US$1.129K. In comparison, a diesel day cab truck costs between US$92K and US$143K and a diesel sleeper truck between US$135K and US$155K[10]. Most cargo transport in Costa Rica is operated by small to medium-sized companies that would not be able to acquire clean mobility trucks at a price several times the price of the cheaper (diesel) option. Finally, it should be recalled once again that most trailers and trucks are very old implying that the frequency at which companies replace their vehicle fleet is very low. The same holds about passenger buses: huge price differentials between diesel-powered and zero-emission units operated by small to medium companies. Only that the average age of public road transport vehicles is much lower (around 6 to 7 years; Government of Costa Rica, 2019, p. 12). One option, which has not yet been explored is whether traditional vehicles with combustion engines might be retrofitted with zero-emission engines.

Currently, there is no government policy or strategy for how to significantly decarbonize the Costa Rican transport sector. Likely, hydrogen will not play a significant role in the private passenger segment. Currently, no fuel cell cars are sold to private customers. Battery Electric Vehicles have reached a market coverage of around 1% and there are at present 38 fast charging stations under ICE license. Fuelling of hydrogen to fuel cell cars is available. Hydrogen

[10] How much does an electric semi really cost? - International Council on Clean Transportation (theicct.org)

may play a role in decarbonizing the fleet of long-range buses and heavy cargo trucks as fuel cells may be technically superior to BEV. However, considering the high unit costs, significant advances in decarbonization will depend on financial support, most likely from international climate funds.

4.5 Challenges

Costa Rica ranks as a middle-income country with a thriving middle class and generally good living conditions. The population of Costa Rica is concentrated in urban areas, over 80% of the 5.2 million people live in cities. Poverty rates are significantly lower in the country's urban, industrialized areas than in its more rural areas (9% among urban population vs. 15% among rural population (World Bank, 2020). The unemployment rate in the country in 2022 was 11.5% of the total labour force with significant differences among the country's regions and a much higher rate of youth unemployment (World Bank, 2022). The development of a green hydrogen economy is estimated to increase employment opportunities and skill development, particularly in the already established industrial hubs as well as the country's northwestern regions of Guanacaste, Alajuela, and Puntarenas.

Costa Rica is facing increasing rates of violence in the country. From 2012 to 2022, the murder rate increased by 66.5% (Gaiser, 2023). The main reason for this is drug-related crime, which has spread rapidly in recent years. Migrant communities as well as indigenous peoples are disproportionally affected by socio-economic challenges such as unemployment and violence, who often work in informal sectors or as cheap manual labour in the agricultural sector.[11] The country's poverty rate is particularly high in those communities. The Cabécar tribe for example faces a rate of 94.3% of their people living below the poverty line (Mamo, 2022, p. 383). Indigenous groups are generally rated as marginalized regarding access to public and social services, education, telecommunication, and electrification rates (Vaage, 2011, p. 15).

Conflicts over land and natural resources have been part of Costa Rica's socio-political landscape. For example, in the 1970s and 1980s, the Bribri and Cabécar tribes faced hardships when a new agricultural system for banana and cacao production was introduced in Talamanca Valley, which led to the loss of their land, as it was forcefully taken for a plantation and eventually used for energy production (Ramírez Cover, 2017, pp. 54, 60). In general, Costa Rica experienced two significant and interrelated social conflicts related to land and natural resources in the past. The first type of conflict relates to the country's centralized, and often heralded as particularly progressive, environmental protection and conservation approach. When natural parks, conservation, and environmental protection areas were declared, the government often claimed already inhabited land. As a result, local, and often indigenous, communities faced resettlement and lost access to their ancestral lands (Girot et al., 1998, p. 1). Cahuita National Park, for instance, saw fishing properties, forestry activities, hunting, and agriculture on traditional lands restricted in the 70s, resulting in significant resistance movements (Girot et al., 1998, p. 4). Around 90% of the land declared as a National Monument belonged to small farmers, who vehemently opposed selling their land, and felt their concerns not adequately addressed (Girot et al., 1998, p. 5). The resistance movement resulted in a shift of governance away from a strictly centralized and top-down approach towards increased

[11] Interview with civil society stakeholder, January 2023

collaboration between authorities and local stakeholders, particularly concerning national resource management (Girot et al., 1998, p. 2). Today, Costa Rica's regulatory framework calls for cooperation and "shared responsibilities" among all groups, including municipalities in park management (Ramírez Cover, 2017, pp. 99 - 100). However, some indigenous communities criticize these mechanisms, as they feel that MINAE dictates conservation regulations without providing sufficient resources for offices and personnel. Furthermore, there is a perceived neglect of traditional knowledge of nature protection practices by indigenous groups (Ramírez Cover, 2017, pp. 99 - 101). Similarly, during the implementation process of the Reducing Emissions from Deforestation and Forest Degradation (REDD+) program, issues of "social injustice, power asymmetry, and unequal access to land" arose as significant challenges (Ramírez Cover, 2017, p. 101).

The second type of conflict relates to land and natural resources in Costa Rica that arose alongside the implementation of renewable energy sites, particularly large-scale hydropower dams. In the past, construction plans for hydroelectric dams triggered two societal values. First, concerns about negative environmental impacts on watersheds and wildlife, and second, the social repercussions of displacing and resettling local indigenous communities (García Sánchez & Avendaño Leadem, 2018, p. 282). Protecting the environment is a shared concern throughout the nation.[12] This sentiment was apparent during the El Diquís project or Proyecto Hidroeléctrico El Diquís (PHED), where environmental and social issues related to indigenous concerns led to the project being shelved completely. The project aimed to construct a large dam on the Diquís River in the southern part of the country. If completed, it would have been one of the largest hydroelectric dams in Central America. The main purpose of the PHED was to generate electricity from the water reservoir created by the dam. Proponents of the project argued that it would provide a significant increase in the country's energy production, enhance energy security, and reduce dependency on fossil fuels by utilizing renewable hydropower. However, the project faced significant opposition from environmentalists, indigenous communities, and various civil society groups. They raised concerns about the potential negative environmental and social impacts of the dam. Critics argued that the dam's construction would lead to the destruction of natural habitats, disrupt ecosystems, and negatively affect local wildlife and watersheds. Additionally, there were worries about the displacement and resettlement of indigenous communities residing in the project area. Due to the controversy and opposition, El Diquís faced numerous delays and obstacles in the permitting and implementation process. ICE suspended the PHED indefinitely in 2018 admitting to many mistakes made in the feasibility study phase of the project.[13] Protests and confrontations surrounding these issues highlight how the pursuit of sustainable energy development through renewable sources like hydropower has now become a constraint on national energy systems (García Sánchez & Avendaño Leadem, 2018, p. 287).

4.5.1 Potential lines of conflicts in a GH2 economy

The following identifies potential areas of conflict within a GH2 economy. It is important to note that the issues outlined in this working paper do not guarantee conflicts but rather

[12] Interviews with civil society stakeholders, November 2022 and January 2023

[13] Interview with government stakeholder, November 2022

underscore sectors, in which the development of national policies and international partnerships should prioritize addressing potential sources of disagreement and discontent.

First, according to recent assessments, Costa Rica has the potential to generate 11 times more hydrogen than its projected demand in 2050 (e.g. Hinicio & GIZ, 2021, p. 18). However, whether Costa Rica will produce enough green hydrogen to only supply domestic demand or enter the export market is currently still an open debate (Álvarez Vergnani, 2023). Due to the expectation that other countries on the international market are producing more cost-effective hydrogen than Costa Rica, some governmental and industry stakeholders would like to see the focus of green hydrogen policies on the domestic market, particularly for decarbonizing the transport sector. The question of how to balance domestic use of green hydrogen with international demand and partnership is thus still open and requires further planning and investigation.

Second, a focus on the domestic sector in the use of green hydrogen would most likely also mean less development of additional renewable energy projects in the country. Hydrogen production and its transformation into derivatives require a significant amount of energy. In countries like Costa Rica, additional electricity is necessary for potential hydrogen production. This electricity can be sourced either from the national grid or from additional renewable energy sites used for electrolysis. Both options have implications for local infrastructure and capacity-building (GIZ et al., 2021, p. 77). On the one hand, and as already mentioned above, experience has illustrated conflicts arising from large-scale hydropower projects that often resulted in the displacement of local (indigenous) communities with a huge impact on local livelihoods (such as fisheries and ecotourism, i.e. water rafting). Additionally, the expansion of wind and utility-scale solar energy generation may compete with tourism, which is a very significant economic activity in the Pacific Coast area. On the other hand, it is likely that future expansion of renewable energy generation will not imply new hydropower plants, but rather go through solar PV, wind, and potentially geothermal energy. These modes of energy generation do not necessarily imply interventions in land use as significant as in the case of hydropower. This might, however, incite additional lines of conflict, as suitable sites are quite often located in national parks and other protected areas, which would violate the country's traditional conservation vision (MINAE, 2022b). Nevertheless, careful planning and dual usage of land for, i.e., agricultural purposes and renewable energy generation or eco-tourism and renewable energy plants, could help to mitigate such potential land-use conflicts. As there are currently no concrete locations defined for large renewable energy projects, discussions around and use conflicts are hypothetical but highlight a relevant issue area for policy and strategy planning.

Third, Costa Rica's current reliance on hydropower poses a risk for electricity supply in light of climate change. Hydropower is reliant on rainfalls and those have already shown some phases of alteration (García Sánchez & Avendaño Leadem, 2018, p. 282). As the amount of rain is already fluctuating and tends to get even more so, phases of drought are likely to affect hydropower generation and thus energy security in Costa Rica (Kuzdas, 2012). This may lead to the need to ramp up electricity generation with imported fossil fuels. In the worst case scenario, there could be conflicts over water use with the agricultural sector in the Western province of Guanacaste, where an expansion of irrigation agriculture is planned, partly supplied by the Arenal Lake, which is a main reservoir for hydropower. On the other hand, the country's agricultural sector could potentially benefit from the development of green hydrogen derivates, such as ammonia and methanol, and the use of such as agricultural fertilizer.

Finally, Costa Rica has experienced some large-scale conflicts over the past decades related to the mistreatment of indigenous and local communities (see previous section), which has eroded feelings of trust in government institutions and processes (GIZ et al., 2021). It is to be expected that civil society groups will view newly planned green hydrogen with past experiences in mind, which might cause scepticism and issues of acceptance of new technologies. However, more recent energy projects planned and implemented by ICE, as well as climate and energy policies, seem to take some of the lessons learned into account (Wallbott & Florian-Rivero, 2018). ICE claims their Reventazón dam project is the best practice for designing large-scale hydroelectricity projects. Their prize-winning process involved the community, and local workforce engagement, and addressed environmental concerns. In its 2019 National Decarbonization Plan, the government emphasizes the importance of promoting equality and human rights throughout the process of implementing decarbonization strategies. The plan acknowledges the significance of gender, diversity, and inclusion as fundamental principles. Moreover, it recognizes that vulnerable segments of society are particularly affected by this development, requiring careful consideration and measurement of their participation and impact. The plan highlights marginalized groups as essential stakeholders in energy transformation processes (Government of Costa Rica, 2019, p. 67).

4.5.2 Public acceptance of new technologies and large-scale projects

The Costa Rican public generally supports environmental protection and recognizes the benefits of renewable energy for environmental protection and conservation. For this reason, green hydrogen is expected to receive public support and little resistance in the country.

However, strong eco-centric values among the population and negative experiences with past energy projects can also result in strong and fast resistance to specific aspects of green hydrogen development and implementation. For example, while most of the population generally favors increased hydroelectricity capacity,[14] debates like the one for El Diquís are likely to continue and might accelerate with increased demand for green hydrogen. It needs to be taken into account that the general knowledge about green hydrogen is rated quite low throughout the Costa Rican population, therefore acceptance may partly rely on the efforts in spreading information about the development.

Additionally, aesthetics concerning landscape changes through RE infrastructure may become an important aspect of technology acceptance in the future (GIZ et al., 2021, p. 74). Financial aspects are considered another obstacle to decarbonization and hydrogen development in Costa Rica regarding public acceptance. The cost of the transition away from oil and gas will likely affect consumers, leading to concerns about increased financial burden under already exceptionally high electricity rates in the region. Financial support, tax revenues, and regulatory clarity are needed to facilitate green hydrogen development regarding public acceptance.[15]

[14] Interviews with government and civil society stakeholders, November 2022 and January 2023

[15] Interview with industry and research stakeholders, November 2022 and January 2023

4.6 Business and investment climate

Costa Rica has a business and investment climate far above the regional average. It has a very diversified middle-income economy and a stable democratic society. In May 2021, the country managed to become a member of the Organization for Economic Cooperation and Development (OECD). The country's well-educated labor force, relatively low levels of corruption, good living conditions, dynamic investment promotion board, and attractive free trade zone incentives all appeal to investors. Foreign direct investment inflow in 2022 was 5.2% of the GDP, significantly above the Latin American average of 4.0% (World Bank, n.d.-a). Costa Rica has had remarkable success in the last two decades in establishing and promoting an ecosystem of export-oriented technology companies, suppliers of input goods and services associated with public institutions and universities, and a trained and experienced workforce. A similar transformation took place in the tourism sector with a plethora of smaller enterprises handling a steadily increasing flow of tourists eager to visit despite Costa Rica's relatively high prices. The highly successful free trade zone sector continued to expand during the COVID-19 pandemic.

Until the 1980s, state intervention in the economy was quite pronounced. All banks were public companies and ICE had a monopoly not only in the energy sector but also in telecommunications. In the 1990s, private banks were allowed to operate and in mobile telecommunications private competitors started to compete with ICE and its mobile branch RACSA - Radiográfica Costarricense S.A.

The Costa Rican investment climate is currently threatened by a high and persistent government fiscal deficit and underperformance in some key areas of government service provision, including health care and education, high energy costs, and deterioration of basic infrastructure. The current government - which took office in 2022 - is planning some institutional reforms. A rather surprising early step in this direction was to terminate the public support to the investment promotion agency Agencia Costarricense de Promoción de Inversiones, CINDE, and passing the investment promotion function and related activities to Costa Rican Foreign Trade Promoter (PROCOMER).

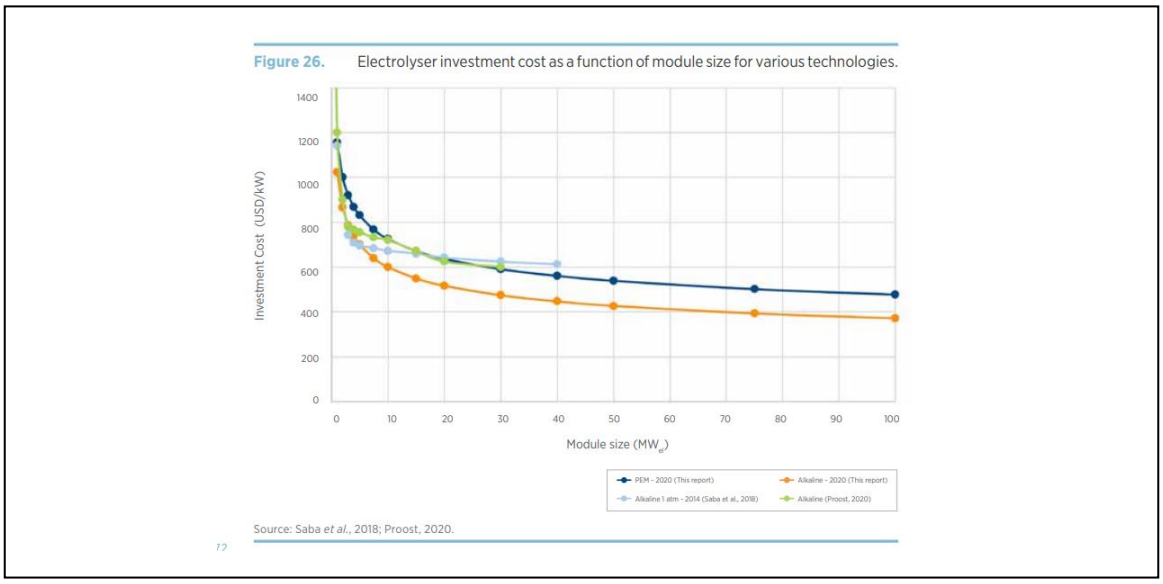
5 Recommendations for international cooperation

5.1 Likely options for the further development of the hydrogen economy in Costa Rica

Currently, the future of the Costa Rican hydrogen economy is uncertain. Uncertainties arise at both international and national level. We will see that the international dynamics have repercussions on the options for ramping up the national green hydrogen economy.

International uncertainties relate, first, to the option for a country like Costa Rica to export GH2 to world regions, where a high demand for hydrogen is predicted, mainly Europe, Japan, and South Korea. Costa Rica would have to compete with a series of locations with larger available land resources and sometimes at a "pipeline distance" to the large markets. Second, it is still not completely clear, how fast the global GH2 economy will be ramped up. Even if exports of GH2 are not the first priority for Costa Rica, there are clear linkages between the international and the national level. A large number of studies assume that in the coming years, prices for core elements of a green hydrogen economy will go down significantly. This is predicted for electrolyzers but is also likely for other elements of the GH2 system, such as buses or trucks powered by hydrogen. However, cost degression is contingent on the speed at which the international market is scaled. If international developments fall significantly short of expectations, price reductions could also slow down. Projects for the domestic market would then face greater financing difficulties. A similar logic also applies to a more static view. Many projects for domestic usage will start at a relatively small scale, as the offtake of the hydrogen has to be organized. For instance, the Haru Oni synfuel project in Chile started with a wind energy capacity of 3.4 MW and an electrolyzer capacity of 1.2 MW (HIF Global, n.d.).

Figure 7: Electrolyzer Investment Cost as a function of module sizes for various technologies



A 2020 IRENA study (see Figure 7) indicates, that the cost degression is very significant in the range between less than 1 MW and 10 MW module size. Export-oriented projects will usually "think big" from the beginning, as the investments in export infrastructure only pay off above certain volumes of exported hydrogen. For instance, the Hyphen project in Namibia plans 1.5 GW of electrolyzer capacities in both its two phases. Linking domestic with export-oriented projects might allow capitalizing on economies of scale and lowering the required efforts to secure the financing. International investors might be granted concessions for export-oriented GH2 projects under the condition that a relevant part of the produced hydrogen goes into domestic usage.

However, currently it is not clear, whether GH2 produced in Costa Rica could find absorptive markets for the given prices. The National Hydrogen Strategy estimates prices to reach between 2 and 3 US$ per kg of GH2 in 2030 (MINAE, 2022a, p. 14). Additional costs have to be added not only for the shipping as such, but also, as hydrogen will not be transported in molecular form, but as a derivative, conversion (e.g. ammonia synthesis) and reconversion costs (ammonia cracking) at the destination port.[16] In addition, it is not yet clear when sufficient vessel capacities for the international transport of GH2 or derivatives will be available.

Uncertainties arise also from the **national level**: The 2022 change in government led to a delay in the implementation of actions foreseen in the National Hydrogen Strategy and still the country has not approved the hydrogen law. This does not mean, however, that the current government would completely oppose the implementation of green hydrogen actions, but might introduce priorities, which are different from those of the previous governments. This mainly concerns the governance of the emerging hydrogen economy. One of the conflicting issues around the draft hydrogen law is the potential role of state-owned companies, such as ICE and RECOPE.

[16] According to a study by Roland Berger from 2021, these additional costs could more than double the "landed costs of hydrogen" compared to production costs (Roland Berger, 2021, p. 17).

In December 2023, the official publication of the Costa Rican government "La Gaceta" published "Decreto Ejecutivo Nº 44318-MINAE".[17] The decree has the potential to give the debate on hydrogen a new twist. It refers to the hydrogen production potential described in the hydrogen strategy to make two key political statements:[18]

- Artículo 1. It is declared of public interest the investments in green hydrogen for infrastructure, businesses, and alliances that are carried out by the electricity distributors for the use of surplus energy resources in the National Electric System; as well as the construction of electricity generation plants for self-consumption with green hydrogen.
- Artículo 2. The electricity service providers, whether public, municipal, or private, as well as the State institutions, shall analyze the production of hydrogen as an opportunity to generate added value in the productive chain, generate qualified employment, and attract investments for the economic development of the country.

To analyze the scope of this decree and the dynamics it can trigger, further interviews would be necessary. A preliminary assessment indicates that

1) The degree gives a certain level of legal security for investments in green hydrogen projects by ICE and the private and public companies, which sell electricity to ICE.
2) It may open up opportunities for small to medium GH2 projects at low costs.
3) Further-reaching projects should first be examined for their potential for socio-economic development in the country.

To understand the important second point on this list, it has to be understood that - even with a significant base-load in the form of geothermal energy and due to a high dependency on hydropower - Costa Rica generates a surplus of electricity in years with high precipitation levels ("La Niña" years), but registers deficits in "El Niño" years, when rainfall is much lower (see Álvarez Vergnani 2023: 9. Recently, ICE, which has the monopoly of electricity transmission, balanced these fluctuations at the cost of private electricity generators. In 2020 and 2022, ICE canceled eight electricity procurement contracts with private power producers, which it reactivated in 2023. Without alternatives, some of these companies turned to using their electricity for mining cryptocurrencies. This surplus might better be used for producing low-cost hydrogen. Álvarez Vergnani (2023: 15) indicates that one of the hydroelectric plants generates electricity at a cost of less than 2 US cents per kWh, which could make hydrogen production internationally very competitive. However, a clear caveat has to be mentioned: In "El Niño" years (e.g. 2023 and most likely 2024) hydroelectric generation is significantly reduced and Costa Rica has to turn to electricity generated via imported fossil fuels. This means that using cheap "surplus" electricity from the national grid permanently can only be feasible if additional generation capacity is built, most likely additional wind farms and the nearly untapped solar energy. We may assume that with Decree 44318, public and private investments in additional generation capacities may be stimulated, as in "La Niña" years with high potentials for hydropower, surplus electricity may be converted to hydrogen, which may become an interesting business case.

[17] https://tinyurl.com/yhyyy4u9

[18] Own non-official translation

A realistic scenario for the development of the Costa Rican hydrogen economy

Based on recent interviews and focus group discussions, Álvarez Vergnani (2023) developed a four-step scenario for the unfolding of Costa Rica's GH2 economy. As it is in line with the findings of our research, and with the phases foreseen in Costa Rica's Green Hydrogen Strategy, we consider it a realistic look into the future even if still subject to major uncertainties. This means that the deadlines for the various steps may move forward or backward by months or individual years without fundamentally questioning the logic of the 4-phases model.

Álvarez Vergnani assumes that in the **short term**, the relevant sector policies need to be concretized and updated and a focus placed on the responsible expansion of renewable energy generation. The role of GH2 in the energy transition has to be clarified, the governing body for the GH2 topic identified, and a GH2 planning with a long-term vision established.

For the **year 2027**, Álvarez Vergnani does not assume significant GH2 exports to happen. Rather, she expects demonstrative pilot projects in several zones of the country, in the field of production, storage, and local usage of hydrogen, e.g. in the transport sector. In addition, she expects research projects in several application fields carried out, such as the production of fertilizer, H2 usage in mobility, PtX, and applications in industry. This last point is very much in line with "Axis 2" of the NHS of Costa Rica, which is entitled "Development of a Green Hydrogen Technology and Innovation Hub".

For the **year 2030**, Álvarez Vergnani still assumes that the country might be in a situation without hydrogen exports. Instead, it focuses on applied research in new hydrogen technologies, projects for the domestic usage of hydrogen (e.g. fertilizer), and demonstration projects for the production of GH2 and its derivatives, with an outlook to possibly scale up. In addition, she expects the domestic electricity sector to be more competitive and flexible and the domestic GH2 market clearly defined. The Costa Rican industry should be evaluating the manufacturing of elements for the GH2 value chain. Linkages of local industries with transnational companies should be in place.

In the long run, according to Álvarez Vergnani's vision, Costa Rica will be considered internationally as a laboratory for green energy and renewable inputs, and an ecosystem for GH2 will be in place with the participation of national and regional academia. A GH2 economy will be in place, which responds to domestic demands and replaces fossil products such as fertilizers and fuels: GH2 will be used as feedstock for several industrial activities located in the country (ammonia, methanol, chemical industry, fertilizers). The country's transport uses fuel cells, hydrogen cells, hydrogen combustion, combined combustion, and synthetic fuels as an option for those lagging (ammonia, methanol, chemical industry, fertilizers). GH2 will have a clearly defined role in the update of the National Decarbonization Plan. GH2 replaces thermal energy backup in periods of drought in the country and the national electricity system will be fully decarbonized. Export of value-added products based on green hydrogen may happen as will the consolidation of one or several industrial clusters related to GH2. Finally, Costa Rica will serve as a reference point for a just and sustainable energy transition.

This 4-phases model by Álvarez Vergnani might look rather defensive, at least in regards to opportunities on international markets. However, if we compare the case of Costa Rica with two other Latin American countries with GH2 strategies of roadmaps that are considered ambitious and export-oriented, we can see that they assume similar timelines. In Chile, some exports of green ammonia are predicted for the second half of the 2020s, but international

trade with molecular hydrogen will be in an infant stage in 2030 (Ministry of Energy, Government of Chile, 2020, p. 18). Similarly, the Hydrogen Roadmap of Uruguay expects the basis for GH2 exports to be established in the second half of the 2020s and international trade of ammonia and synfuels to grow in the 2030s (Ministry of Industry, Energy and Mining, Uruguay, 2022).

The following and final subchapter will make an effort to carve out some approaches for international cooperation with Costa Rica to support the implementation of a "dual and gradual" GH2 strategy in Costa Rica.

5.2 Approaches for international cooperation with a special focus on Germany

Costa Rica has graduated from Official Development Aid (ODA) in past years. ODA is today only around 0.1% of Gross National Income (GNI; World Bank, n.d.-b). The country, however, is still a partner of international cooperation for sustainable development. The German GIZ implements environmental and climate protection projects, among them some related to developing a green hydrogen economy. Non-state actors are also active in the country. e.g. the Deutsch-Costaricanische Industrie- und Handelskammer (AHK), German Academic Exchange Service (DAAD), foundations such as FES and KAS, and charity organizations such as Bread for the World. Some of the projects also reach out to other Central American countries. Fundacíón CRUSA (see 4.3.2) is a very important player, founded under Costa Rican law, but with important initial funding from the USA. Several UN entities are present in Costa Rica, and UNDP is transferring significant financial resources to MINAE

In the green hydrogen topic, Costa Rica could serve as a "living lab" for developing and testing new approaches for producing and using GH2. The opportunities are many and reach, for instance, from the production of GH2 from geothermal energy generation to Agri-PV, combining the usage of land for agriculture and for the generation of solar electricity using green hydrogen. The topic of using GH2 in the transport sector can be further explored, e.g., for which transport modalities fuel cell systems are appropriate and where BEVs are superior. Another topic for local RD&I in cooperation with international partners could be, whether traditional busses and trucks with combustion engines might be retrofitted to work with zero-emission engines (see 4.4). Costa Rica has actors in the energy sector (e.g. ICE) and in academia, who could cooperate with German/international actors in exploring these questions. Regional actor networks exist and could serve to transfer this kind of newly generated knowledge to partners in Central America.

Technologies related to GH2 evolve very fast as do international actor constellations and market opportunities. Without solid and up-to-date knowledge, developing countries need to make far-reaching decisions under high levels of uncertainty. This might hamper the ramp-up of a global hydrogen economy. This problem could be mitigated by establishing a regional (cross-country) think tank, which conducts research and disseminates knowledge to stakeholders in the region. Costa Rica has a tradition of regional Master programs and similar institutions with outreach beyond the borders of the country, e.g. the "Peace University" or INCAE Business School, or FLACSO Costa Rica. Costa Rica, thus, could host a think tank for the Central American region on GH2. Because of its political stability and relatively good civil

security, international research partners might be attracted to research and teach at such an institution.

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