© Sucar Canes / Unsplash

United Nations Climate Change
Technology Executive Committee

Bioethanol activities in Brazil

Case study. Good practices and lessons learned on the setup and implementation of National Systems of Innovation

This document is part of a collection of six case studies selected from the work conducted by the Technology Executive Committee (TEC) on "Good practices and lessons learned on the setup and implementation of National Systems of Innovation". It specifically focuses on the bioethanol innovation system in Brazil.

The Summary for Policymakers of the TEC's work presented in June 2023[1] explains that the primary objective of an innovation system is to produce, diffuse, and use innovations. To accomplish this objective, the Summary for Policymakers document identifies specific activities or functions that should be carried out to facilitate the innovation process. Based on empirical evidence, innovation studies identify seven main functions as outlined in Table 1. Evaluating to what extent an innovation system can perform these functions is necessary to identify and assess the innovation system's achievements, failures and gaps or barriers.

Table 1. Brazilian case of innovation system

Country	Brazil	Focus	Mitigation
Scope	Renewable energy	Key innovation system functions (F)[a]	**Key functions:** F1 Knowledge development and diffusion F2 Entrepreneurial experimentation F3 Market formation F5 Resource mobilization F6 Legitimation F7 Development of positive externalities **Non-key functions:** F4 Influence on the direction of the search
Approach	Bottom-up and top-down	Starting year	1900s: Early developments in the sugar cane sector 1970s: National ethanol strategy 2000s: Market expansion, inclusion of sustainability concerns

[a] See the Summary for Policymakers of "Good practices and lessons learned on the setup and implementation of National Systems of Innovation",[2] and table 3 for the description of functions.

1 TEC, 2023, Summary for Policy makers: Good practices and lessons learned on the setup and implementation of National Systems of Innovation, UNFCCC Technology Executive Commission, Bonn. Available at https://unfccc.int/ttclear/tec/NSI.html

2 TEC (2023).

This document begins with a general introduction of the case study, followed by a description of the legislative framework and an examination of its context within the national innovation system. This provides a foundation for a more detailed exploration of the case. These sections serve as the basis for assessing the case by analysing its functions. The last sections include additional analysis of the case's role within the national system of innovation, key success factors and lessons learned, and good practices.

© Christine Walker / Unsplash

1. Introduction of the case

The development of sugar cane-based ethanol[3] in Brazil is one of the most successful examples of the rapid replacement of fossil fuels in transport.[4] For example, flexible-fuel vehicles (FFVs) using ethanol currently account for over 70% of the Brazilian light-duty vehicle fleet, and the country is a leading producer and exporter of ethanol fuel globally.[5] Moreover, the production of ethanol in Brazil is one of only a few examples where a developing country has achieved leadership in the transport industry.[6] The Brazilian experience with ethanol fuel can therefore provide useful lessons for other countries.

The Brazilian ethanol innovation system has a long history, shaped by economic and political conditions,[7] that can be traced back to Brazil's development as a sugar exporter in the early 20th century, when sugar cane producers began looking for ways to diversify their income and started bottom-up experimentation with ethanol. They also formed coalitions to pressure the Government for supportive policies for the ethanol fuel industry. Economic dependency, energy security and the need to promote industrialization were important drivers for government policies that helped to create a market, mobilize funding and establish regulations for ethanol fuel.

The ethanol Technology Innovation System (TIS) in Brazil is the result of a long interaction between bottom-up experimentation initiatives and top-down government policies. Moreover, its trajectory has been shaped by interactions between a diverse set of actors, institutions and technologies in the agriculture, energy and industry sectors, with strong links to the sugar, car manufacturing, and oil and gas industries.[8]

The case of ethanol activities in Brazil shows the importance of adapting technology innovation policies and strategies over time. Different ethanol technologies have been developed and supported, with priorities changing on the basis of available knowledge and evolving societal concerns related to, for example, deforestation, greenhouse gas (GHG) emission reduction in the transport sector, food security and municipal governance impacts.[9] Therefore, a distinction needs to be made between different types of ethanol fuel to better understand the dynamics in the ethanol innovation system, as described in the sections below:

- Hydrous vs. anhydrous ethanol:
- Hydrous ethanol is used for 100% ethanol-fuelled engines, whereas anhydrous ethanol is usually blended with gasoline.[10]
- First generation vs. second generation ethanol: first generation ethanol (E1G), like other biofuels, is usually produced using biomass that could also have been used for food production (e.g. sugar cane (in Brazil) and corn (in the United States)), whereas second generation ethanol (E2G) is produced from non-food biomass (e.g. perennial grasses or sugar cane residues (called bagasse)). E2G is also referred to as cellulosic ethanol owing to the chemical process involved in its production. E2G is usually considered a more sustainable option due to lower trade-offs with food production.[11]

3 The production of bioethanol from sugar cane in Brazil is different from its production in other countries such as the United States. References to ethanol and ethanol fuel in this paper are to bioethanol produced from sugar cane, unless otherwise specified.
4 Silveira, Semida; Johnson, Francis X. (2016): Navigating the transition to sustainable bioenergy in Sweden and Brazil: Lessons learned in a European and International context. In Energy Research & Social Science 13, pp. 180–193. DOI: 10.1016/j.erss.2015.12.021.
5 Campos, Julio N.; Viglio, José E. (2022): Drivers of ethanol fuel development in Brazil: A sociotechnical review. In MRS Energy & Sustainability 9 (1), pp. 35–48. DOI: 10.1557/s43581-021-00016-6.
6 Andersen (2015). A functions approach to innovation system building in the South: the pre-Proálcool evolution of the sugarcane and biofuel sector in Brazil. Innovation and Development, 5(1), pp. 1–21. DOI: 10.1080/2157930X.2014.996855.
7 Campos and Viglio (2022).
8 Andersen (2015).
9 Stattman, Sarah L.; Hospes, Otto; Mol, Arthur P.J. (2013): Governing biofuels in Brazil: A comparison of ethanol and biodiesel policies. In Energy Policy 61, pp. 22–30. DOI: 10.1016/j.enpol.2013.06.005.
10 Campos and Viglio (2022).
11 Tete, Marcelo and De Souza, Eda Castro (2017) A Formação e o Desenvolvimento do Sistema Tecnológico de Inovação em Etanol de Segunda Geração Brasileiro. ALTEC 2017, XVII Congresso LatinoAmericano de Gestão Tecnológica, 16-18 October 2017.

2. Legislative framework

The ethanol innovation system in Brazil was initially developed as part of a sugar cane/agricultural innovation system related to efforts by sugar cane producers and the Government to promote economic diversification and reduce dependency on the international sugar market.

The first regulatory agency responsible for these efforts was the Sugar and Alcohol Institute (IAA), established in 1933. The first regulation for ethanol was decree 1.917/1931 in 1931, stipulating a 5% blend into gasoline, which was followed by several regulations to increase required blending shares in the following decades. In the 1970s, the Government identified ethanol as an industry of national interest and established ProÁlcool, the first national ethanol programme. The National Alcohol Commission was created to implement the programme.

Ethanol regulation moved from the agriculture sector to the energy sector in the 1990s when, like many other countries, Brazil went through liberalization reforms. In Brazil, the reforms included measures such as reducing government intervention by promoting deregulation and privatization. IAA and the National Alcohol Commission became defunct at the end of the ProÁlcool programme, owing to liberalization and deregulation in the energy sector. The National Council of Energy Policy and the National Petroleum Agency (ANP) were subsequently created as government bodies responsible for providing guidelines for the energy sector, including ethanol fuels.[12] One important stipulation from ANP is the clause of the 1%, from law 9.478/1997, which requires oil and gas exploration companies working in Brazil to invest 1% of gross revenue from their exploration activities into research and development (R&D) projects in "the interest of the national energy sector".[13]

Since the 1990s, developments in ethanol innovation in the energy sector in Brazil have been driven mainly by energy policy.[14] In 2017, the national biofuel policy RenovaBio was established and was the first Brazilian ethanol strategy that explicitly incorporated environmental and other sustainability concerns. In 2019, GHG emission targets were established for the fuel mix, to be implemented via a certification scheme. Table 2 summarizes 25 years of major bioethanol-related regulations in Brazil.

The first regulation for ethanol was decree 1.917 in 1931, stipulating a 5% blend into gasoline

12 Campos and Viglio (2022).
13 The law did not further define what that would entail.
14 Sousa et al (2016).

Table 2. Main regulations for the Brazilian ethanol sector[15]

Year	Mechanism	Number	Resolution
1997	Law	9.478	Brazilian National Council for Energy Policy (CNPE) and National Petroleum Council (CNP)
1998	Law	9.660	Establishes criteria for the gradual substitution of the official government fleet for biofuel-powered vehicles
1999	Interministerial Sugar and Ethanol Council (CIMA) resolution	15	Suspends payment for hydrated ethanol producers
2005	ANP resolution	36	Establishes technical specifications for anhydrous and hydrous ethanol commercialized in the country
2005	Law	11.097	Introduces biodiesel in the Brazilian energy matrix
2006	ANP resolution	5	Requires the registration of supplliers, distributors and importers of ethanol fuel by ANP
2009	ANP resolution	9	Requires fueling stations to label the fuel as "ethanol" instead of "alcohol"
2011	ANP resolution	67	Requires minimum anhydrous ethanol stocks and proof of ability to meet the blend mix
2011	Law	12.490	Includes ethanol among the products to be regulated by ANP (production, distribution and sales)
2014	Law	13..033	Establishes that federal blend mandates can range from 18% and 27.5%
2015	Ministry of Agriculture, Livestock and Supply (MAPA) resolution	75	Mandatory 27% ethanol blend for gasoline
2017	Law	13.576	Institutes Renovabio – the national biofuel policy
2018	Law	9.308	Defines attributions for ANP within the biofuel sector
2018	ANP Resolution	758	Regulates biofuel production certification and inspecting firm's accreditation
2019	ANP resolution	802	Regulates decarbonization credit issuance for certified importers and producers
2019	Presidential decree	265	Defines the annual mandatory targets for the reduction of greenhouse gas emissions required for the commercialization of biofuels

15 Source: Campos and Viglio (2022).

3. The Brazilian national system of innovation: actors, institutions, drivers and gaps

The Brazilian national innovation system includes multiple government agencies that interact and promote innovation, thereby ensuring a broad mix of policies such as technology push and demand pull.[16]

Key institutions and actors exist across education and research, production and innovation, and public and private funding. Innovation policies contributed over time, but especially in the 21st century, to a national system of innovation that is able to produce useful knowledge in some key areas, including the oil and gas and agriculture sectors. For instance, the Brazilian Agricultural Research Corporation (Embrapa), a key player in ethanol innovation, is a leading organization in the agriculture sector. Public funding for innovation enables long-term finance commitments through organizations such as the Brazilian National Development Bank (BNDES) and the innovation funding agency Finep.[17]

Public initiatives that support the development of technology parks, including substantial investments from Finep and the National Council for Scientific and Technological Development, and a national incubator policy, the National Programme of Incubators and Technological Parks, led to the establishment of 94 technology parks and over 280 incubators in Brazil by 2013. Additionally, several sectoral programmes followed a mission-oriented approach in recent years and were considered quite successful, including the Agriculture Joint Action Plan in the ethanol sector.[18]

Nevertheless, while the variety of actors ensures a richness in policy instruments, it can also result in fragmentation between scientific research and education and the productive sector. Such fragmentation can lead to a lack of direction for innovation, as well as low demand for knowledge produced in academia, which, together with a low propensity for private actors to invest in R&D in Brazil, indicates that the biggest gap in the national innovation system is a coordination issue. That is, the main systemic problem of fragmentation results not from a lack of skilled researchers or scientific knowledge, but from a lack of uptake of this knowledge owing to weak coordination between knowledge producers and users.[19]
The success of the Brazilian ethanol TIS can be explained by the ability of actors to overcome the fragmentation by ensuring coordination through networks – either from the bottom up through research and industry associations or from the top down through the active engagement of stakeholders throughout the innovation and supply chains promoted by the Government.

16 Mazzucato, M. and Penna, C. (2016) The Brazilian Innovation System: a Mission-oriented Approach. Temas Estratégicos para o Desenvolvimento do Brasil. Março, (1). Centro de Gestão e Estudos Estratégicos (CGEE). Brasília, Brazil. Available at: https://www.cgee.org.br/the-brazilian-innovation-system.
17 Mazzucato and Penna (2016).
18 Mazzucato and Penna (2016).
19 Viotti, E. B. (2002). National learning systems: A new approach on technological change in late industrializing economies and evidences from the cases of Brazil and South Korea. Technol. Forecast. Soc. Change, 69(7), 653–680, doi:10.1016/s0040-1625(01)00167-6.

4. Description of the case

Given the context described above, the early development of the ethanol TIS is outlined first, as initially driven by the sugar cane sector.

The following subsection explains how ethanol became part of a broader national strategy for energy security and industrialization in the 1970s, with the establishment of the national bioethanol programme ProÁlcool being a milestone. The final subsection explains recent programmes that led to an increase of FFVs in the market and to the introduction of climate change related concerns in ethanol policies.

4.1 Early development: ethanol for economic diversification in the sugar cane sector

A historical economic dependency on sugar exports in times of crises in the international sugar market led to efforts to develop alternative uses for sugar cane by the late 19th century. Public decrees 2.687/1875 and 10.393/1889 helped mobilize funding for innovation in and modernization of the sugar industry. As a result of such efforts, several sugar mills started experimenting with sugar cane-based biofuels in the 1920s, while pressuring the Government to promote the diversification of sugar cane uses. The Piracicaba Cane Experimental Station (EECP) promoted knowledge development and experimentation, and provided coordination between scientists and sugar mill owners. Local equipment suppliers and repair and maintenance shops started manufacturing components that needed frequent replacement and improved their own knowledge. These efforts led to the introduction of the first ethanol fuel variety into the market in 1927, and EECP built a sound basis for future innovation activities, for example under the Agronomic Institute in Campinas and the Copersucar Sugarcane Technology Center (CTC), in the 1940s–1970s.[20]

The Great Depression (1929–1939) helped to reinforce government interest in developing an ethanol industry. The compulsory addition of 5% of ethanol (anhydrous alcohol) to imported gasoline was introduced in 1931. In 1933, IAA was established to regulate the installation and operation of ethanol distilleries, including their buy and sell quotas, and provided technical and financial support. IAA, together with the National Petroleum Council (CNP), had the responsibility of regulating the national fuel mix.[21] The ethanol industry became an industry of national interest in 1942 owing to sugar overproduction during the Second World War. Import restrictions during the war created an additional incentive to produce capital goods locally, including the equipment and technologies for ethanol production. Policy incentives followed, resulting in ethanol industry expansion.[22,23]

Various developments in national politics, as well as both national and international markets, resulted in another period of sugar overproduction in the early 1960s and to efforts to further develop ethanol production. In 1969, the Copersucar cooperative was the primary representative for the CTC, which is an R&D centre created by private sector organizations in the Brazilian sugar cane industry. Several government initiatives were developed around the same time, including the National Plan for Improvement of Sugarcane (PLANALSUCAR) in 1971, a long-term R&D programme with five regional operation centres that supported regional experimentation of ethanol production.[24]

20 Andersen (2015).
21 Campos and Viglio (2022).
22 Campos and Viglio (2022).
23 Andersen (2015).
24 Campos and Viglio (2022).

4.2 Ethanol promotes energy security, economic growth and industrialization through ProÁlcool

In 1973, an oil crisis further exposed Brazil's reliance on oil imports and commodity exports. To promote energy security and reduce Brazil's economic vulnerability to external shocks, the Government created ProÁlcool in 1975. It was part of the National Development Plan II and had four main goals:

1. Increase domestic ethanol production to reduce demand for imported fuels and energy dependence;
2. Create additional income opportunities for the Brazilian sugar industry;
3. Better leverage Brazilian natural resources for economic development;
4. Promote growth of the agricultural and industrial sectors.[25,26,27,28]

To coordinate implementation of these goals, the Government established the National Alcohol Commission.[29] ProÁlcool stimulated innovation in ethanol from production to distribution and final use.[30] The programme also focused on creating a market for ethanol, to be done in three steps:

1. Promote the mixture of anhydrous ethanol to gasoline;
2. Adapt gasoline car engines to ethanol use;
3. Develop special engines to run exclusively on hydrated ethanol.[31]

To implement these goals, the Government established minimum requirements for the share of ethanol in gasoline, ranging from 5 to 25%. It also provided fiscal incentives and financial loans with subsidized interest rates to sugar cane producers to expand and upgrade ethanol processing plants, and to automobile manufacturers to develop ethanol-fuelled vehicles. Public funding was substantial and included up to 90% of the funding needed for building new ethanol distilleries and up to 100% for increasing sugar cane production. Cumulative subsidies for ProÁlcool were estimated at US$7 billion between 1975 and 1989. In addition, the Government determined minimum ethanol sales prices via Petrobras, the national oil and gas company, to make producing ethanol more attractive than exporting sugar. Petrobras also provided minimum purchase guarantees to ethanol producers. The Government established production quotas to avoid fluctuations in supply and price, which resulted in consumer prices for ethanol always remaining below gasoline prices (per kilometre driven).[32,33,34]

The Government played a key role in bringing stakeholders together and overcoming their resistance to its policies,[35] which initially came from all sectors. Sugar mill owners argued that sugar was a low risk market given the IAA price guarantees, despite a similar system having been created for ethanol. Petrobras expressed concerns about ethanol as possible competition for gasoline, and the automobile industry was not in favour of adapting car engines for ethanol solely for the Brazilian market. Government efforts to overcome such concerns led to an increase in ethanol production, employment and income in rural areas. They also led to the introduction of the first ethanol vehicles in Brazil in 1978.[36],[37]

25 Campos and Viglio (2022).
26 Francisco (2022). "Proálcool"; Brasil Escola. Available at: https://brasilescola.uol.com.br/brasil/proalcool.htm
27 Gomes da Cruz et al (2012) A Evolução da Produção de Etanol no Brasil, no Período de 1975 a 2009. Documentos techno-científicos. Vol.43 n.4, pp.141-159.
28 Stattman et al (2013).
29 Campos and Viglio (2022).
30 Silveira and Johnson (2016).
31 Stattman et al (2013).
32 Gomes da Cruz et al (2012).
33 Francisco (2022).
34 Stattman et al (2013).
35 Stattman et al (2013).
36 Gomes da Cruz et al (2012).
37 Campos and Viglio (2022).

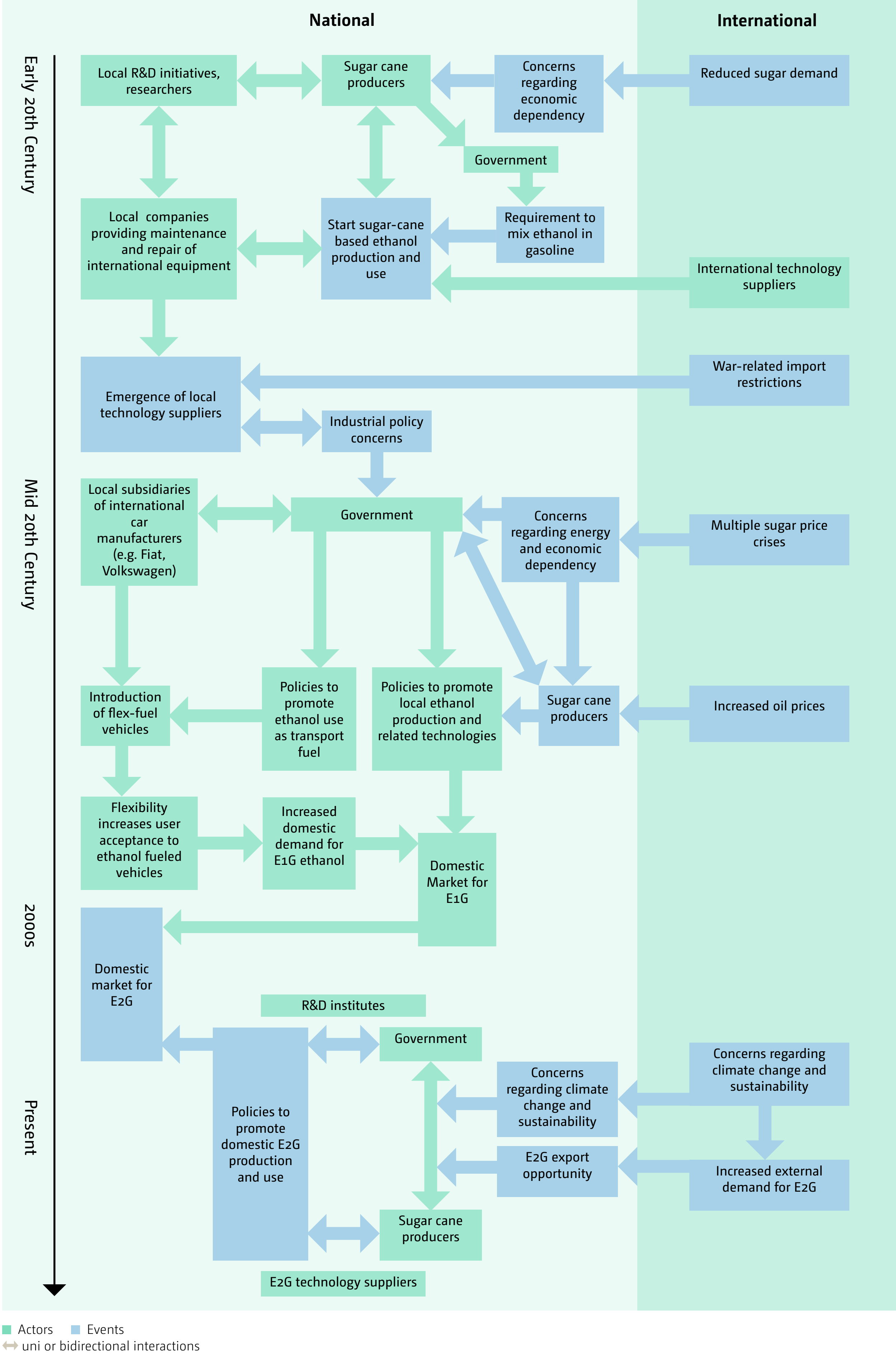
In 1979, a second oil crisis confirmed ethanol's role as an alternative energy supply source in Brazil. During the following years the Government focused on increasing efficiency of ethanol production and developing an ethanol supply infrastructure, as well as creating a market for ethanol by supporting the deployment of ethanol-fuelled vehicles and stimulating ethanol use in the chemical sector.[38,39]

Measures to stimulate the market for ethanol fuel included:[40,41]

1. Establishing a government vehicle fleet that was predominantly ethanol-fuelled;
2. Requiring a minimum share of 20% ethanol in gasoline;
3. Establishing a maximum price of ethanol at 65% of the price of gasoline;
4. Reducing taxes for ethanol products and ethanol-fuelled vehicles, including for taxi fleets.

38 Gomes da Cruz et al (2012).
39 Campos and Viglio (2022).
40 Gomes da Cruz et al (2012).
41 Silveira and Johnson (2016).

Figure 1. A historic overview of national and international trends that shaped the Brazilian ethanol innovation system



In addition, the strategy for increasing use of ethanol-fuelled vehicles focused on campaigns to gain consumers' trust to influence their car-purchasing decisions, which included touring with ethanol-fuelled vehicles and holding demonstrations.[42] This strategy was relatively successful in stimulating demand for ethanol-fuelled vehicles in the early 1980s. By 1985, ethanol-fuelled vehicles accounted for over 95% of total sales of otto-cycled vehicles for the Brazilian domestic market, compared with only 0.50% in 1979.[43,44,45]

Multiple pilot and demonstration projects were developed via multi-stakeholder partnerships in the early 1980s, funded mostly by the Government. For instance, Project Hidrocon was established in 1980 by the Technology Development Company, a partnership between the Secretariat for Industrial Technologies from the Ministry of Science and Innovation, the State University of Campinas (UNICAMP) and private company Aços Villares S.A. There were also initiatives from the private sector, most notably the R&D programme for Dedini, an equipment supplier for ethanol distilleries.[46]

There was no clear predominance of one technological route in the 1980s and activities focused on multiple options. The Government asked the National Technology Institute to conduct studies on the development of ethanol from different sources.[47] R&D activities on enzymatic hydrolysis under way during this period proved important for the later emergence of E2G. However, the small-scale production of ethanol from cassava, initially considered an opportunity for economic development for smallholder farmers in poorer regions, was unable to compete with larger-scale sugar cane-based production and ultimately disappeared.[48] By the mid-1980s, there was a clear dominance of large-scale sugar cane-based ethanol production.

Stagnation occurred from 1986 to 1995, and the dire economic situation in the late 1990s made it very difficult for the Government to maintain fiscal incentives for industrial programmes, including support to the ethanol fuel.[49] A perception of domestic ethanol-fuelled vehicles as being inferior to cars from developed countries led to uncertainty about future political support.[50,51]

The first ethanol shock from 1989 to 1990 was partially due to international developments in the oil and sugar markets, which resulted in an ethanol supply shortage in the domestic market.[52] The shortage led to the need to import ethanol to meet increased domestic demand due to the size of the ethanol-fuelled vehicle fleet. The subsequent increase in the supply of ethanol reduced the competitiveness of ethanol fuel and hence the attractiveness of ethanol-fuelled vehicles, and sales decreased from 96% of total sales to 12% between 1985 and 1990, which resulted in a loss of interest from the car industry in producing ethanol-fuelled vehicles.[53,54]

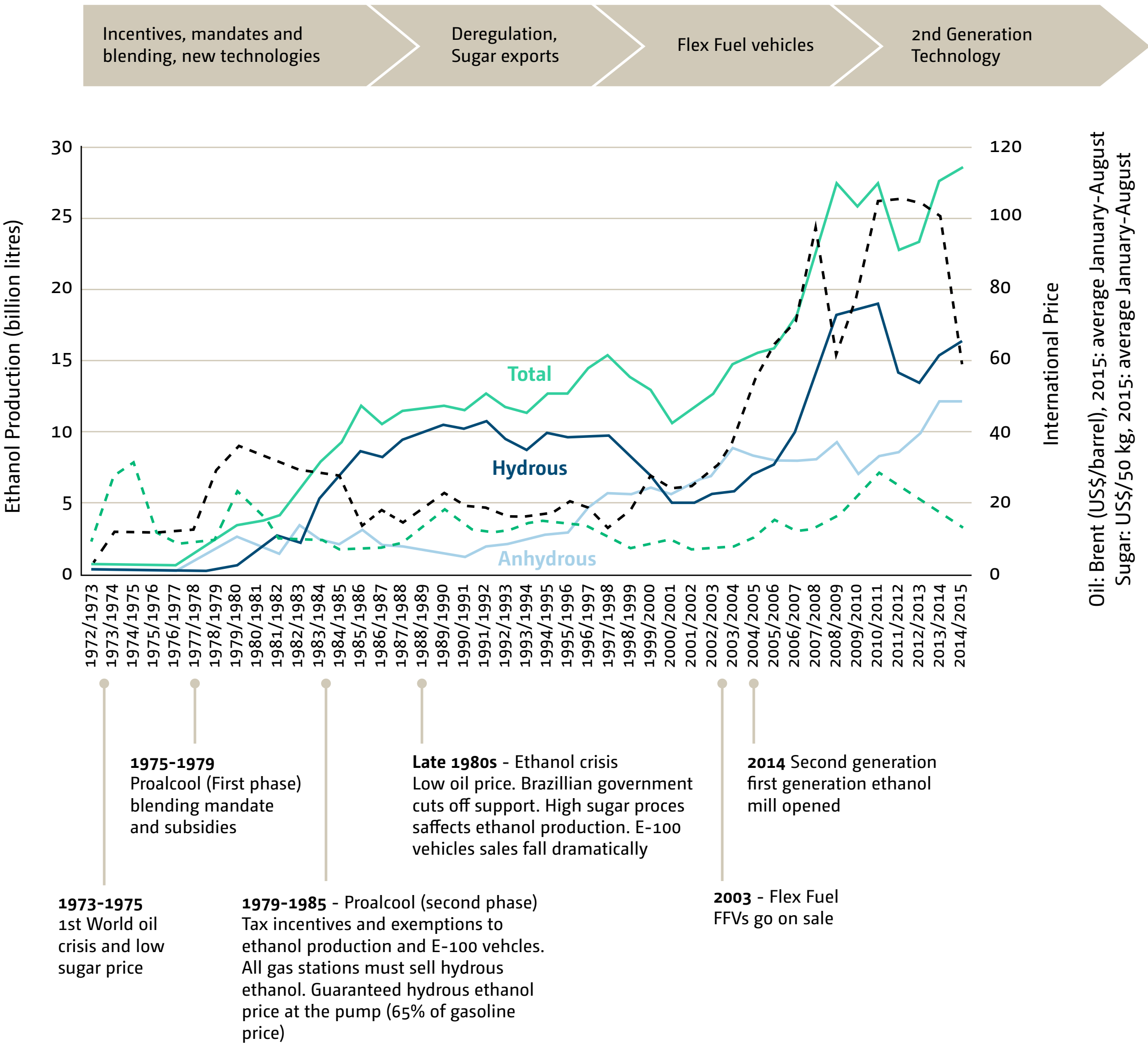
Major changes occurred in the institutional landscape for ethanol fuel in the 1990s. During ProÁlcool, ethanol competitiveness heavily relied on subsidies and price regulations. When the sector was deregulated in the 1990s and subsidies were removed, ethanol became uncompetitive. Some producers went bankrupt, while others turned to sugar production. Fuel substitution was no longer a priority given the low oil prices, environmental issues were not yet on the agenda and development concerns took priority during the economic crisis.[55,56] ProÁlcool ended in 1991 and IAA was abolished,[57] as was PLANALSUCAR.[58] In addition, the Ministry of Development, Industry and Trade was closed in 1990, which also terminated the Industrial Technology Department, one of the key institutions promoting technology development under ProÁlcool. These closures marked the end of the phase where ethanol fuel production was driven by Brazil's industrial policy.[59]

42 Campos and Viglio (2022).
43 Stattman et al (2013).
44 Gomes da Cruz et al (2012).
45 Francisco (2022).
46 Tete and De Souza (2017).
47 Tete and De Souza (2017).
48 Stattman et al (2013).
49 Francisco (2022).
50 Stattman et al (2013).
51 Gomes da Cruz et al (2012).
52 Campos and Viglio (2022).
53 Gomes da Cruz et al (2012)
54 Stattman et al (2013).
55 Gomes da Cruz et al (2012).
56 Silveira and Johnson (2016).
57 Campos and Viglio (2022).
58 The Interuniversity Network for the Development of the Sugarcane Industry in Brazil took over the R&D activities from PLANALSUCAR; see Interuniversity Network for the Development of the Sugarcane Industry in Brazil (2022). Our history. https://www.ridesaufscar.com.br/historico.
59 Sousa, L. C. de; Vonortas, N. S.; Santos, I. T.; Toledo Filho, D. F. de (2016): Innovation Systems of Ethanol in Brazil and the United States: Making a New Fuel Competitive. In: Global Bioethanol: Elsevier, pp. 93–121.

By the end of the 1990s, the ethanol sector was in crisis, marked by uncertainty and a lack of direction for technical change. This led some businesses to create associations to try and rescue the sector. For instance, the Brazilian Sugarcane Industry Association was established in 1997 and a sugar cane cartel was created to control ethanol prices. However, stagnation lasted until the introduction of FFVs in 2003,[60] described below.

By the end f the 1990s, the ethanol sector was in crisis. This led some business to create associations to try and rescue the sector.

Figure 2. Trends in international sugar, bio-ethanol and oil prices over time[61]



60 Campos and Viglio (2022).

61 Luís A. B. Cortez, L.A.B. , L.A.H. Nogueira, M.R.V.L. Leal, R. Baldassin Jr. 2016, 40 Years of the Brazilian Ethanol Program (Proálcool): Relevant Public Policies and Events Throughout Its Trajectory and Future Perspectives, 22nd International Symposium on Alcohol Fuels, See: https://bioenfapesp.org/gsb/lacaf/documents/papers/05_ISAF_2016_Cortez_et_al.pdf.

4.3 Ethanol revival: combining market creation and local sustainable technology innovation support

From 2000 to 2010, energy security concerns led to a revival in the Brazilian ethanol innovation system owing to increased oil prices and increased international attention given to the negative environmental impacts of fossil fuels, with ethanol being seen as a solution to both problems. Two separate but complementary processes strengthened the ethanol TIS during this period.

The first process was the creation of both a renewed domestic and an international market for ethanol, which contributed to the further development of the Brazilian ethanol TIS through a demand-pull effect and helped to increase alignment between public and private sector interests, given the expected economic benefits. Domestic policies and measures included government incentives for anhydrous ethanol, for instance via blend mandates, tax benefits for industrialized goods and fuel subsidies. The main outcome from these efforts was the introduction of FFVs in 2003.[62,63] Three companies carried out technological development in the 1990s.[64,65,66,67] Internationally, support for E2G increased because increasing sustainability concerns regarding E1G helped create an export market for Brazilian producers. On the basis of the expectation that ethanol would become more important in Brazil and internationally, the private sector increased ethanol production.[68] E2G was identified as a key opportunity for Brazilian exports in a study commissioned by the President's Committee for Strategic Issues. These expectations for economic opportunities from ethanol production and exports contributed to an alignment of the public and private sector on their interests and policies concerning biofuels.

The second process was the ability to overcome technological bottlenecks to meet growing demand for ethanol for the expanding domestic vehicle fleet and for export markets. Government efforts to support technological development, especially improving Brazil's technological leadership in E2G, further contributed to strengthening the ethanol TIS through a technology-push effect. In 2005, the Ministry of Science and Technology asked the Centre for Strategic Studies to identify the public policies needed to promote the sustainable expansion of ethanol as part of the Ethanol Project. The Centre recommended providing incentives for producing E2G, increasing public investment in R&D and establishing a centre for research and development to coordinate activities across different technological routes and international developments.[69] In response to the recommendation, State-owned Embrapa established a decentralized unit called Embrapa Agro-Energy in 2006 to modernize biofuel production technologies.[70] The aim of the unit was to:

- Coordinate research activities;
- Assemble existing expertise and create a knowledge centre to share knowledge at the national level;
- Support the National Agro-Energy Plan;
- Coordinate with relevant networks and consortiums on research and innovation.

62 Gomes da Cruz et al (2012).
63 Campos and Viglio (2022).
64 Bosch, Delphi and Magnetti Marelli. The model to first reach the market was the Volkswagen Gol Power 1.6 Total Flex, with a price difference of only USD 320 more compared with a conventional gasoline-fuelled vehicle. Several other models followed, including the Fiat Palio, Chevrolet Celta and Fiat Uno Mille.
65 Silveira and Johnson (2016).
66 Campos and Viglio (2022).
67 Stattman et al (2013).
68 Gomes da Cruz et al (2012).
69 Tete and De Souza (2017).
70 Sousa et al (2016).

Moreover, the Brazilian Bioethanol Science and Technology Laboratory was launched in 2009, with the aim to produce research on industrial technologies for E2G and to create sustainability models for the ethanol sector.[71] In addition, Ethanol Project participants joined efforts with Brazilian universities and created a network called Rede Bioethanol. The network included over 150 researchers affiliated with 15 Brazilian universities and four international universities, as well as national and multinational companies.[72] Several other R&D projects were carried out in Brazilian federal universities (Federal University of Rio de Janeiro, UNICAMP and University of Brasilia) and funded by innovation agencies such as Finep and the São Paulo Research Foundation (FAPESP),[73] as well as the mandatory 1% of revenues from oil and gas companies being set aside for funding R&D activities. This was possible because bioethanol regulation came under ANP responsibilities in 2011 (see section 1.1.2). Funds acquired through international cooperation also supported research efforts during this period.[74]

The Joint Plan of Support for Technological Innovation of the Industrial and Chemical Industries using sugar cane (PAISS) was launched by BNDES and Finep in 2011 with the aim to increase coordination between stakeholders (e.g. companies, research institutes and financial organizations), increase participation of the private sector in innovation activities, and increase and consolidate public funding incentives.[75] Efforts by PAISS led to the establishment of one demonstration plant (by CTC) and two industrial-scale production plants (by the companies GranBio and Raízen) for E2G. In 2014, PAISS, GranBio and Raízen founded the Brazilian Association for Industrial Biotechnology with the aim to increase the legitimacy of E2G in Brazil, improve industrial biotechnologies regulations, discuss sector policies and incentives, promote knowledge development by partnering with institutions of science and innovation, and coordinate knowledge diffusion in the sector.[76] In 2014, an agricultural version of PAISS was created to foster the development of agricultural machinery for ethanol production.[77]

71 Sousa et al (2016).
72 The network jointly applied for research funding for the Bioethanol I project, which received BRL 3 million in funding from Finep between 2006 and 2009. The Bioethanol II project followed, with a budget of BRL 9.9 million, which led to the creation of the Bioethanol Laboratory at the Federal University of Rio de Janeiro in 2013. Tete and De Souza (2017).
73 A public foundation funded by taxpayers in the State of São Paulo.
74 Tete and De Souza (2017).
75 Sousa et al (2016).
76 Tete and De Souza (2017).
77 Sousa et al (2016).

Decarbonization credits for biofuel supplies under RenovaBio

Under RenovaBio, national GHG emission reduction targets are broken down into mandatory individual targets for individual fossil fuel distributors, in proportion to their market share. To meet their reduction targets, fuel distributors need to buy a set amount of decarbonization credits (CBIOs[78]). These CBIOs are generated by biofuel producers and importers on the basis of their purchase and sales invoices. Different grades are assigned to each biofuel producer and importer through the Biofuel Certification and the Energy-Environmental Efficiency Rating system. Producers receive higher grades if they produce higher amounts of net energy, with lower carbon dioxide emissions, throughout the life cycle. This process of certification allows producers and importers to generate CBIOs, which are equivalent to one tonne of carbon. They are valid for three years and need to be issued by inspecting firms accredited by ANP. The certificates are registered by financial institutions and can be traded on the Brazilian stock exchange.

Various factors led to a situation where E2G was developed to mainly target exports, especially to the United States.[79] The factors included technological problems in E2G production that led to uncompetitive prices in the domestic market,[80] a lack of specific demand for E2G in the domestic market and policies encouraging E2G use in other countries. Therefore, there was a need to create a domestic market specifically for E2G. Earlier policies did not affect E1G and E2G in a similar way, as E2G was not yet as mature and competitive as E1G. Hence, in 2014, the ANP regulation requiring 1% of oil and gas exploration companies' revenues to be invested in R&D was updated to recognize E2G as a fuel to be used in the Brazilian energy mix, which guaranteed that E2G would be accessible in the Brazilian market. The recognition of E2G as a fuel to use in the Brazilian energy mix was further supported by the inclusion of climate change related concerns in RenovaBio in 2017 and the establishment of GHG emission reduction targets for the national fuel mix for 2019–2029,[81] which helped manage expectations and reduce uncertainty in future ethanol demand while rewarding low-carbon ethanol production routes through the implementation of carbon reduction credits (CBIOs, see text box above).[82]

78 Certificates of efficient production of biofuels.
79 Sousa et al (2016).
80 Tete and De Souza (2017).
81 National Council of Energy Policy resolution 15 of June 2019.
82 Grangeia et al (2022).

5. Assessment of the case functions

The following points discuss the vital systemic functions performed by the bioethanol innovation system, which have strengthened the Brazilian innovation system's structural elements. The table 3 describes the systemic functions.[83]

Table 3 Functions of systems of innovation[a]

Number	Function	Description
F1	Knowledge development and diffusion	Expansion and intensification of the knowledge base of the innovation system, dissemination of knowledge among actors in the system, creation of new combinations of knowledge
F2	Entrepreneurial experimentation	Designing business models for emergent technologies and knowledge, practices of uncertainty reduction through experimentation with new technologies, applications and strategies
F3	Market formation	Creation of a space or an arena in which goods and services can be exchanged between suppliers and buyers. Includes processes related to definition of demand and choices, positioning (pricing, segmentation) of products, regulation of standards and the rules of exchange
F4	Influence on the direction of search	Processes that influence the direction of research of firms and other actors; that is, which technologies they explore, which problems or solutions they choose to invest in, where they channelize their resources from, etc.
F5	Resource mobilization	Processes by which the system acquires the resources required for innovation, which could be financial and human resources (workforce and capabilities), complementary assets such as infrastructure, etc.
F6	Legitimation	Mechanisms by which an emergent technology, its developers and the TIS in question attain regulative, normative and cognitive legitimacy as viewed by the stakeholders concerned
F7	Development of positive externalities	Creation of system-level utilities (or resources), such as pooled labour markets, complementary technologies and specialized suppliers, which are also available to system actors that did not contribute to building them up

[a] Adapted from Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Research policy, 37(3), 407-429.

Knowledge development and diffusion Several initiatives in the Brazilian ethanol innovation system contributed to knowledge development across the entire ethanol fuel value chain: from improvements in sugar cane production, to ethanol production, to development of ethanol-fuelled cars se. Multi-stakeholder partnerships and organizations such as the European Cluster Cooperation Platform,[84] the Interuniversity Network for the Development of the Sugarcane Industry in Brazil, CTC, the Government, research networks and industry associations contributed to strengthening coordination between actors, aligning expectations and promoting knowledge-sharing and diffusion.

The Government's active role in supporting efforts for Brazil to achieve technology leadership globally in ethanol fuel resulted in many of the initiatives having an industrial development component with an explicit aim to strengthen local industry. As a result of these efforts and collaborations, the ethanol TIS was able to overcome remaining gaps in the national system of innovation related to fragmentation between knowledge production. Collaboration with international actors (e.g. multinational companies, foreign researchers) also had an important role in knowledge development and diffusion, for instance through international research networks.

83 TEC (2023).
84 An online hub for industry clusters with the aim to strengthen the European economy through collaboration; see https://clustercollaboration.eu/.

Entrepreneurial experimentation Technologies and business experimentation began early in the ethanol fuel industry and from the bottom up by sugar cane producers in the private sector aiming to diversify their business. Over time, organizations in the public and private sector, as well as academia, further promoted experimentation, often in collaboration with each other. Collaborators included the European Cluster Cooperation Platform, CTC, GranBio, Raízen, Dedini, and federal universities in Brazil. Experimentation through multi-stakeholder partnerships (including academia, Government and the private sector) were key to strengthening coordination, sharing knowledge and mobilizing funding for experimentation. Experimentation also increased interaction between knowledge producers and users, making learning from experimentation more dynamic. Programmes such as the Technology Innovation Partnership Programme and the Industrial PAISS were key facilitators for establishing demonstration plants.

Market formation Market formation was a crucial function in the success of the ethanol innovation system in Brazil, especially after 2000. Domestic market formation was achieved mainly through regulations that established minimum requirements for blending ethanol into gasoline and measures to stimulate the introduction of ethanol-fuelled vehicles, such as tax incentives and public procurement. The introduction of FFVs was a major driver for domestic ethanol demand, with the market share of hydrous ethanol increasing from 4% to 15% between 2003 and 2019. This policy is widely considered a milestone in the development of the ethanol TIS in Brazil, as it led to the establishment of a domestic market for ethanol fuel by creating a demand-pull effect.

One of the reasons this policy was considerably more successful than previous efforts to support the ethanol fuel industry was that it contributed to overcoming the resistance against (exclusively) ethanol-fuelled vehicles caused by the ethanol shortages in the early 1990s. The availability and price of engines provided consumers the flexibility to choose between using gasoline or ethanol.[85,86,87,88] Another success factor related to FFV implementation was that FFVs were tailored to the Brazilian socioeconomic context because they targeted economical car models priced under USD 10,100 in 2005, accounting for 38% of total sales at the time of the introduction of the policy and over 90% in 2013, which led to the share of FFVs accounting for over 70% of the light-duty vehicle fleet in Brazil in 2017. Similarly, flexible-fuel motorcycles, introduced into the market in 2009, accounted for around 50% of motorcycle sales in 2016.[89,90,91]

In addition, international developments contributed to the formation of an export market for ethanol fuels, though mainly for E2G. Following the adoption of the Kyoto Protocol in 1997, increasing concerns about the sustainability of available biofuels pushed countries to establish policies to promote more sustainable biofuels, creating an opportunity for Brazilian ethanol producers. This opportunity was especially important as the domestic market at that time did not meet the conditions needed for E2G to become competitive. However, the E2G domestic market expanded after the establishment of national targets for GHG emission reduction and of RenovaBio that led to the implementation of carbon credits. RenovaBio and the emission reduction targets were part of Brazil's efforts to meet the long-term goals of the Paris Agreement, again showing how the international context influenced the local ethanol TIS.

Influence on the direction of the search Alignment between the productive sector, Government, academia and users was a key factor in the development of the ethanol industry in Brazil. External factors such as international market crises and wars also played a role by highlighting structural dependencies of the Brazilian economy. A strong sugar cane industry was paramount to furthering the ethanol technology route based on sugar cane. However, this dependency highlights the risks related to path dependencies in innovation. The ethanol technology route in Brazil was influenced by the economic and social structure in place during the expansion of Brazil's sugar cane industry, which provided an advantage in terms of leveraging existing production and innovation capabilities. Thus, other routes that could not build on existing capabilities were unable to compete. For example, smaller-scale cassava-based ethanol production, seen as an opportunity for supporting economic development among smallholder farmers in poorer regions, ended up disappearing as the farmers could not compete with the larger-scale, more industrialized sugar cane-based production.[92]

85 Gomes da Cruz et al (2012).
86 Campos and Viglio (2022).
87 Silveira and Johnson (2016).
88 Stattman et al. (2013).
89 Silveira and Johnson (2016).
90 Campos and Viglio (2022).
91 Stattman et al (2013).
92 Stattman et al (2013).

Resource mobilization Several stakeholder groups contributed to resource mobilization through the development of the ethanol sector in Brazil. Early on the ethanol TIS, public and private sector resources were mobilized for sugar cane producers to experiment with ethanol production. Over time, there were multiple public incentives for ethanol-related innovations, production and use, for instance through R&D funding, subsidies to make ethanol prices competitive and tax exemptions, under national programmes such as ProÁlcool and PAISS. Public innovation funds such as Finep and FAPESP, state-owned enterprises such as Coalbra and Petrobras, and BNDES were key in mobilizing funding for research, development and demonstration (RD&D) projects. The mobilization of public funding increased the availability of long-term capital and often reduced risks for private investors. The ANP 1% clause also ensured the availability of funds for RD&D projects in companies in the energy sector. Private technology suppliers such as Dedini, GranBio and Raízen, as well as cooperatives such as CTC, also mobilized resources. International cooperation led to additional support. Resource mobilization involved both individual actors and partnerships.

Legitimation Several decrees establishing minimum blends of ethanol into gasoline and establishing ethanol as a fuel helped legitimate the introduction of ethanol in the fuel mix in Brazil. Research networks and industry associations helped support the legitimacy over time by coordinating with the Government and emphasizing the importance of the fuel to the national economy. Word of mouth among consumers was an important factor in legitimizing ethanol-fuelled vehicles. The introduction of FFVs provided consumers with the flexibility to choose between ethanol and gasoline, which helped overcome resistance to ethanol-fuelled vehicles. Moreover, international events such as the adoption of the Kyoto Protocol and the Paris Agreement, together with developments for increased production of E2G in the United States, increased the legitimacy of E2G in Brazil.

Development of positive externalities Development of the ethanol sector in Brazil has always been closely linked to broader goals for economic development and to industrial policy. This development helped to diversify income for the sugar cane industry and led to the growth of a local industry for FFVs, ethanol production equipment manufacturers and service providers. These stakeholders created associations and networks to advocate for increased government support for the technologies involved. Energy security and affordability were also key goals behind governmental ethanol policies, as they would help Brazil to become less dependent on oil imports and hence less vulnerable to external shocks. The introduction of FFVs led to consumers being able to benefit from lower fuel costs by being able to choose cheaper fuels, which helped increase the popularity of ethanol among users. The expectation of economic benefits from E2G exports contributed to the alignment of interests between the private and public sector regarding the promotion of E2G production, resulting in a substantial acceleration of innovation and development in this technological route in the early 2000s. Environmental externalities have been a strong incentive for further developing the market for E2G, first abroad but then domestically.

Table 4 summarizes the structure–function coupled analysis of Brazil's bio-ethanol innovation system.

Table 4. Structure–function coupled analysis of bio-ethanol innovation system in Brazil

Function[a]		Structural element	Interventions in the Brazilian ethanol innovation system
F1	Knowledge development and diffusion	Actors	• Many actors contributed to knowledge development and diffusion of the ethanol TIS, including cooperatives (e.g. Copersucar's R&D centre CTC), private companies (e.g. Dedini, BIOBRAS, Coalbra, GranBio, Raízen), public universities and knowledge institutes (e.g. UNICAMP, Federal University of Rio de Janeiro, University of Brasilia, National Technology Institute and Brazilian Bioethanol Science and Technology Laboratory), government entities such as the Secretariat for Industrial Technologies (Ministry of Science and Innovation), the Interuniversity Network for the Development of the Sugarcane Industry in Brazil and international entities (e.g. international congresses, networks of scientists, companies)
		Institutions[b]	• Many policies and regulations implemented through national programmes promoted knowledge development and diffusion (e.g. PLANALSUCAR and ProÁlcool) • The ANP regulation requiring 1% of oil and gas exploration companies' revenues to be invested in R&D ensured the availability of funding for knowledge development
		Interactions	• Multi-stakeholder partnerships and networks played an important role in promoting knowledge development and diffusion, especially by allowing knowledge producers and users to learn by interacting. Key examples were the collaboration networks with the European Cluster Cooperation Platform in the 1920s; later the Agronomic Institute in Campinas, CTC and the Interuniversity Network for the Development of the Sugarcane Industry in Brazil; networks of university researchers such as Rede Bioethanol; and collaboration with international universities under Bioethanol Projects I and II
		Infrastructure	• Sugar cane productivity improved as a result of knowledge development • Dedini created a local equipment manufacturing and service industry by increasing the knowledge and learning of its employees by using imported materials
F2	Entrepreneurial experimentation	Actors	• Private sector entrepreneurs from the sugar cane sector were the first to start experimenting with ethanol technologies. EECP experimented with sugar cane varieties in the 1920s and many demonstration programmes were implemented over time through multi-stakeholder collaborations. Experimentation by companies such as Dedini, Raízen and GranBio was key for developing a local technology supply industry
		Institutions[b]	• Many policies favoured experimentation, making public funding available for early experimentation in the 19th century. The Technology Innovation Partnership Programme and the Industrial PAISS were key examples in incentivizing entrepreneurial experimentation
		Interactions	• As many of the experimentation initiatives involved a multiplicity of stakeholders, the interaction between these actors improved resource mobilization for experimentation and led to accelerated learning by doing . Lessons learned from these initiatives could then be incorporated more easily in the producer and user sectors. Examples are the coordinating role of EECP between scientists and sugar cane producers, the role of the Brazilian Sugarcane Industry Association and the partnership between Dedini, CTC and FAPESP
		Infrastructure	• Dedini's experimentation plants and three demonstration plants for E2G are some examples of infrastructure that support experimentation

[a] See the Table 3 for the description of functions.
[b] References to institutions as a structural element in this table are to systems of formal and informal rules.

Table 4. (continued) Structure–function coupled analysis of bio-ethanol innovation system in Brazil

Function[a]		Structural element	Interventions in the Brazilian ethanol innovation system
F3	Market formation	Actors	• Government coordinates with the automobile industry and establishes public policies for stimulating demand, including public procurement • Automobile industry developing FFVs
		Institutions[b]	• Many policies and regulations contributed to domestic market formation, including mandates for adding ethanol to gasoline, public procurement for ethanol vehicles (and FFVs), fiscal incentives and loans to develop ethanol-fuelled vehicles under ProÁlcool, price regulation to avoid competition with gasoline, purchase guarantees from Petrobras and stimulating ethanol use in chemical production under ProÁlcool • International agreements such as the Kyoto Protocol and the Paris Agreement contributed to increased concerns about GHG emissions and sustainability, leading to countries implementing policies for increasing their use of sustainable biofuels, which created a market for exports of Brazilian E2G
		Interactions	• Government played a key role in engaging sugar producers, the automobile industry and the oil and gas sector (mainly via Petrobras), helping to align expectations and coordinate action to expand the ethanol market in Brazil
		Infrastructure	• The infrastructure of the oil and gas industry was used for transportation and distribution after Petrobras bought ethanol from producers
F4	Influence on direction of search	Actors	• Government helped provide direction via national strategies and policies, especially by considering the ethanol industry an industry of national interest • Institutes such as the National Technology Institute, the President's Committee for Strategic Issues and the Centre for Strategic Studies helped to align expectations through studies about ethanol technologies, including from multiple production routes
		Institutions[b]	• Government policies aligned expectations for the future of ethanol technology (and market) development, also by helping to set standards through regulations • International agreements and policies in other countries contributed to a reprioritization between E1G and E2G
		Interactions	• International cooperation (e.g. with the Soviet Union, scientific networks, organizations, regulations in other countries such as the United States for E2G) • Industry lobbying since the 1920s helped influence government policies in certain directions
		Infrastructure	• A strong sugar cane industry, allowing for a more favourable starting point for sugar cane-based ethanol production

[a] See the Table 3 for the description of functions.
[b] References to institutions as a structural element in this table are to systems of formal and informal rules.

Table 4. (continued) Structure–function coupled analysis of bio-ethanol innovation system in Brazil

Function[a]		Structural element	Interventions in the Brazilian ethanol innovation system
F5	Resource mobilization	Actors	• Public funding was a main source for resource mobilization, via government subsidies and public R&D funding (BNDES, FAPESP, Finep) • Private funding was mobilized primarily through private R&D institutes, technology suppliers and manufacturers, including private companies such as Dedini, GranBio and Raízen; cooperatives such as CTC; and car manufacturers
		Institutions[b]	• Many policies and regulations contributed to resource mobilization, especially the ANP regulation requiring 1% of oil and gas exploration companies' revenues to be invested in R&D and the Industrial PAISS
		Interactions	• Collaboration between the private sector, universities and government funding institutions was common in RD&D projects
		Infrastructure	• The use of existing infrastructure in many cases (sugar production, gasoline distribution, etc.) meant ethanol production did not require creating an entirely new infrastructure, which helped to reduce the need for resources
F6	Legitimation	Actors	• Sugar cane producers legitimized ethanol by advocating its use as a solution to economic dependency and energy security risks • Government promoted legitimation, for example, by introducing mandatory blending requirements early. Recognition of ethanol as an industry of national interest and as part of broader socioeconomic priorities contributed to increased support from industry and created jobs
		Institutions[b]	• Introduction of an ethanol fuel variety in 1927 was the first policy to contribute to ethanol being seen as a legitimate fuel in the Brazilian fuel mix • Public campaigns for ethanol vehicles aimed to increase awareness and overcome resistance
		Interactions	• Scientific meetings facilitated information-sharing on best available knowledge on ethanol technology development, leading to recognition of progress • Consumers' word of mouth on ethanol-fuelled vehicles and FFVs helped to build (and unbuild) trust in the technology
		Infrastructure	• Dependency on imported gasoline and commodity exports increased vulnerability to external shocks and the legitimacy of ethanol production

[a] See the Table 3 for the description of functions.
[b] References to institutions as a structural element in this table are to systems of formal and informal rules.

Table 4. (continued) Structure–function coupled analysis of bio-ethanol innovation system in Brazil

Function[a]		Structural element	Interventions in the Brazilian ethanol innovation system
F7	Development of positive externalities	Actors	• Companies in the sugar cane, automobile and energy sectors could benefit economically from ethanol development, motivating them to support policies thereon • Government recognizing ethanol as an industry of national interest created opportunities and increased support for industrial development and job creation • Consumers could save money by choosing between ethanol and gasoline, depending on prices, owing to the flexibility provided by increased use of FFVs
		Institutions[b]	• ProÁlcool was part of the national development plan that explicitly aimed to promote national economic development and industrialization, as well as to increase energy security and affordability • Introduction of FFVs led to the creation of a local industry that was able to increase economic benefits and create jobs • Support under PAISS helped to establish three of the main technology suppliers in ethanol technologies in Brazil • RenovaBio creates positive environmental externalities by incentivizing GHG emission reduction via carbon credits and reduction targets
		Interactions	• Industries benefiting from ethanol created associations to coordinate action and lobby for promoting the ethanol industry • Rede Bioethanol advocated for improving technology to reduce the environmental impacts of ethanol production
		Infrastructure	• Employment creation in the industry • Development of technological routes with low environmental impacts

[a] See the Table 3 for the description of functions.
[b] References to institutions as a structural element in this table are to systems of formal and informal rules.

6. Role of the case in Brazil's nationally determined contribution

Biofuels play an important role in Brazil's energy mix. According to the IEA Bioenergy Technology Cooperation Programme[93], biofuels represented 25% of transport fuels in Brazil in 2021, which is a very high share compared with other countries.

Among biofuels, ethanol is the most common, with 49% of energy use in Brazil coming from gasoline and ethanol combined. Biofuels are key to reducing transport emissions.[94] RenovaBio was established as the national biofuel policy in 2017 with the explicit aim of contributing to the implementation of the Brazilian nationally determined contribution and to energy security. Therefore, it sought to increase the share of biofuels in the energy mix,[95] reduce the carbon intensity of the transport fuel matrix by 10% and achieve a reduction in emissions of 620 million tonnes of carbon dioxide equivalent by 2030 compared with the 2018 level.[96]

In contrast to previous policies, RenovaBio explicitly values the environmental externalities of biofuel production and use. It aims to promote the expansion of biofuels in the Brazilian energy matrix by providing incentives to biofuel producers. It has provisions for commercializing the fuel market and increasing its predictability, and proposes the creation of a market for CBIOs. However, this policy is relatively recent, so the long-term contribution of RenovaBio to the Brazilian nationally determined contribution is not yet known. In addition, some issues related to the detailed accounting methodology and some legal and regulatory aspects are not yet defined.[97]

The development of biofuels, including ethanol, has also contributed to meeting sustainable development goals in Brazil. It has promoted job creation and income generation in ethanol production, but also throughout the value chain (e.g. in sugar cane production and FFV manufacturing). In 2019, ethanol production was estimated to support around 1.5 million direct and indirect jobs in the country. Moreover, development of the ethanol industry in rural areas has had positive impacts on local infrastructure and supports livelihoods in surrounding areas.[98]

93 IEA Bioenergy was set up in 1978 to improve cooperation and information exchange between countries with national programmes in bioenergy RD&D. Technology cooperation programmes, of which there are currently 42, are independent bodies operating in a framework provided by the International Energy Agency. Available at https://www.ieabioenergy.com/about/.

94 IEA Bioenergy (2021) Country reports: Implementation of bioenergy in Brazil – 2021 update. Available at https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021_Brazil_final.pdf.

95 Grangeia et al (2022).

96 IEA Bioenergy (2021).

97 Grangeia et al (2022).

98 IEA Bioenergy (2021).

7. Key success factors and lessons learned

Technology-push and technology-pull policies are needed for successful innovation.

The case of ethanol activities in Brazil has shown the effectiveness of having policies that aim to further develop existing technologies (technology push, e.g. incentives for RD&D) and policies that reduce demand risks by creating a market for a product (e.g. via quotas, public procurement, incentives for ethanol use in vehicles), which could be clearly seen for both E1G and E2G. While RD&D played a key role in learning and improvement in the first decades of the ethanol industry in Brazil, establishing minimum blending shares and introducing FFVs reduced demand uncertainties for ethanol producers. Moreover, while government policies and incentives in the 2000s enabled the acceleration of technology development for E2G, the creation of export markets prompted both private investors and the Government to increase efforts owing to expected future economic opportunities.

> **The case of ethanol activities in Brazil has shown the effectiveness of having policies that aim to further develop existing technologies**

Innovation policies and coordination are needed across the value chain.

The development of ethanol in Brazil was facilitated by simultaneous incentives and coordination from sugar cane production to ethanol production to ethanol use in the transport sector. For each of these steps in the value chain, both technology-push and demand-pull policies were implemented. The Government played a key role in promoting coordination and collaboration between the actors involved, in order to avoid actors waiting for others to make the first move in order to reduce their own risks.

A combination of bottom-up and top-down measures facilitates innovation.

The ethanol technology innovation system in Brazil was developed through a combination of bottom-up initiatives, led mainly by the private sector and academia, and top-down measures from the Government. While the initiatives from the private sector and academia were crucial in enabling experimentation with different technological methods, ensuring support from stakeholders and facilitating learning, they were not sufficient on their own to make ethanol competitive as a fuel. Top-down measures helped increase the competitiveness of ethanol as a fuel by introducing purchasing quotas, price caps and minimum blend requirements; ensuring coordination across sectors; and reducing uncertainty by clearly making long-term commitments to an industry designated by the Government as an industry of national interest.

Coordination between knowledge producers and users accelerates diffusion.

Experimentation with ethanol development in Brazil led to the establishment of several multi-stakeholder networks and partnerships that ensured coordination and feedback between technology development and use, greater dynamism and a faster uptake of lessons learned in production, which accelerated technology development and increased productivity.

Aligning technological development with societal goals facilitated the formation of coalitions that provide political support and legitimacy to new technology.

Because the development of the ethanol sector was always linked to other societal goals, such as reducing international economic dependency for fuels and commodities and promoting energy security and employment opportunities, policies for ethanol promotion enjoyed relatively high political support and social acceptance. The flexibility provided by FFVs allows consumers to choose fuels according to relative prices, which increases affordability and helps to overcome user resistance. Increased concerns regarding environmental sustainability were a major factor in the increased support for E2G.

Innovation takes time, is uncertain and is highly dynamic.

Despite the overall success of the ethanol sector in Brazil, several projects and initiatives failed over the years. Early stages of innovation faced high uncertainties regarding technological methods and unforeseen impacts. For example, ethanol was initially developed owing to economic and energy security concerns, but ended up helping to meet climate change mitigation goals. The expansion of ethanol production also had unforeseen negative impacts, such as on food production, population displacement and deforestation. The need remains for continuous monitoring and evaluation of innovation and technology development to ensure alignment with changing societal goals and emerging insights, as the negative impacts became evident only later on.

International cooperation can intentionally or unintentionally influence the development of local innovation systems.

Local support for technology innovation and early market formation increased Brazil's ability to compete in international markets. For example, the development of an ethanol industry began as a result of a crisis in the global sugar market. World wars provided an extra push for developing a local industry owing to difficulties importing goods such as equipment for ethanol production. In addition, environmental policies in the United States created demand for E2G production in Brazil. International cooperation within networks of organizations and researchers have been an important mechanism for knowledge development and diffusion. However, even though such collaborations created opportunities for ethanol development, local government and entrepreneurs ensured that the opportunities were seized. Without local support, technology leadership would not have been achieved, even though the international context created favourable conditions. In fact, these favourable conditions initially led to the products that were more environmentally sustainable being exported and the products that were less sustainable remaining in the domestic market. Government intervention through RenovaBio helped change the situation.

Different capabilities are needed across stakeholders.

The case of ethanol activities in Brazil has highlighted that different stakeholders need different capabilities. For instance, building appropriate scientific and technological capacity helped to develop a knowledge base to promote technological development and learning. Developing an appropriate business base among existing firms and entrepreneurs was crucial to developing production capabilities. In addition, knowledge of formulating and executing policies was required within public organizations. Moreover, user capabilities were crucial for creating demand for ethanol, for instance in terms of understanding the advantages of FFVs.

International cooperation in innovation and technology transfer, in many forms, was crucial in all phases of ethanol development in Brazil.

Networks of scientists; cooperation between local, international and multinational organizations; and government-led visits to other countries were important mechanisms for knowledge development and diffusion. Local ethanol manufacturers were able to assess imported equipment to start manufacturing their own versions. However, it should be noted that the protection of intellectual property rights has since increased.

8. Good practices for potential replication

On the basis of the above success factors and lessons learned in the ethanol sector in Brazil, the following good practices could lend themselves to replication in other countries.

Ensure continuous monitoring and evaluation, providing room for realignment if needed.

As new knowledge is produced or societal goals change, it is important to assess whether innovation policies are still fit-for-purpose. Conditions may also change over time, and some technology options that were not attractive earlier may become a good solution. Examples can be clearly seen in the different evolutions of E1G and E2G in Brazil, and can be a lesson for other technologies and countries.

Strengthen networks to ensure coordination between stakeholders.

Strong networks facilitate knowledge development and diffusion across systems and help overcome coordination failures. Such networks also help align expectations and provide a direction for technological change. Closer collaboration between knowledge producers and users makes the incorporation of lessons learned more dynamic and accelerates progress.

Facilitate a combination of top-down and bottom-up measures.

Bottom-up initiatives have high levels of ownership from stakeholders (e.g. local entrepreneurs searching for opportunities to diversify income), as they are more likely to reflect the variety of stakeholder interests, needs and concerns. However, bottom-up initiatives on their own are usually not enough to make innovations competitive in existing markets, as new technologies or products can face high levels of uncertainty and fragmentation. Top-down measures help to provide guidance, reduce uncertainty, establish more favourable regulations and ensure coordination between actors from multiple sectors and across the value chain.

Ensure policies address both technology-push and technology-pull aspects.

Innovation policies should promote the development of new technologies, for example by investing in R&D. However, new technologies are often unable to compete with established technologies or are not yet integrated into existing regulations. Proactive policymaking can help to ensure there is a demand for innovations in the market, for instance through public procurement and user incentives.

Strengthen international collaboration and coordination to strengthen mutual opportunities.

National policies and initiatives can affect innovation abroad, just like international developments affect local innovation systems. For example, the ethanol TIS in Brazil developed as part of a response to international developments in the sugar and oil markets, and, for E2G, to policies and regulations for more sustainable biofuels globally. Many countries import ethanol from Brazil and therefore benefit from Brazilian national policies and initiatives over the past century. The situation where policies in one country help to strengthen innovation systems in other countries has also occurred elsewhere, such as in the wind energy sector in Denmark which is other case in the NSI cases compilation. Knowledge-sharing via transnational networks plays a role in strengthening innovation systems in other countries; however, this knowledge sharing should be about more than just technical aspects and include, for example, policies and regulations that can promote certain innovations. International cooperation can play an important role in facilitating collaboration in the innovation, development and transfer of technology, but it is crucial that knowledge is transferred and adapted to the local context.

Strengthen capabilities across stakeholders.

Different actors require different capabilities for contributing to innovation, and capabilities need to be built across stakeholders, including researchers, producers, users, consumers and policymakers.

Transform challenges into opportunities to achieve multiple societal goals.

Bioethanol development in Brazil has been driven by the need to achieve societal goals related to energy security, industrial development barriers and economic vulnerability to external shocks. Achieving these societal goals contributed to increased support for ethanol production and use in the private and public sector, which resulted in pressure for government policies and regulations more supportive. Such policies created opportunities to achieve additional societal goals, such as job creation and GHG emission reduction, which can lead to synergies in achieving still more societal goals, as also illustrated in the case of the wind energy sector in Denmark. The ongoing achievement of societal goals is especially important in the context of achieving the multiple goals entailed in sustainable development.

About the Technology Executive Committee

The Technology Executive Committee is the policy component of the Technology Mechanism, which was established by the Conference of the Parties in 2010 to facilitate the implementation of enhanced action on climate technology development and transfer. The Paris Agreement established a technology framework to provide overarching guidance to the Technology Mechanism and mandated the TEC and CTCN to serve the Paris Agreement. The TEC analyses climate technology issues and develops policies that can accelerate the development and transfer of low-emission and climate resilient technologies.

Acknowledgements

The Technology Executive Committee extends its appreciation to Dian Phylipsen of SQ Consult, Heleen de Coninck and Clara Caiafa of Eindhoven University of Technology, Ambuj Sagar and Nimisha Pandey of Indian Institute of Technology Delhi, for their development of this report. It also extends its appreciation to the representative of observer organizations participating in the TEC activity group.

Contact Details

The Technology Executive Committee may be contacted through the United Nations Climate Change Secretariat

Platz der Vereinten Nationen 1,
53113 Bonn, Germany
Email: tec@unfccc.int

Website: www.unfccc.int/ttclear/tec

UN Climate Change Technology Linkedin Group:
https://www.linkedin.com/groups/14126588/

#climatetech #TEC tclear/tec/NSI.html

A digital copy of this report can be downloaded from:
https://unfccc.int/ttclear/tec/NSI.html