Ocean Conservancy®

Zero-Carbon for Shipping

Propelling investment in South and Central America with hydrogen-based shipping fuels

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Who is Ocean Conservancy?

Ocean Conservancy is working to protect the ocean from today's greatest global challenges. Together with our partners, we create science-based solutions for a healthy ocean and the wildlife and communities that depend on it.

Ocean Conservancy's shipping emissions campaign focuses on targeted policy changes and science-based solutions with the goal of reducing carbon emissions and bolstering protections for the marine environment, its living marine resources and the communities that are part of and dependent on ocean ecosystems.

Ricardo Energy & Environment

At Ricardo Energy & Environment, our vision is to create a world where everyone can live sustainably: breathing clean air, using clean energy, travelling sustainably, accessing clean water and conserving resources. Adopting renewable electrofuels for shipping would bring the world closer to these aims.

Since the 1950s, we have worked to deliver improvements in air quality, pioneered the use of renewable energy technology and worked on the development and implementation of The Paris Agreement on Climate Change, helping countries and organizations to mitigate climate change by reducing greenhouse gas emissions.

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Executive summary

South and Central America has an active shipping sector, which is underpinned by trade within the region and globally. Shipping is currently reliant on fossil fuels, but decarbonization goals set by the International Maritime Organization (IMO) and governments require the sector to adopt zero-carbon fuels in the coming years. Synthetic fuels made with renewable electricity, also known as 'green electrofuels', have an important role to play.

The development of electrofuels infrastructure is a significant opportunity for countries in South and Central America. The decarbonization of seaborne trade routes will require new refueling infrastructure and supply chains. Electrofuels can be produced sustainably, with the main inputs being renewable electricity and water. The required technology is available now and has been commercially proven in other sectors. With their abundant untapped renewable potential, the countries in South and Central America are well placed to attract investment to establish supply chains for electrofuels, including renewable energy technologies.

The development of electrofuels also has spillover benefits for decarbonizing other sectors, with the potential to produce carbon-neutral fuels for other sectors such as aviation and hydrogen for heavy industry. Moreover, it will help to establish infrastructure, skills and supply chains for renewable technologies in the region, driving down their costs and encouraging increased adoption. In addition, there would be reduced reliance on imported fuels, increasing energy security and fuel price stability.

> The South and Central American region can use its status as a key trading hub to attract investment in electrofuel supply chains to serve a growing number of zero-carbon vessels.

The business case for electrofuels infrastructure and the associated benefits will depend on the unique characteristics of each port. This report features four case studies of ports in South America to illustrate how adopting electrofuels for shipping could attract investment to the region based on five main themes:

Ports could provide zero-carbon refueling on busy shipping lanes.
There is significant vessel traffic in the region's waters, and ports located along busy and established shipping lanes could provide bunkering* for zero-carbon vessels that are passing by or visiting to load/unload.

Adoption could be supported by demand from existing port activity.
Ports along reliable and established trade routes provide a long-term business case for electrofuels. Electrofuels infrastructure could be added to the existing port operations, allowing vessels to refuel while loading/offloading.

Electrofuels offer a new lease on life for ports reliant on trade of fossil fuels.
Where a port is reliant on trade of fossil fuels (or another commodity with a constrained or declining demand), investing in electrofuels infrastructure could provide a way to diversify by offering decarbonized fueling options or by exporting electrofuels as an alternative product. This would provide the port with a more sustainable future.

Collaboration within port clusters would provide economies of scale.
Where multiple ports are located close together, demand from zero-carbon vessels can be aggregated. Ports with favorable conditions could offer bunkering for vessels visiting the ports in the cluster, providing economies of scale.

Electrofuels could support decarbonization in other sectors.
Renewable energy and green electrofuels both have an important role to play in decarbonizing sectors reliant on fossil fuels, such as transport, electricity, and industry. Establishing an electrofuels supply chain for shipping will bring down the cost of decarbonization through economies of scale, development of skills, and mature supply chains.

The case studies in this report demonstrate the investment possibilities that could be unlocked in South and Central America through adoption of electrofuels for shipping. They also indicate that in aggregate across the region, there is potential to attract considerable investment in sustainable infrastructure. This will bring benefits far beyond the ports themselves, including increased energy security, creation of green jobs and support for wider decarbonization.

The countries within the South and Central America region are well coordinated on IMO policy issues, giving them a consistent voice with significant influence in the shipping sector internationally. As the investment potential of decarbonizing the shipping sector becomes increasingly apparent, it makes economic sense for governments within the region to use their influence to push for acceleration of the IMO's climate-related goals.

** 'Bunkering' is the shipping term for refueling. The name is derived from the bunkers (tanks) where fuel is stored.*

The decarbonization of shipping is an opportunity to develop sustainable infrastructure in South and Central America

In 2018, the International Maritime Organization (IMO) set a target for the international shipping sector to reduce its greenhouse gas emissions by at least 50% by 2050 compared to 2008 levels. Although improvements in fuel efficiency will get some of the way to achieving this target, further reductions will need to be achieved through the widespread use of fuels that emit zero carbon dioxide over their lifecycles. Considering that the typical vessel life is 20 to 30 years, the first zero-carbon ships need to be commercialized by 2030.

Studies have shown that 'electrofuels' made using renewable electricity – particularly hydrogen and ammonia – have an important role to play in decarbonizing shipping [1,2]. Electrofuels are synthetic fuels (i.e. they are manufactured) that involve electrolysis of water to produce hydrogen[1], which is either used as a fuel itself or combined with other molecules to make other fuels. When only renewable electricity is used for the electrolysis, electrofuels are defined as being 'green'.

The technology required to produce green electrofuels is well proven and shipbuilders have already started designing vessels to use these fuels, with the aim of having the first vessels in the water in the mid-2020s [3]. Planning for the development of green electrofuel plants needs to begin now so that the production capacity will be ready when demand ramps up in the second half of the decade. First-mover countries stand to benefit from the bourgeoning demand for the fuels.

[1] *A large volume of water is required to produce green electrofuels at the scale needed for shipping. It is recommended that production facilities be located near the sea and be equipped with a desalination plant and suitable brine treatment equipment, so that seawater can be used rather than drawing on freshwater sources. The examples given in this report use this approach.*

The Global Maritime Forum [4] has estimated that decarbonization of shipping will require investment of between

$1.0-1.9 trillion by 2050

More than three quarters of this amount is required to develop the onshore supply chain, which presents a substantial investment opportunity for countries with significant renewable energy potential.

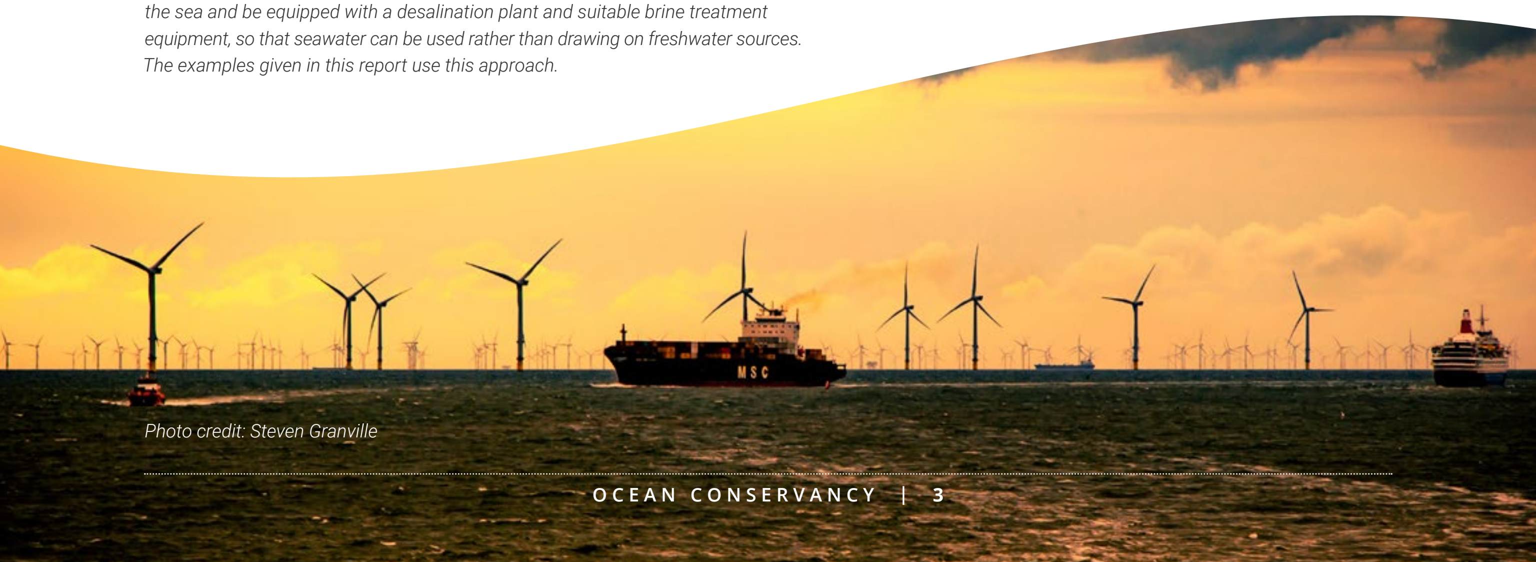


Photo credit: Steven Granville

This report shows how the production of green electrofuels for shipping within South and Central America could bring numerous benefits to the region, including:

1. Investment in sustainable infrastructure (including renewable electricity plants) underpinned by demand from large, credit-worthy corporations in the global shipping sector.
2. Stimulus for the domestic hydrogen sector, resulting in reduced reliance on imported fuels.
3. Creation of green jobs with transferrable skills for workers currently employed in the fossil fuel sectors.

A key hurdle to widespread adoption is that green electrofuels are expected to be more expensive than the fossil fuel alternatives for the foreseeable future [1]. Therefore, policy intervention is required to ensure that progressive ship owners and operators are not disadvantaged by adding the first zero-carbon vessels to their fleets. The IMO, shipping states and multilateral blocs have an important role to play in removing subsidies for fossil fuels and incentivizing the use of green alternatives. There are mechanisms that have been effective in encouraging adoption of renewable energy around the world which could be tailored for shipping, such as research and development subsidies, carbon taxes and carbon fuel levies.

There is a unique opportunity to act decisively on these issues as the world seeks to revive the global economy in the wake of the COVID-19 crisis. This report seeks to illustrate the significant potential for electrofuels to catalyze a green economic recovery, and foster investment in sustainable infrastructure to serve a growing demand for electrofuels into the future.

A glossary is provided at the end of the report to assist readers who may not be familiar with some of the terms that are used.

Green hydrogen and green ammonia are zero-carbon fuels made with renewable electricity

The shipping sector is considering many different candidate fuels for the decarbonization transition. All these fuels have a role to play in decarbonizing shipping, but it is difficult to predict the market share each type will have. Green ammonia and green hydrogen have emerged as favorites in many studies for the shipping sector because they are well-suited to the needs of the industry [2,5]. Other options are introduced briefly below.

Carbon-containing electrofuels

Carbon-containing electrofuels (such as e-diesel and e-methanol) require carbon dioxide as an input. This needs to be extracted from the air for the fuel to be carbon-neutral over its lifecycle because the carbon dioxide ultimately returns to the atmosphere when the fuel is burned. This requires significant amounts of additional renewable electricity and relies on technologies that are not currently commercially available at the scale required to produce shipping fuels [6].

Blue hydrogen-based fuels derived from fossil sources

Currently, the most common method of producing hydrogen is through a process known as steam methane reforming, with fossil fuels used as the main input. Hydrogen produced in this way is known as 'blue hydrogen' and can be combined with other molecules to produce a range of blue fuels. The process involves the creation of carbon dioxide that is usually emitted into the air. If the carbon dioxide is captured instead of emitted, then it can be stored underground. Blue hydrogen can be carbon-neutral if combined with carbon capture and storage, and there are no emissions of greenhouse gasses over the whole lifecycle of fuel supply, conversion and use.

Fuels derived from biomass

Fuels derived from biomass sources are often considered carbon-neutral because the carbon they release when burned was absorbed from the air as they grow. South America is a world leader in biofuels. However, the converting fertile land to grow biomass crops is problematic and unsustainable especially if it replaces virgin forest or food crops.

Why green hydrogen and green ammonia were chosen for this report

This report focuses on green hydrogen and green ammonia because the countries in South and Central America could capitalize on their abundant untapped renewable electricity potential to produce them at industrial scale. In addition, these two fuels do not contain carbon and therefore do not emit carbon dioxide at any point in their lifecycle if they are produced using renewable electricity. As this report shows, development of infrastructure to produce green hydrogen and green ammonia will increase demand for renewable electricity plants; strengthening supply chains, creating clean jobs and reducing costs of renewable technologies in the region.

Renewable plants need to be built responsibly

Renewable electricity plants need to be planned and developed responsibly to ensure that they provide a net benefit to the surrounding communities and environment. A few key points are noted below.

Renewables in addition to those required to decarbonize the electricity grid

The renewable electricity for electrofuels should not be diverted from supplying the needs of consumers through the grid. Hence, the renewable plants should make use of surplus or untapped sources. The best case is to build new renewable plants that supply most of the electricity that they produce directly to the electrofuel facility, with a connection to the grid to export to the grid in times of excess production.

Avoiding indirect land use change

Indirect land use change refers to the ripple effect on how land is used, especially when land that was previously used to produce food is re-purposed to produce fuels. It is often discussed when referencing biofuels, but it is also a consideration for electrofuels. It is imperative that when land is selected to build solar and wind farms, for example, it should not displace agricultural activity, leading to deforestation or other negative impacts on the environment.

Sustainable and responsible hydropower

Hydropower has been the mainstay of renewable electricity production in South and Central America, as evidenced in the case studies later in this report. However, this report assumes that existing hydropower plants will continue to serve the electricity grid, while wind and solar will be the primary sources of renewable electricity for electrofuels. In cases where new hydropower could be developed to supply electricity for electrofuels, the plants should be developed in a socially and environmentally responsible manner with due regard for all possible impacts.

Shipping supports vibrant trade in South and Central America

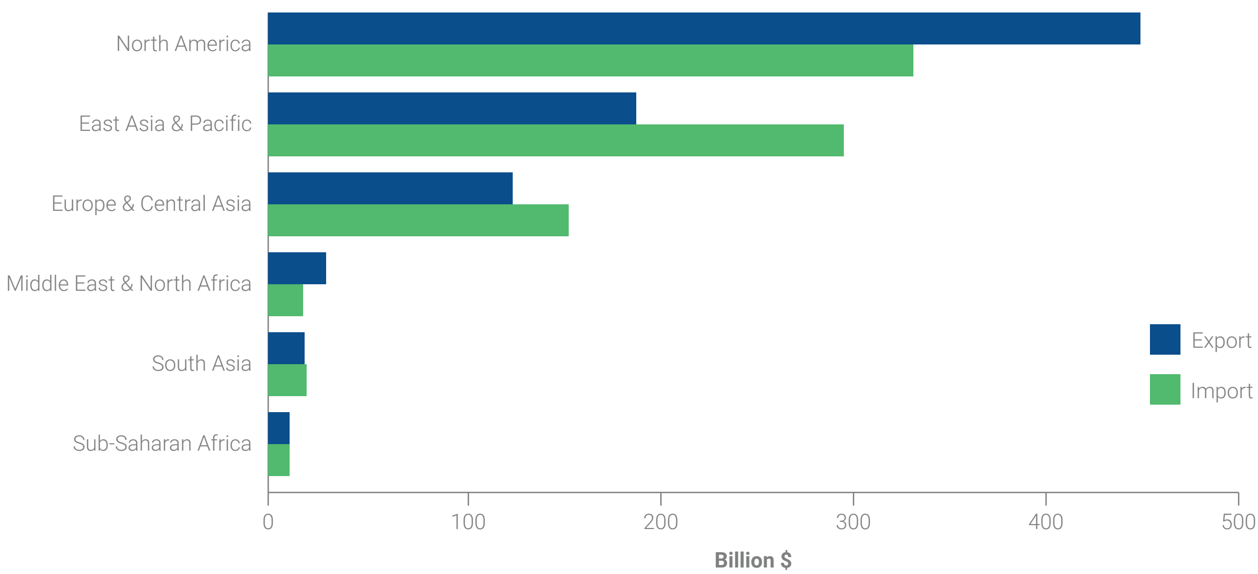
There is an active shipping sector in South and Central America, which is underpinned by trade within the region and globally. Total imports to the region are about the same as exports at approximately $1 trillion[2]. The region's main trading partner is the United States of America (43% of exports and 32% of imports respectively), followed by China (12% and 19%). Other countries each make up less than 5% of trade [7]. Trade flows with other regions are shown in the chart.

THE TOP FIVE PRODUCTS EXPORTED FROM THE REGION ARE:

1. **$74.9 billion** Petroleum
2. **$37.3 billion** Soya beans
3. **$36.9 billion** Copper ores and concentrate
4. **$36.3 billion** Vehicles
5. **$24.7 billion** Electronic equipment

(2018 values [7]):

TOTAL VALUE OF IMPORTS AND EXPORTS FROM SOUTH AND CENTRAL AMERICA TO OTHER REGIONS

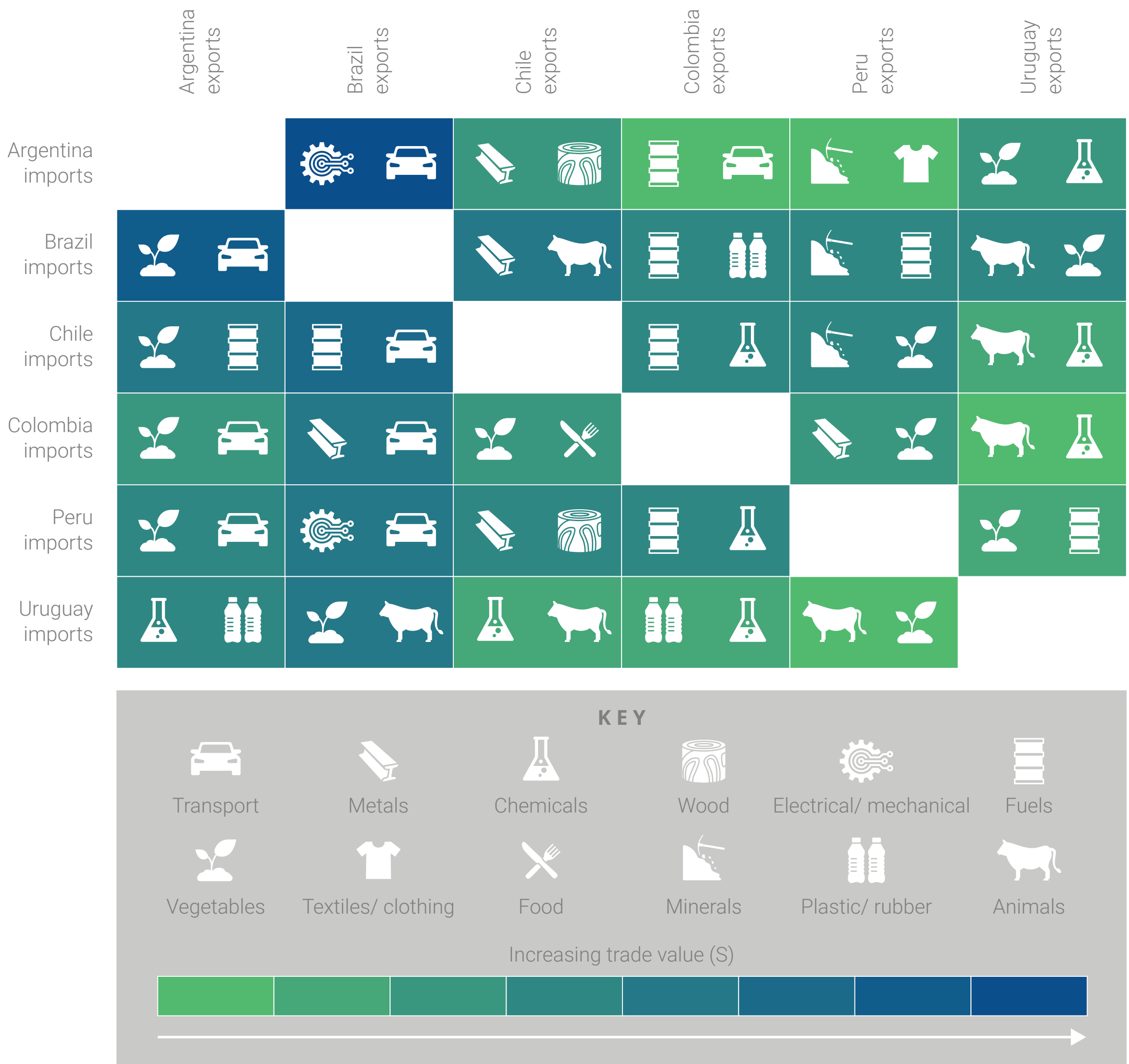


[2] *The symbol '$' is used throughout this report to denote United States dollars.*

A variety of goods are traded between countries in South America

There is also healthy trade between countries within South America. The matrix below shows the top two products traded between pairs of countries in the region, indicating a wide range of commodities. At a total value of about \$26 billion, bilateral trade between Brazil and Argentina is the largest in the region, followed by Brazil's trade with Chile (approximately \$9.8 billion). Due to geography, these relationships are primarily reliant on seaborne trade. More information about trading relationships within the region is provided in the case studies later in this report.

MATRIX SHOWING TOP 2 PRODUCTS TRADED BETWEEN SELECTED COUNTRIES IN SOUTH AMERICA



Decarbonization of seaborne trade routes will attract investment to the region

The South and Central America region is a key nucleus for maritime policy. Significant maritime traffic passes through its waters due to the high levels of trade and to use the Panama Canal. The countries in the region are well coordinated on IMO policy issues, giving them a strong and consistent voice. Moreover, with the world's largest flag state (Panama) among their number, the region has significant influence in the international shipping sector.

As a key hub for international trade, the drive to decarbonize shipping fuels will provide opportunities for countries in the region to attract investment in electrofuel supply chains. Therefore, it would make sense for governments in South and Central America to use their influence to push for acceleration of the IMO's climate-related goals to capitalize on this economic potential.

Electrofuels have an important role to play in the journey to decarbonize shipping. However, with less energy per unit volume than fossil fuels [1], it is likely that vessels operating on electrofuels will need to refuel more often, so more bunkering stops will be required along popular shipping routes. Establishing a supply chain for electrofuels will attract investment in sustainable industry and develop capabilities within the renewable energy sector. In addition, there would be reduced reliance on imported fuels, leading to increased energy security and price stability for the economy.

Likewise, at a local level, electrofuel bunkering can be beneficial for ports and surrounding areas as it presents an additional revenue stream, creates skilled green jobs and could also be used by smaller domestic vessels. This is illustrated in the four case studies later in this report.

Effective policies and incentives will be required

Governments need to create a favorable market environment to attract private investors to develop electrofuel plants. The countries in the South and Central America region have good experience of the types of policies and incentives that are effective in encouraging investment in renewable plants. If they are bold first movers, they could establish themselves as leading hubs for green electrofuels.

Uncertainty about the scale of uptake in the initial phases of the decarbonization transition might require governments to take the lead in developing plants or the infrastructure could be developed under a public-private partnership model to reduce risks to private investors. However, private investors are likely to take the lead as the market matures and income streams become more predictable.

Electrofuels have decarbonization spillover benefits for other sectors

Decarbonization of industry and trade is becoming a necessity on the global stage, driven by international goals to mitigate climate change. Electrofuels – hydrogen in particular – have an important role to play in decarbonizing sectors of the economy that have traditionally been reliant on fossil fuels. Therefore, it is important for countries to establish supply chains and build up the necessary skills to facilitate production of electrofuels.

This report focuses on the application for shipping, but electrofuels will also have an important role in decarbonizing aviation. Hydrogen will also be needed to decarbonize heavy industries that are carbon-intensive, such as the production of steel, cement and chemicals. This is because combustion of hydrogen can achieve the very high temperatures that these processes require. This is an important consideration for the likes of Brazil, Peru and Chile, which are key players in iron ore, steel and copper production.

As a progressive sector in decarbonization, establishing an electrofuels supply chain for shipping will create economies of scale, provide vital labor skills and expertise, and forge trading relationships that will enable other sectors to scale up hydrogen production.

In addition, electrofuels will create significant demand for renewable energy in addition to traditional consumption from the grid. Therefore, the cost of renewable electricity will decline due to economies of scale and mature supply chains, which will facilitate decarbonization of other sectors through electrification.

Case study:
Porto do Pecém, Brazil

The adoption of electrofules in this port could provide decarbonization spillover effects to the nearby industrial zone which includes production of steel and chemicals. See page 15.

Fuel production plants can be built now

The equipment required to produce green electrofuels has been in commercial operation for years and is well-proven. Therefore, plants can be designed and constructed in the next few years to satisfy the demand from shipping.

There are some key prerequisites for developing green electrofuel plants: they require a significant renewable generation capacity, adequate land availability, and a suitable governance and policy environment to support the industry.

It is also important to consider the specific characteristics of the port where the plant will be situated. The preferred solution will differ between locations and must be tailored to the requirements and opportunities available at each site. This also means that electrofuel production can be a valuable solution for a wide range of geographies, vessel types and local contexts.

Some requirements are summarized below.

ELECTROFUEL PLANTS CAN BE TAILORED TO THE REQUIREMENTS AND OPPORTUNITIES OF THE PORT, THE SURROUNDING GEOGRAPHY, AND THE LOCAL AND NATIONAL CONTEXT

Shipping volumes and future opportunity

An established port with a large throughput of goods could provide sustainable demand, which could grow over time as electrofuels become more widespread. The future potential of the port should also be considered. For example, if the port is located along a busy shipping route, could it be used for bunkering? Or, if the port focuses on handling fossil fuels, could it benefit from diversifying to export electrofuels?

Renewable energy resources

Renewable electricity is required to produce green electrofuels. Ideally, the renewable energy plants should be near to the fuel production plant, so the local availability of wind (onshore and offshore) and solar resources should be considered. However, in some cases, renewable electricity could be generated in other locations, and delivered to the plant through the electricity grid. Some plants might have a combination of the two approaches, which provides flexibility.

Land availability and land use

Electrofuel plants themselves require a relatively small amount of land, but wind and solar farms require significantly more (see the case studies later in the report). The current use of the land must be considered carefully when selecting locations for plants, such as protecting virgin forest, respecting land owned by indigenous people, avoiding indirect land use change and safeguarding the local community and environment.

National and local context

The location of the port within the geography, the surrounding community, and the national context should be considered. Electrofuels can be a valuable addition to the local and national economy, but funders need to have confidence that they will be able to make a reasonable return on their investment. Supportive policies and incentives are vital to provide investor certainty, as is buy-in from community stakeholders.

The business case for each port will depend on its unique characteristics

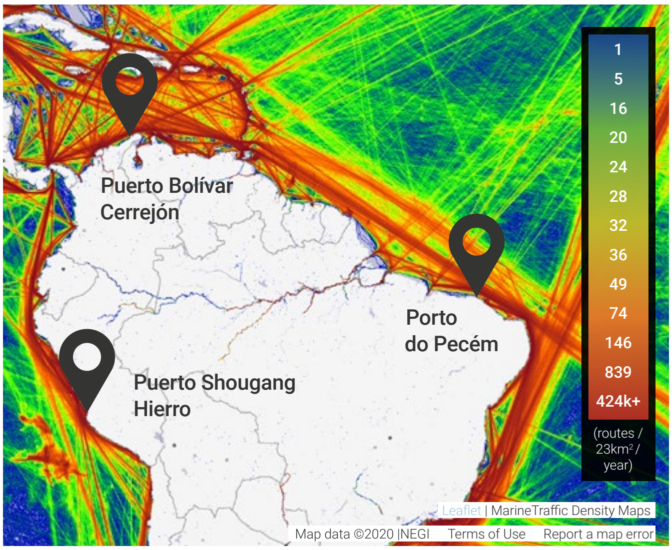
Electrofuels can be applied to a range of commercial and geographical contexts and the business case for each port will depend on its own characteristics. The case studies at the end of this report provide a few examples but are not exhaustive. Some of the possible themes are described below.

Zero-carbon bunkering on busy shipping lanes

Ports located along busy and established shipping lanes could provide bunkering facilities for zero-carbon vessels. The surrounding economy would benefit from the local production of electrofuels, attracting investment and increased trade.

There are many locations that could become bunkering stops, including the international shipping routes over the north coast of South America leading to the Panama Canal as well as along the western and eastern shores.

LOCATIONS OF THREE CASE STUDY PORTS SHOWN ON BUSY SHIPPING LANES (HIGH TRAFFIC ROUTES SHOWN IN RED)



Vessel traffic data from MarineTraffic.com used with permission.

Case study:
Porto do Pecém, Brazil

Located on the northern coast of Brazil, this port is located on the shipping lanes stretching from the eastern coast of South America and the southern tip of Africa to the east coast of the USA, or through the Panama Canal. This location would provide a convenient bunkering stop for international and regional vessels alike. See page 15.

Case study:
Puerto Shougang Hierro, Peru

This port has a significant throughput of iron ore, which is primarily exported to New Orleans, USA. This dedicated route is ideal for zero-carbon vessels and could provide predictable long-term demand. See page 39.

Adoption of electrofuels supported by existing port activity

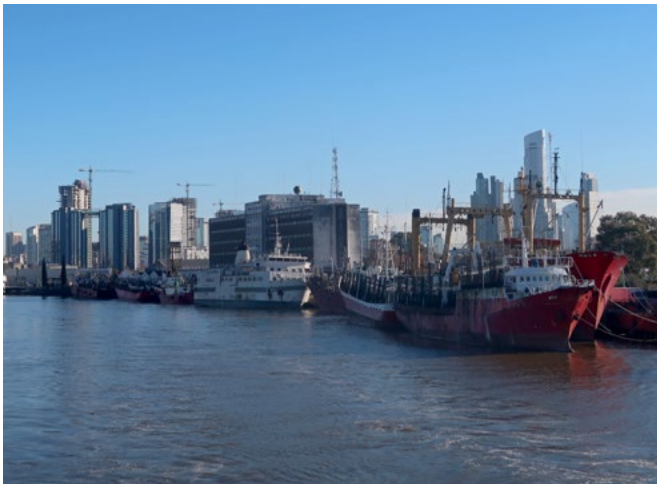
Ports located on reliable and established trade routes provide a long-term business case for electrofuels, particularly where trade is likely to continue for years to come. Zero-carbon vessels could be used on dedicated routes and electrofuels infrastructure could be added to the existing operations at the destination and origin ports. This would enable vessels to refuel while loading/offloading cargo, so increasing their operational efficiency.

Electrofuels as a new lease on life for fossil fuel ports

Ports that specialize in a single commodity are at risk if the future of that commodity is constrained or uncertain. For example, ports that primarily deal with coal, oil and other fossil fuels face the prospect of reduced demand over the coming decades as the global economy decarbonizes. There is an opportunity for these ports to benefit from electrofuels infrastructure by diversifying their activities and attracting investment to the area. This could be an effective strategy for mitigating the waning demand for fossil fuels and providing a more sustainable future for the ports and their surrounding economies.

Case study: Puerto Bolívar Cerrejón, Colombia

This port specializes in the export of coal, but it has excellent wind and solar potential. Hence, electrofuels could provide a new hope for the port's future. Investment in electrofuels infrastructure could enable the port to provide bunkering to vessels using the busy lane past the north of Colombia or electrofuels could be exported from the port. See page 31.



Collaboration within port clusters to aggregate demand

Where multiple ports are located close together, demand from zero-carbon vessels visiting the various ports can be aggregated. Ports with favorable conditions could provide bunkering for vessels visiting others in the cluster and benefit from the diversity of demand from zero-carbon vessels of various types. Coordinated vessel-to-vessel bunkering could also be adopted. It would also provide ship operators and owners with flexibility, knowing that zero-carbon bunkering is available nearby, if not at the port of call.

Case study: Cluster of ports around Río de la Plata mouth, Uruguay and Argentina

There are nine ports located in this area in Uruguay and Argentina. The ports include both urban and isolated locations, including some with abundant renewable energy resources. The ports trade in a wide range of products between them, providing diversity of demand. See page 23.

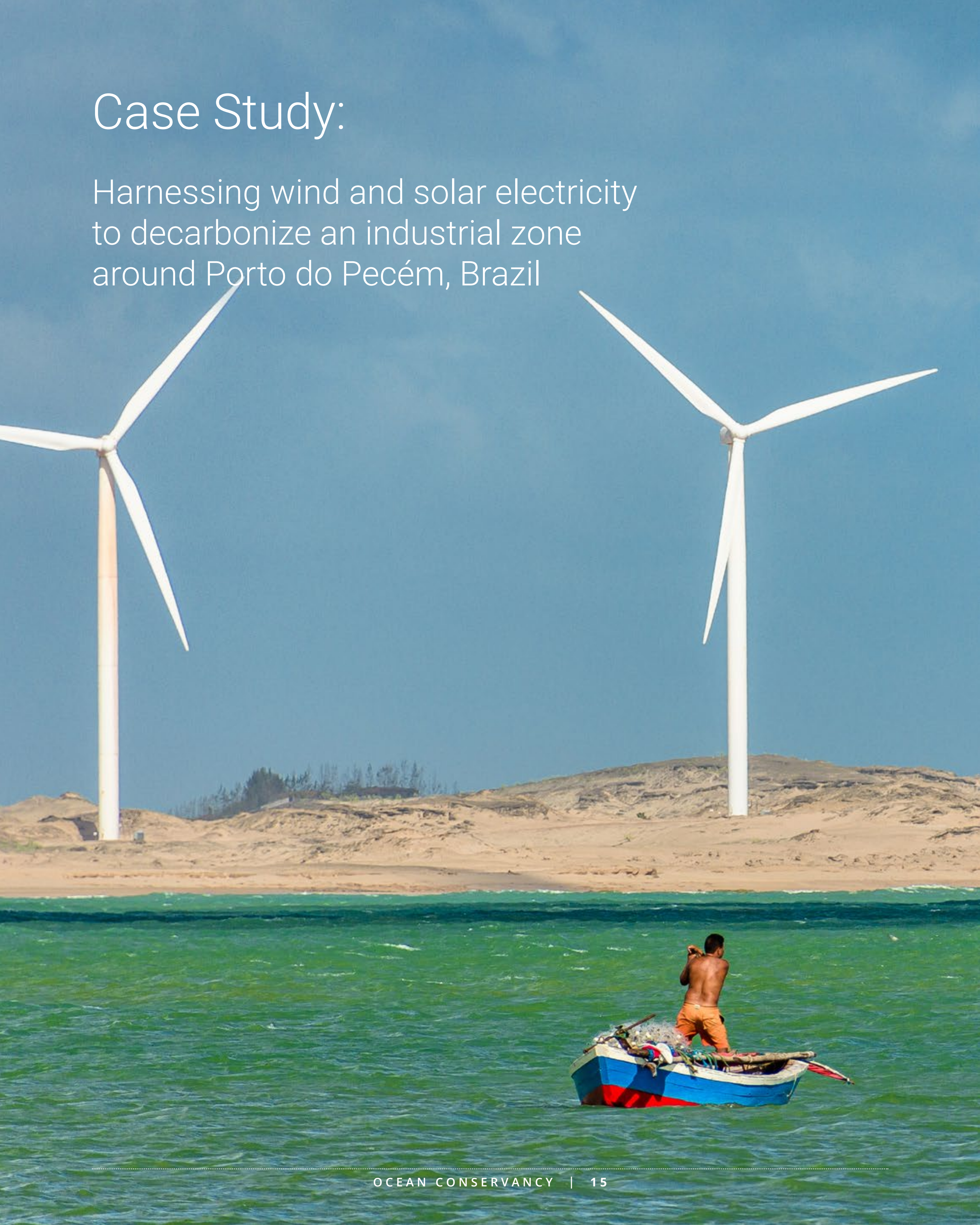
Summary

The adoption of zero-carbon electrofuels by the shipping sector presents an opportunity for countries in the South and Central America region to attract investment in sustainable infrastructure. The potential benefits extend far beyond ports to renewable energy supply chains, increased energy self-sufficiency, improved balance of payments, creation of green jobs and fostering a wider hydrogen economy.

This report concludes with four case studies to show how electrofuels plants can be built in the next few years to capitalize on this investment opportunity. The case studies provide a flavor of the approaches and benefits that electrofuels infrastructure could bring to South and Central America. However, the possibilities extend far beyond the specific locations and applications shown.

Case Study:

Harnessing wind and solar electricity to decarbonize an industrial zone around Porto do Pecém, Brazil



Brazil is the most active trading country in the region

Brazil is the largest country in South America and has the continent's largest economy. Its location means it has easy access to North America, Europe and Africa through the Atlantic Ocean, and the Panama Canal provides a route to the Asia-Pacific region.

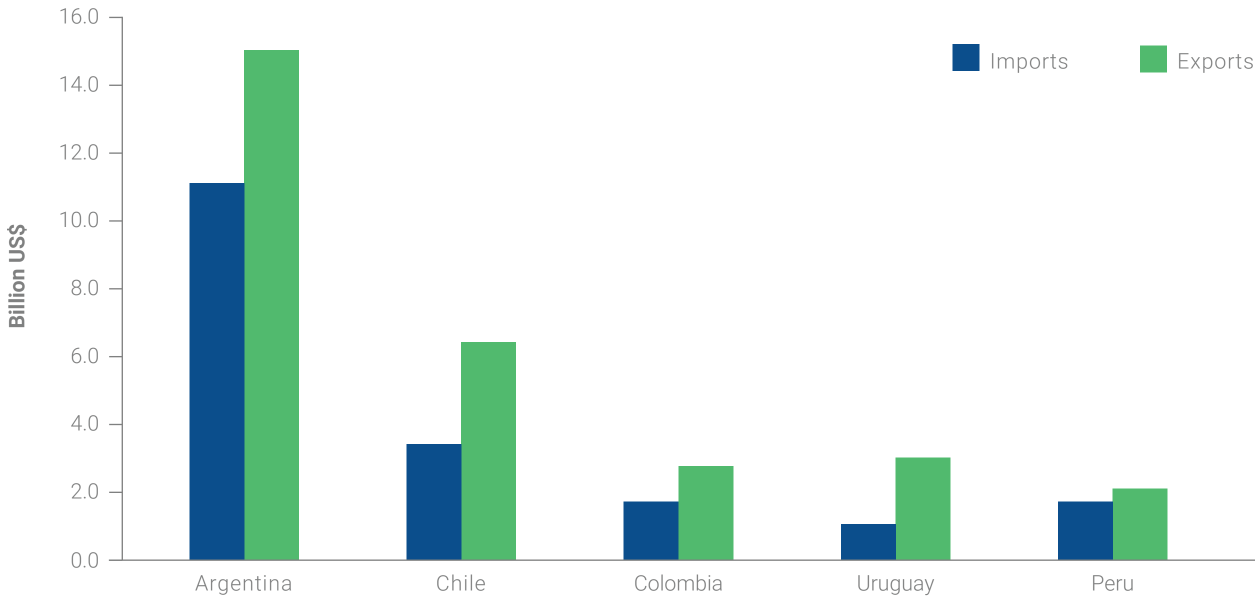
Its main trading partner is China, which receives 27% of its exports by value ($64.2 billion) and provides 19% of its imports ($34.7 billion), the highest share of both flows [8]. The United States is the second most significant trade partner, with 12% of exports and 16% of imports by value.

The chart below shows that Brazil is a net exporter to all of its main trading partners in the region. Brazil's trading relationship with Argentina has by far the highest value of any two countries in South America, totalling $26 billion in 2018.

TOP 5 GLOBAL TRADING PARTNERS IN 2018

1. China
2. United States
3. Argentina
4. Germany
5. Netherlands

TOP REGIONAL TRADING PARTNERS



Source for data: [7]

Brazil trades a diverse range of products

Brazil has a diverse portfolio of export products, including foodstuffs, minerals and fuels, so it is not overly reliant on a single commodity. Its largest export product is soybeans (12%), followed by iron ore (9%) and crude petroleum (8%). Brazil's highest imports are machinery and electrical equipment, followed by chemicals.

As the dominant economic force in the region, if Brazil invested in electrofuels infrastructure, it would provide a significant market to drive down costs and lead the region in capitalizing on the significant opportunities available.

BRAZIL'S TOP 5 IMPORT COMMODITIES

Machinery and electrical

Chemicals

Fuels

Transportation

Metals

BRAZIL'S TOP 5 EXPORT COMMODITIES

Vegetables

Fuels

Minerals

Transportation

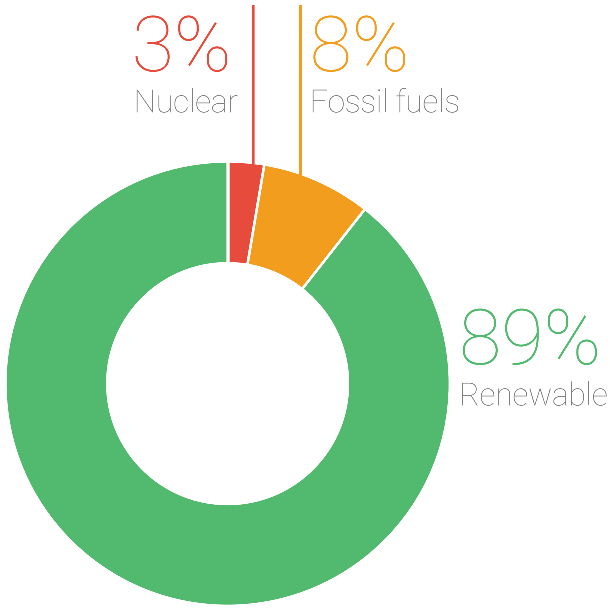
Food products

Brazil is encouraging investment in renewables

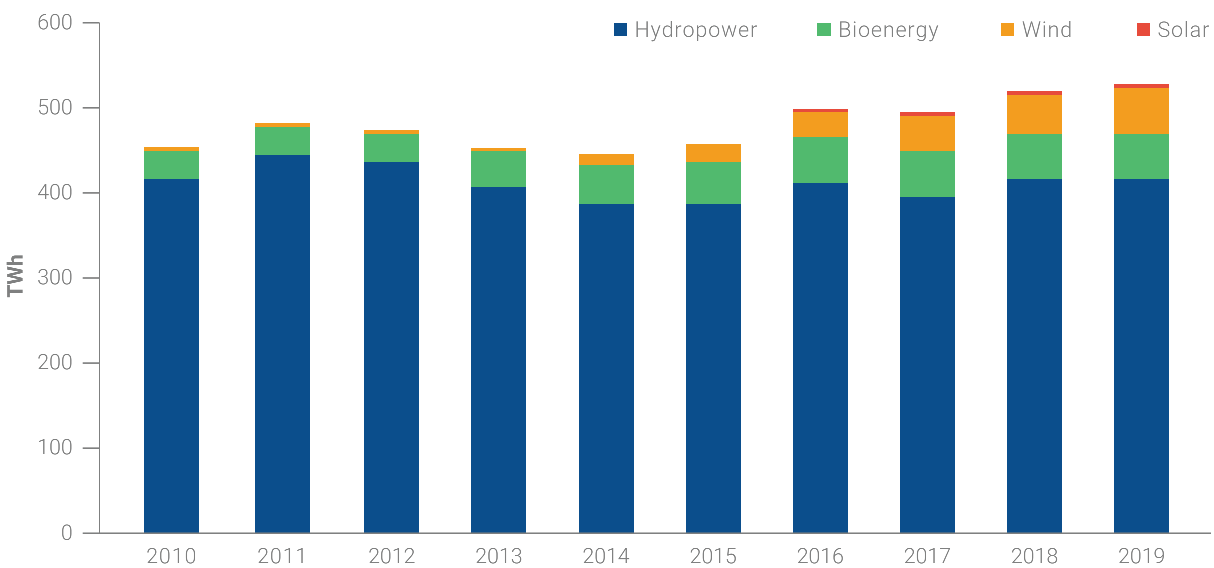
Approximately 89% of Brazil's electricity is generated by renewable sources, which is predominantly from large hydropower plants. In recent years, Brazil has significantly increased the contributions from wind and solar with intentions for further growth into the future [9,10]. Yet, there are still abundant untapped renewable resources that could be used. In 2019, the installed capacity of onshore wind was 14.8 GW; a fraction of the theoretical potential within the country of 522 GW [10]. For solar, the installed capacity in 2019 was 2.0 GW, whereas the theoretical potential has been estimated to be more than a 1,000 GW (some further work is required to determine the potential in areas that are practically exploitable without indirect land use change) [10].

The government has supported development of large renewable plants through auctions, with the latest auction offering long-term contracts between power plants and distributors, starting delivery in January 2024. It is also supporting the development of local and private renewable developments through a credit line for renewable energy projects [11]. The credit line provides low interest rates for renewable energy projects and will finance up to 80% of the project's total costs.

SHARE OF ELECTRICITY GENERATION 2019



RENEWABLE ELECTRICITY GENERATION



Source for data in charts: [9,12]

Porto do Pecém could be an important bunkering and hydrogen hub

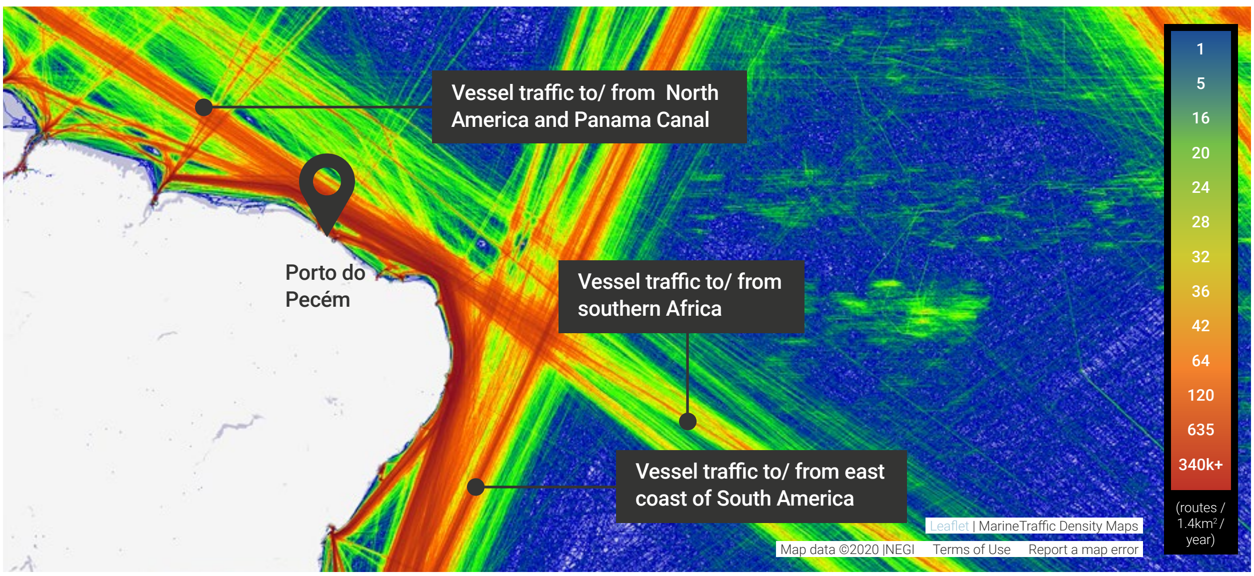
Porto do Pecém is an important part of the Industrial and Port Complex of Pecém, located in the State of Ceará in north-eastern Brazil. The complex stretches over more than 50 square miles, hosting a range of industrial activities, such as a steel mill, two coal power plants and fuel storage facilities among others [13]. In 2019, cast iron and steel products made up about half the tonnage loaded onto vessels in the port, while iron ore and coal each comprised about one third of products offloaded. Containerised cargo comprised about 20% of imports and 40% of exports by tonnage [14].

Despite the carbon-intensive activity in the complex, the port is the first in Brazil to offer a discount to ships that are certified according to the Green Award programme for promoting environmental performance, safety and quality in transportation [15]. These ambitions for increased sustainability could be further strengthened by developing facilities to produce and store electrofuels.

The port is located on a busy shipping lane that runs along the north-eastern shore of Brazil (see figure below). The lane is used by vessels travelling north from the eastern coast of South America as well as those heading westwards from southern Africa. The port is therefore ideally placed to provide electrofuel bunkering for the many vessels that moor there for loading and unloading (730 in 2019 [15]) as well as ships that are passing by.

Having the ability to produce hydrogen at scale near the port could have spillover benefits for other applications within the complex. For example, hydrogen could be used to decarbonize the nearby steel industry. Steel-making is carbon intensive because coal coke is usually used to produce iron from its ore, which is further processed to make steel. Due to hydrogen's high combustion temperature it can be used instead of coal coke and eliminate the carbon dioxide emissions from the process.

VESSEL TRAFFIC AROUND THE NORTHERN COAST OF BRAZIL



Vessel traffic data from MarineTraffic.com used with permission.

North-eastern Brazil has abundant renewables and a well-developed grid

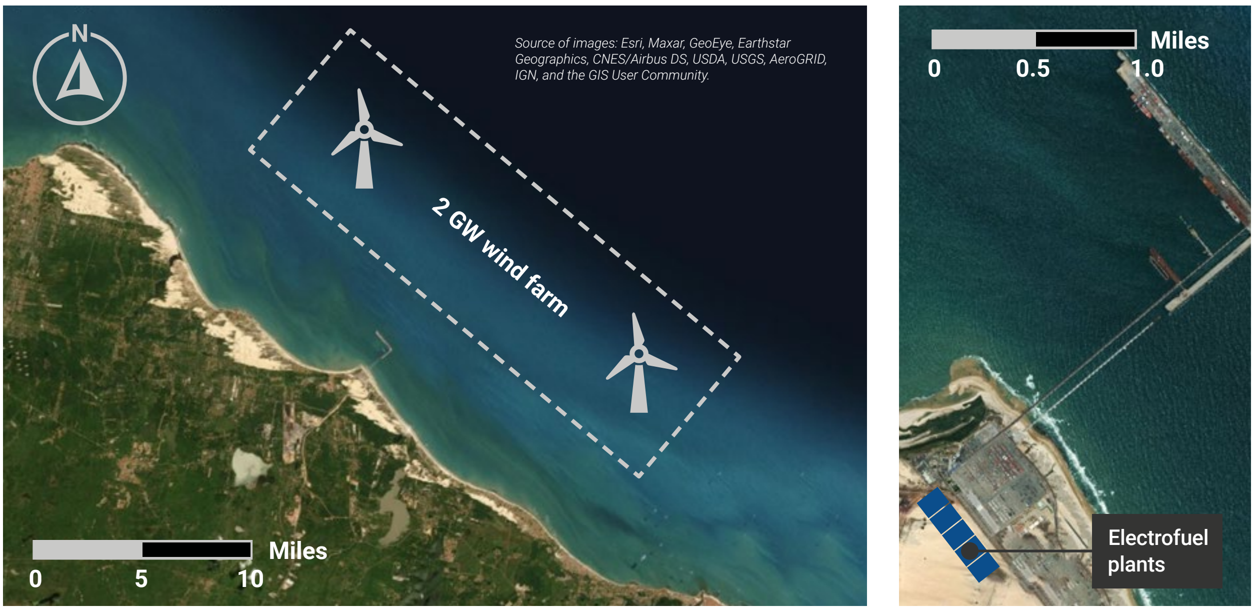
Ceará is a leader among Brazil's states in renewable electricity generation. The solar potential around the port is excellent and there is also potential for onshore wind, but the land immediately surrounding the Pecém industrial and port complex is protected [16]. Therefore, onshore renewable plants would need to be sited elsewhere and the electricity imported through the grid.

There is great potential for offshore wind around Porto do Pecém. If an offshore wind farm of 2 GW was installed in the waters off the coast and it was combined with an 200 MW onshore wind farm (similar to nearby Itarema), they would be able to supply about 80% of the energy requirements of electrofuel plants with capacity of 1.4 GW . These would be able to refuel about 1.8 Panamax bulker vessels per day on ammonia or 1.9 vessels on hydrogen[3]. This is the typical size of a bulk solids vessel that visits the port (119 vessels in 2019 averaging 81 kilotonnes). Other vessels that visit the port tend to be smaller; in 2019 the 584 ships that were not bulkers averaged 14.5 kilotonnes each [14].

Electricity supplied by the wind farms would be intermittent, so the electrofuel plants would also need a grid connection to import renewable electricity when wind speeds are low and export when there is excess supply. Therefore, power purchase agreements could be signed with other renewable electricity plants further afield to ensure a more consistent supply of electricity. Through this approach, electrofuels plants would encourage development of renewables in optimal locations in the region. This model could be replicated in other ports that don't have space nearby or suitable potential for renewables.

The offshore wind farm would require an area of about 155 square miles. Although Brazil does not have any offshore windfarms operational at present, there are three projects in preparation. Capital costs are decreasing rapidly as more offshore wind farms are installed in other parts of the world.

LOCATION OF POSSIBLE 2GW OFFSHORE WINDFARM AND ELECTROFUELS INFRASTRUCTURE AT PORTO DO PECÉM, BRAZIL



[3] *See assumptions in Appendix.*

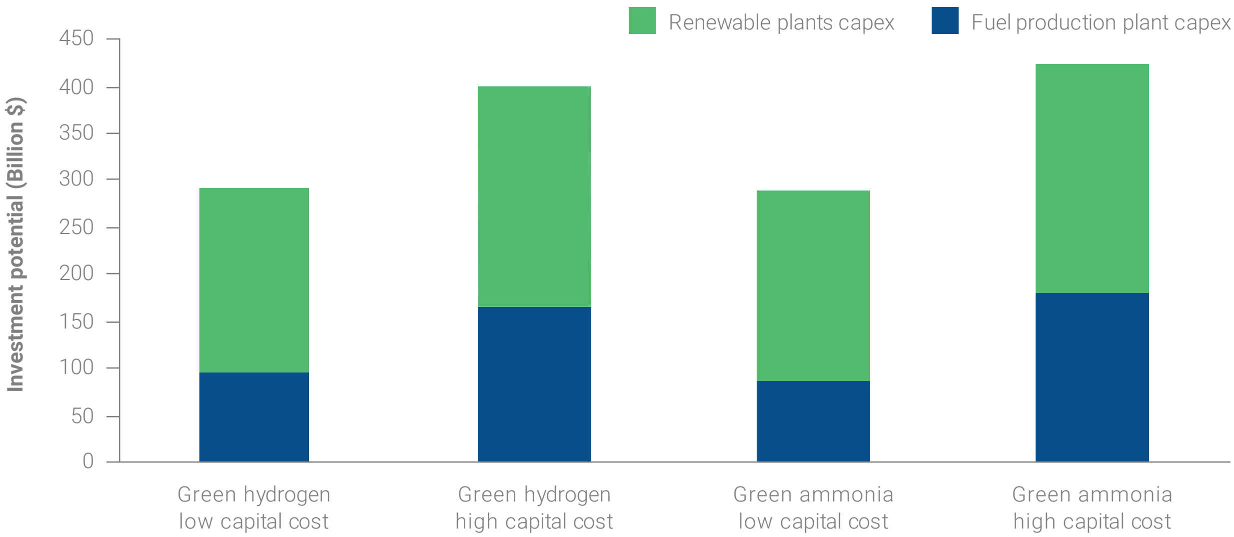
Investment potential for electrofuel infrastructure to supply shipping throughout Brazil

The chart below gives an impression of the potential level of investment that could be attracted to Brazil if electrofuels were used to fuel the vessels that visited its ports in 2019 [17]. The average demand for green ammonia would have been about 175 kilotonnes/day, requiring an average of 1,700 GWh electricity per day (27.4 kilotonnes/day and 1,630 GWh for green hydrogen). This is approximately equal to the country's average daily electricity consumption [18] and would need to be installed in addition to the existing generation plants to avoid diverting renewables from supplying the grid. The estimated investment potential for infrastructure of this scale is between $290 billion and 430 billion. Of this, 55% to 70% would be for new renewable electricity plants.

$290 - 430 billion

Estimated investment potential for electrofuel infrastructure to supply the ships visiting Brazil's ports

POSSIBLE RANGE OF INVESTMENT POTENTIAL FOR ELECTROFUELS INFRASTRUCTURE TO SUPPLY VESSELS IN BRAZIL



The difference between high and low capital cost estimates in the chart above reflect the variability of investment costs in different locations around the country. Future values are not discounted.

There are other ports in the region that could benefit from electrofuels in a similar way

This case study highlights how electrofuels plants could be used to complement existing industrial activity around ports, provide bunkering locations for busy shipping routes, and contribute to wider decarbonization efforts. There are many other ports in the South and Central America region that also handle a diverse range of products and support industrial activity in surrounding areas. The figure below gives some examples of where electrofuels could support wider decarbonization, with demand underpinned by vessels bunkering at the port.

SAMPLE OF OTHER PORTS ACROSS THE REGION THAT COULD SIMILARLY BENEFIT FROM INVESTMENT IN ELECTROFUELS

Puerto de Manta, Ecuador

The port in Manta is being upgraded to increase its cargo handling capacity. There is space nearby to develop electrofuels plants and bunkering facilities for the many ships that sail past. The area also has good potential for wind power.

Mejillones, Chile

The port of Mejillones is positioned along the shipping lane between the trading hub around Santiago and neighbors to the north, including Peru, Ecuador and Colombia. Located in the solar-rich Atacama Desert, there is excellent potential for renewables.

Port Sucre, Venezuela

Venezuela has already invested in renewable energy generation, with 64% of electricity produced by hydro plants. Located on the busy shipping lane on the northern coast of the continent, many ports in Venezuela are well suited to being electrofuel bunkering locations.

Guyana and Suriname

Ports such as Georgetown and Paramaribo, which are located on the north-eastern coast of the continent are well placed to provide bunkering or export locations for electrofuels.

Case Study:

Demand for electrofuels can be supported by multiple industries around the Río de la Plata

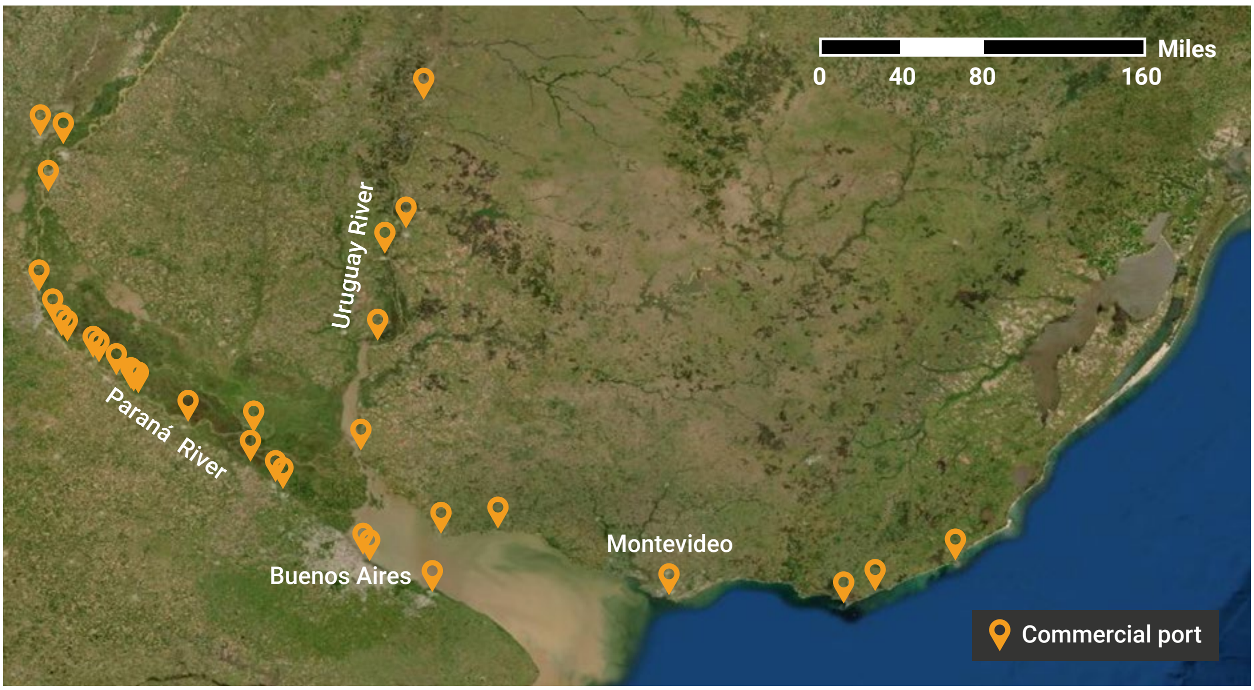
The Río de la Plata is the gateway to many of Argentina's and Uruguay's commercial ports

The Río de la Plata is an estuary fed by the Uruguay and Paraná rivers, which flows into the Atlantic Ocean. The capital cities of Argentina (Buenos Aires) and Uruguay (Montevideo) are situated on its southern and northern shores respectively and it is home to the countries' main shipping hubs.

Argentina's two largest container ports are in Buenos Aires as well as the sixth largest port for bulk products. La Plata port, a medium-sized port is also on the southern bank of Río de la Plata [19]. Eighteen other ports are located along the Paraná River, including Argentina's third largest port, Terminal 6. Similarly, all of Uruguay's commercial ports are located on the Río de la Plata or the Uruguay River, its tributary [20].

A large volume of commercial vessels, carrying a variety of cargo pass through the Río de la Plata. Therefore, if electrofuel refueling facilities were established on the Río de la Plata or on the Atlantic shore near its mouth, there could be a sustained demand from the various zero-carbon vessels visiting ports in this cluster.

MAP OF THE PORTS ON THE RÍO DE LA PLATA AND ITS TRIBUTARIES



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

Argentina and Uruguay have trading relationships with countries from various regions

Argentina and Uruguay both have strong trading relationships with Brazil, the United States and China. Both countries trade actively with countries from various regions, including South America, North America, Europe and Asia [7].

Vegetable products and foodstuffs – primarily soybean meal, soybeans and corn – comprise the majority of Argentina's exports, with a combined value of $28.5 billion in 2018. Transportation and animals are also major exports. The main products imported by Argentina include machinery, transportation and chemicals.

Argentina's Top 5 trading partners in 2018

1. Brazil
2. China
3. United States
4. Germany
5. Chile

ARGENTINA'S TOP 5 IMPORT COMMODITIES

Machinery and electrical

Chemicals

Fuels

Transportation

Metals

ARGENTINA'S TOP 5 EXPORT COMMODITIES

Vegetables

Food products

Transportation

Animals

Chemicals

Animal products, including meat, milk and cheese make up the bulk of Uruguay's exports and were worth about $2.9 billion in 2018. This is followed by vegetable products (mainly soybeans and rice) as well as wood. Uruguay's largest imports include machinery, chemicals and fuels.

Uruguay's Top 5 trading partners in 2018

1. China
2. Brazil
3. Argentina
4. United States
5. Free zones

URUGUAY'S TOP 5 IMPORT COMMODITIES

Machinery and electrical

Chemicals

Fuels

Transportation

Food products

URUGUAY'S TOP 5 EXPORT COMMODITIES

Animal products

Vegetables

Wood

Chemicals

Plastic and rubber

Argentina has great potential to expand its renewable resources

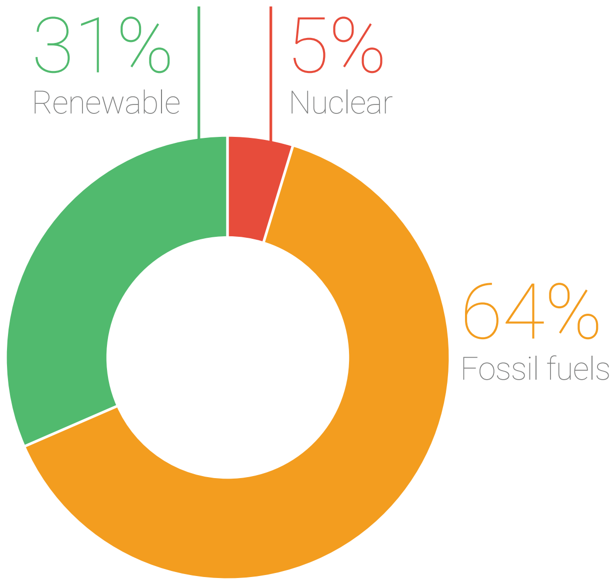
In comparison with other South American countries, hydropower contributes a smaller share of overall electricity generation in Argentina. However, large hydro plants still provide most of the country's renewable electricity. Natural gas is the primary source of Argentina's electricity generation, making up more than half of the total, and renewables accounted for 31% in 2018. Other fossil fuels for electricity generation include oil and coal.

Argentina has an ambitious goal to increase the contribution of renewable electricity from sources other than hydro from 2.3% in 2018 to 20% in 2025 [21]. It has enacted legislation favoring renewable generation including financial benefits and establishing renewable independent power producers.

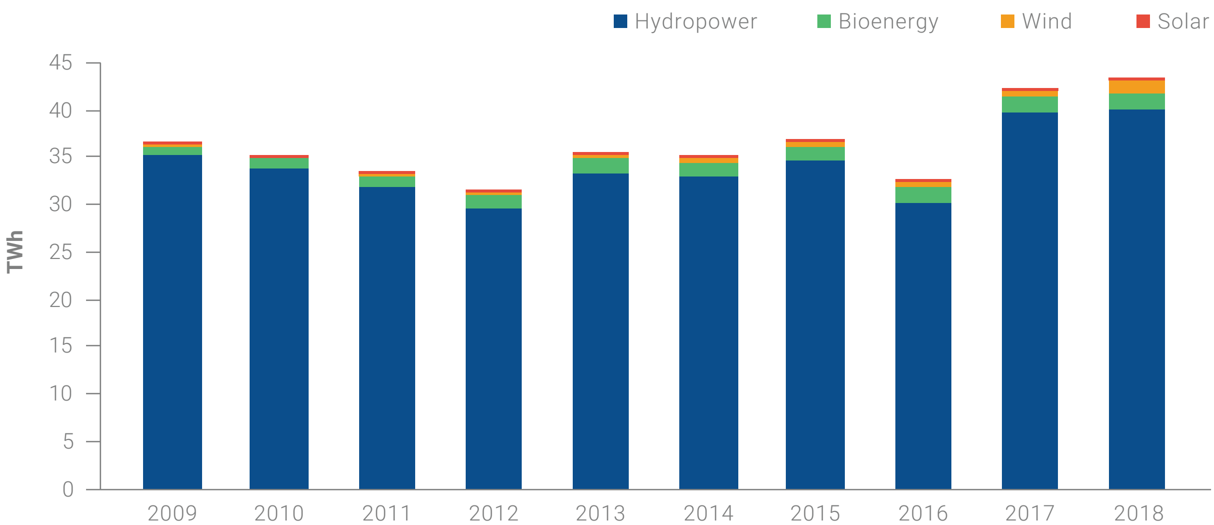
The RenoVar renewable energy auction was established to attract international bidders and create a market for private investment in renewable energy in Argentina [22]. At the end of the program, more than 2.4 GW of capacity was awarded, primarily to wind and solar projects.

A move towards green electrofuels could support increased investment in renewable generation in Argentina, developing experience and lowering the barrier to adoption in other sectors.

SHARE OF ELECTRICITY GENERATION IN ARGENTINA 2018



RENEWABLE ELECTRICITY GENERATION IN ARGENTINA



Sources for data in charts: [12,23]

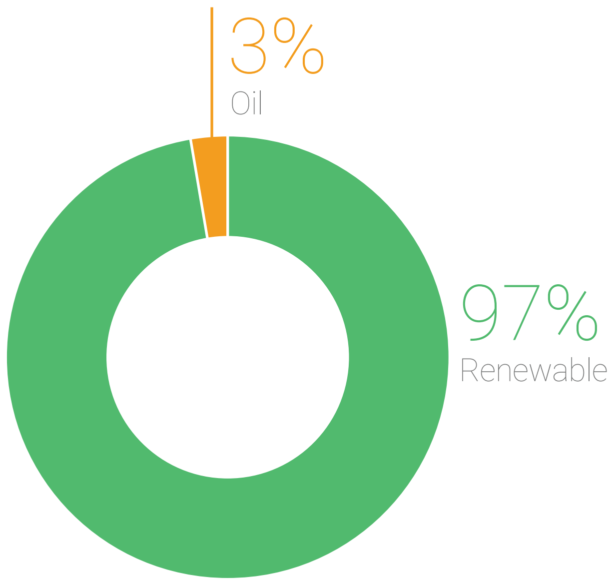
Uruguay's electricity is almost entirely from renewable sources

Uruguay is a flagship in South America for the development of renewable generation. The bulk of its electricity has traditionally been provided by hydro plants, but the contribution from onshore wind has increased significantly in the last few years, as shown in the chart below. Solar power only contributed about 3% in 2018, but it has been increasing steadily from a low base since 2014 [24].

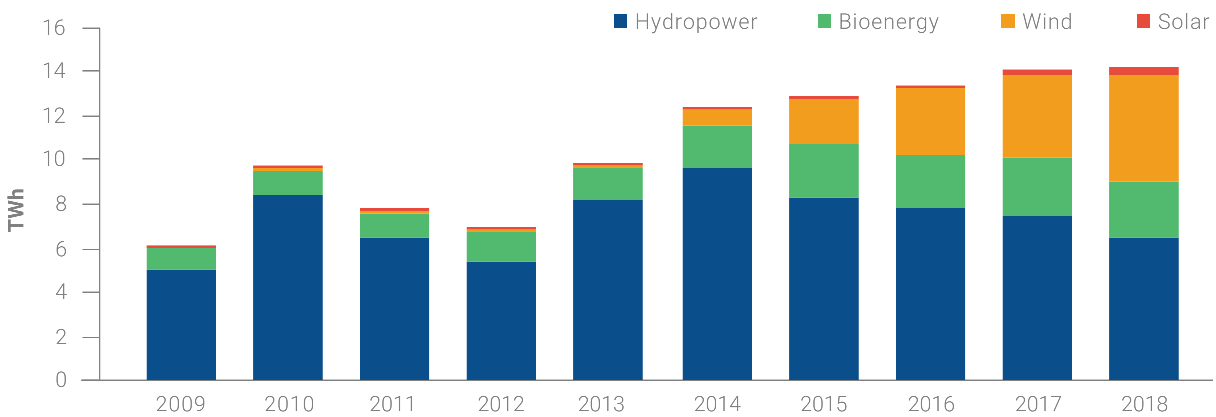
Auctions have successfully facilitated the development of new wind and solar projects, where the government-owned electricity utility awards power purchase agreements to independent power producers [25].

Uruguay therefore has an accommodative market for the development of new renewable plants, which will support investment in electrofuel infrastructure.

SHARE OF ELECTRICITY GENERATION IN URUGUAY 2018



RENEWABLE ELECTRICITY GENERATION IN URUGUAY



Sources for data in charts: [12,24]

Photo credtit: Inkiantonana

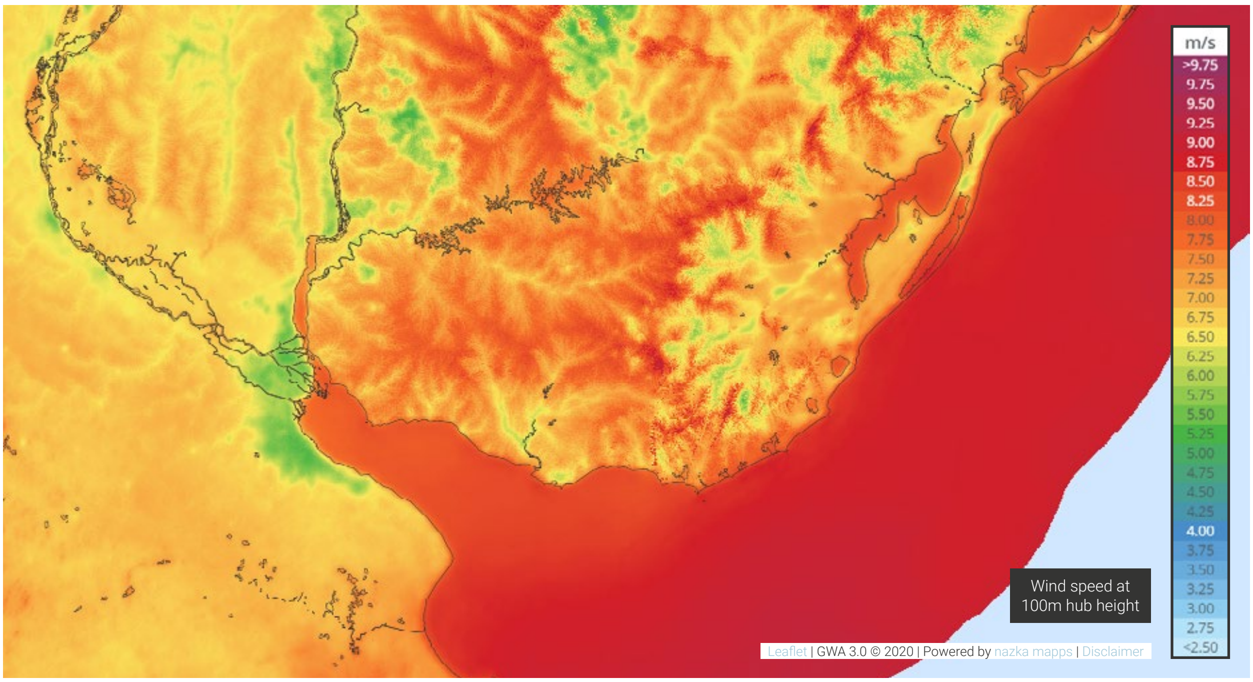
There is excellent potential for renewable generation around the Río de la Plata

The land around the Río de la Plata has excellent wind energy potential and reasonable solar potential, providing an opportunity for the development of wind and solar farms. As for all renewable electricity developments, sites would need to be selected in consultation with the local community to avoid indirect land use change. In addition, waters off the coasts of Argentina and Uruguay are favorable for offshore wind generation due to the high and consistent wind speeds (see map below).

One of the benefits of siting electrofuel facilities near a cluster of ports is that it can provide diverse options for location and design of the production infrastructure, including the renewable electricity generation. Existing ports could be expanded to include electrofuel bunkering, dedicated refueling ports could be established or there could be a combination of these two approaches. The bunkering ports could be located on the banks of the river as well as on the Atlantic coasts to the north and south of the river mouth. In this way, supply could be scaled-up incrementally as demand for electrofuels increases from vessels visiting the many ports in this area.

Renewable electricity could be sourced from a combination of onshore and offshore wind farms as well as solar plants. These might be developed to solely supply the electrofuel plants or imported through the grid with power purchase agreements. Having multiple, geographically dispersed generation plants is advantageous because it provides a more consistent supply of electricity, mitigating intermittency from individual plants.

MAP SHOWING WIND SPEEDS AROUND THE RÍO DE LA PLATA ILLUSTRATING THE EXCELLENT POTENTIAL FOR ONSHORE AND OFFSHORE WIND FARMS



Map obtained from the Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info

Investment potential for electrofuel infrastructure to supply shipping throughout Argentina and Uruguay

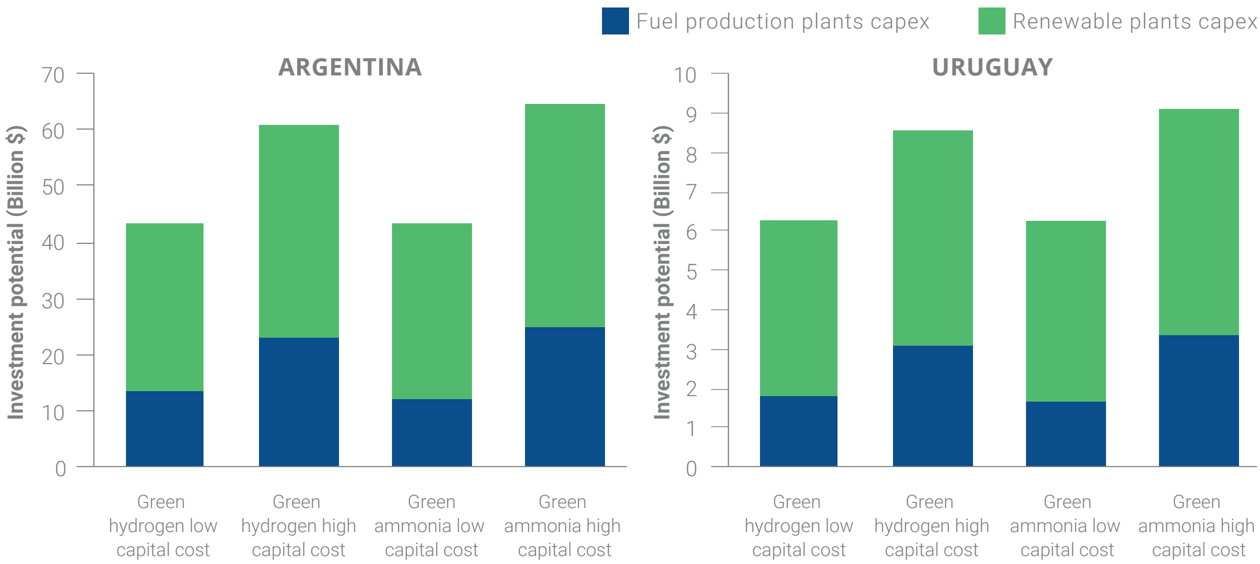
The Río de la Plata is not the only area in Argentina and Uruguay where electrofuels could be developed to serve the commercial shipping sector. For example, there are other important ports in Argentina further to the south, such as Bahía Blanca and Rosales, where there is potential to develop electrofuel facilities powered by renewable electricity.

To give an idea of the possible scale of investment in Argentina and Uruguay, the table below provides estimates of what the average aggregate demand would have been in 2018 if all the commercial vessels visiting these countries had refueled with electrofuels.

	Argentina	Uruguay
Green ammonia consumption and renewable electricity requirement	24.1 kilotonnes/day 234 GWh/day	3.2 kilotonnes/day 31 GWh/day
Green hydrogen consumption and renewable electricity requirement	3.8 kilotonnes/day 225 GWh/day	0.5 kilotonnes/day 30 GWh/day

The estimated investment potential for infrastructure of this scale is between $43 and 65 billion for Argentina and between $6 and 9 billion for Uruguay, as shown in the charts below. The potential for Uruguay could be even higher if it was to establish electrofuel facilities to supply vessels on their way to Argentina's ports.

POSSIBLE RANGE OF INVESTMENT POTENTIAL FOR ELECTROFUEL INFRASTRUCTURE TO SUPPLY VESSELS IN ARGENTINA AND URUGUAY



The difference between high and low capital cost estimates in the chart above reflect the variability of investment costs in different locations in the countries. Future values are not discounted.

There are other port clusters in South and Central America that could develop electrofuels capacity

This case study describes how electrofuel infrastructure could be beneficial for a cluster of ports. Multiple ports handling diverse products would provide consistent demand for electrofuels and the infrastructure can be developed in locations that are best suited to the application and scaled-up as demand for zero-carbon fuels increases in the future.

OTHER PORT CLUSTERS IN THE REGION THAT COULD DEVELOP SHARED ELECTROFUEL INFRASTRUCTURE

Lima ports cluster, Peru

This cluster includes APM Terminals Callao, and DP World Callao, which are in and around Lima. One of the ports has a petrochemical refinery nearby - adoption of electrofuels could help the local economy to transition from dependence on fossil fuel processing to a sustainable alternative.

Cluster around Santiago, Chile

There are at least four significant ports located around Santiago, with a diversity of cargo including containers, bulk solids and liquids. With Chile's ambitious plans for renewable electricity and hydrogen, this cluster would be a good fit for electrofuel infrastructure.

Cluster around the Panama Canal

The Panama Canal is a busy and vital shipping route, with many port facilities clustered in this area. Having electrofuel options at this key location could give ship owners and operators confidence to invest in zero-carbon vessels. Land availability and renewable energy potential around the canal is limited. Therefore, it may be necessary to build the generation plants away from the canal and use the grid to transmit renewable electricity to the electrofuel production facilities located near the ports.

Case Study:

Puerto Bolívar in Colombia could transition away from coal to become an electrofuel bunkering hub

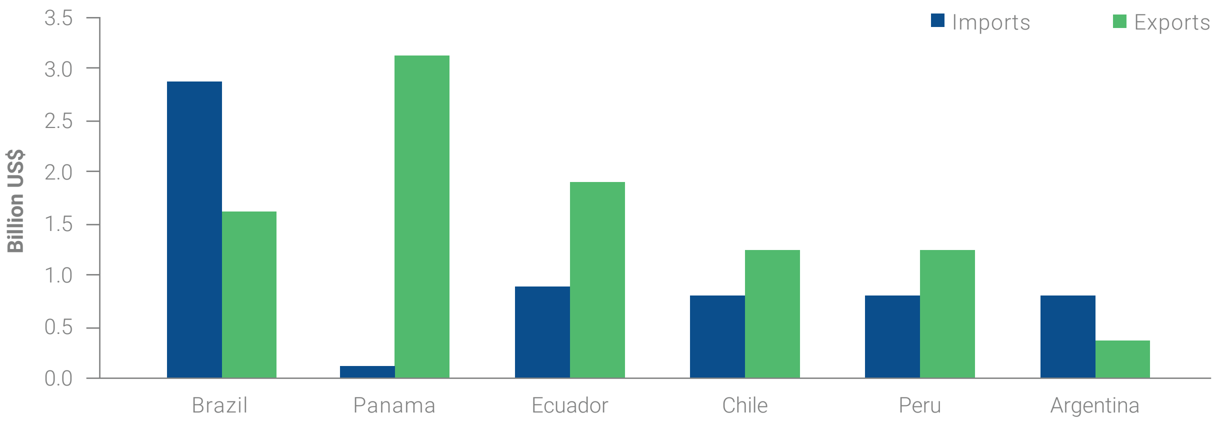
Colombia is ideally placed for trade

Colombia's geographical location is particularly advantageous with coasts on the Pacific Ocean and Caribbean Sea to the Atlantic Ocean – giving it access to East Asia, Central & North America as well as Europe and Africa. Although it trades actively with other countries in the South & Central America region, its top two trading partners – the United States and China – are in other regions.

TOP 5 GLOBAL TRADING PARTNERS IN 2018

1. United States
2. China
3. Mexico
4. Brazil
5. Panama

TOP REGIONAL TRADING PARTNERS



Source for data: [7]

Trading electrofuels could make Colombia less reliant on income from fossil fuels

Fuels account for the majority of Colombia's exports (59%), with petroleum and coal comprising the bulk of this [8]. Having an economy that is so heavily reliant on exports of fossil fuels is potentially a risk as the world seeks to decarbonize in the coming years.

Colombia is also located along busy shipping lanes along its northern and western shores on both sides of the Panama Canal. Ships using electrofuels are likely to require bunkering stops for long journeys, and Colombia's location means that it would be easy for vessels to stop for bunkering at its ports on their way past. More than 7,500 vessels bunkered around the Panama Canal in 2019, which gives an indication of the large potential demand [26].

COLOMBIA'S TOP 5 IMPORT COMMODITIES

Machinery and electrical

Chemicals

Transportation

Metals

Fuels

COLOMBIA'S TOP 5 EXPORT COMMODITIES

Fuels

Vegetables

Stone and glass

Chemicals

Plastic and rubber

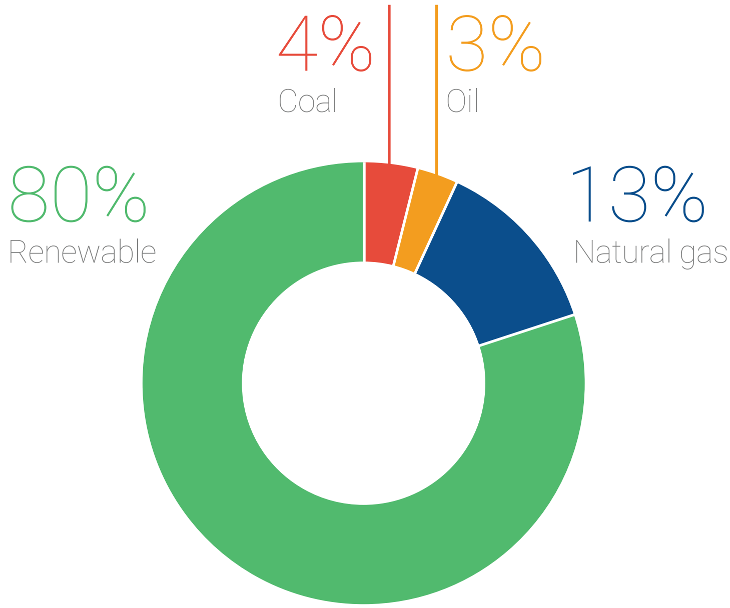
Colombia is a leader in renewable electricity with aspirations to go further

Colombia's electricity generation is dominated by large hydro plants, with renewables accounting for 80% of the country's electricity generation in 2017 [12].

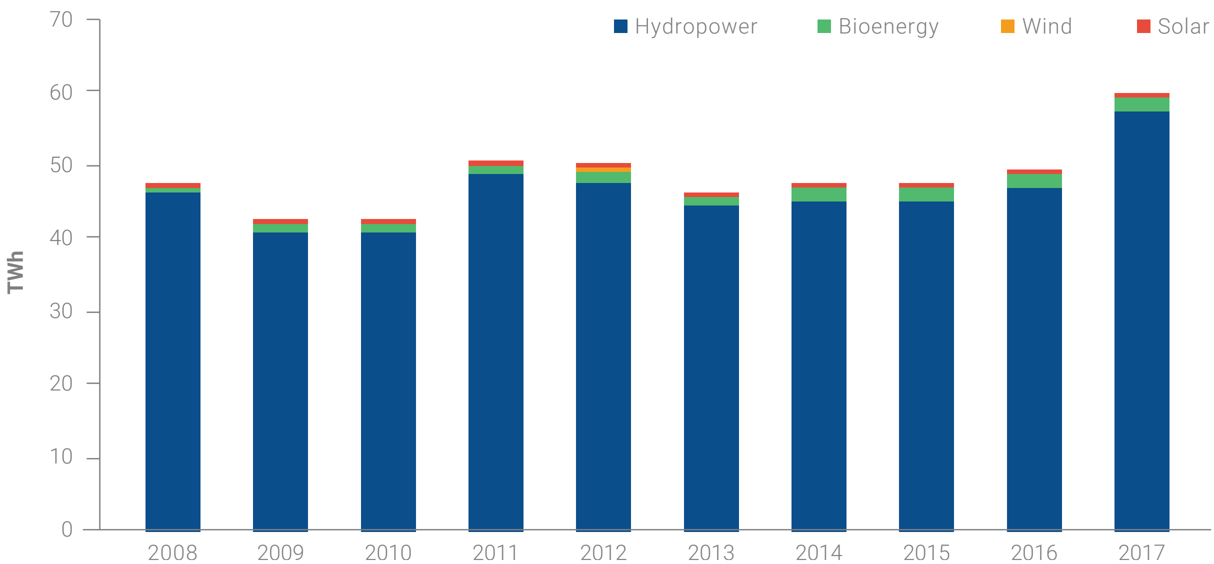
Wind and solar sources have contributed a relatively low proportion of electricity up to now, but this is likely to increase substantially in the coming years. In 2019 alone, Colombia awarded an additional 1.3GW of wind and solar projects through auctions – showing its ambitions to develop other forms of renewable energy. The government aims to increase the capacity of wind and solar sources from 50 MW in 2019 to at least 1,500 MW by 2022 [27].

Colombia has also supported development of distributed renewable generation through legislation which seeks to actively promote and integrate more wind and solar sources into the national energy system. This has been through a range of tax exemptions, income tax incentives and allowances for accelerated depreciation of assets.

TOTAL GENERATION 2017



RENEWABLE ELECTRICITY GENERATION



Source for data in charts: [12]

Puerto Bolívar Cerrejón could be an important bunkering stop for ships passing through the Panama Canal

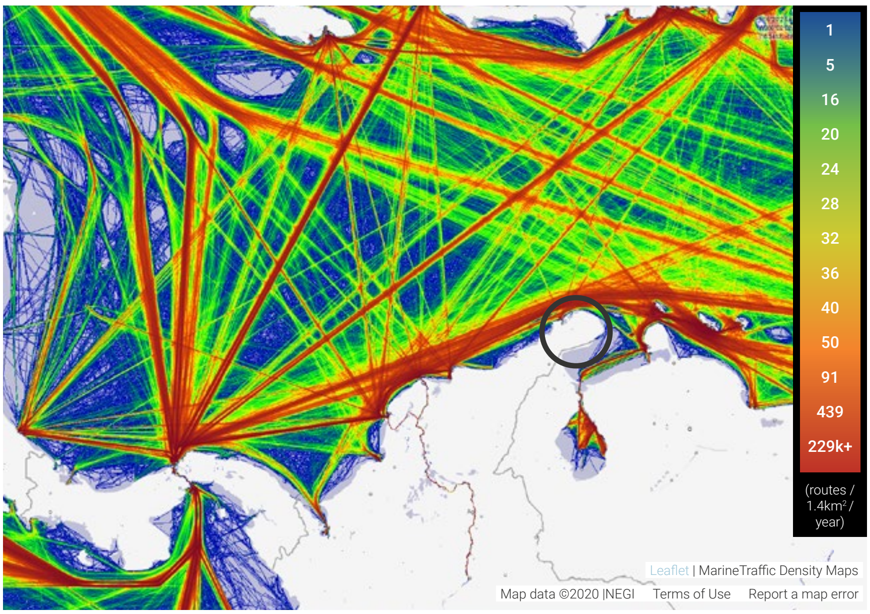
Puerto Bolívar is mostly used to export coal from the Cerrejón coal mine, which is about 170 km inland to the south-west. The port is located on Peninsula de la Guajira next to a large natural bay and is surrounded by desert. As the northern-most point of South America, all maritime traffic between the Panama Canal and eastern cost of the continent as well as southern Africa passes this peninsula (see map below). There is a unique opportunity to develop electrofuels plants in this area to provide zero-carbon bunkering to ships sailing along this busy lane.

The global demand for coal is falling rapidly as countries around the world close coal power plants to reduce emissions. Therefore, the Colombian government has an ambition to reduce its reliance on coal exports, which have ranged between 12 and 20% of export revenue over the last 5 years [28]. About a third of this was exported from Cerrejón, mainly to Europe [29].

Producing electrofuels for the shipping sector would allow the economy and community around Puerto Bolívar Cerrejón to transition away from the declining coal sector towards a sustainable and climate-friendly alternative.

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

VESSEL TRAFFIC AROUND THE NORTHERN COAST OF SOUTH AMERICA



Vessel traffic data from MarineTraffic.com used with permission.

Skilled jobs would be created for the local community within the fuel plants as well as building and maintaining the wind farms that serve it. Currently, about 11,000 jobs in the area are linked to mining activity.

Electrofuels plants are expected to have significantly lower overall environmental impacts compared with coal mining.

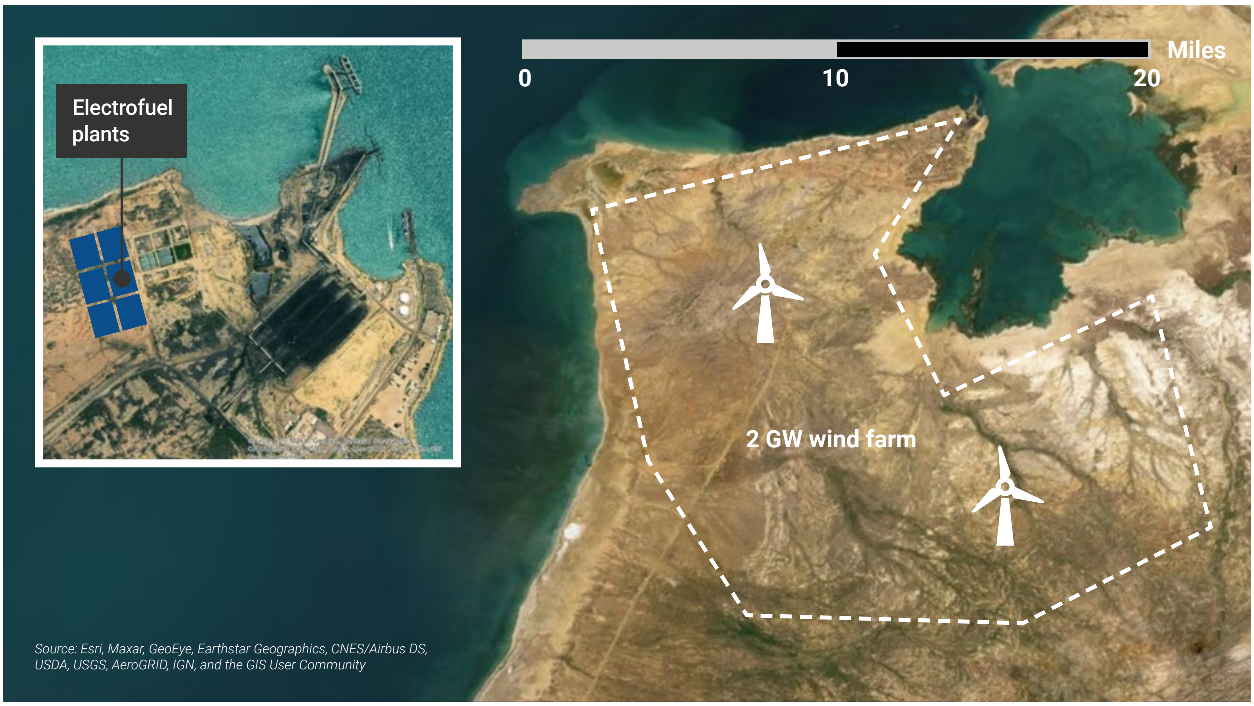
The port has exceptional wind resources nearby

The land and waters around the port have exceptionally high potential for wind power generation with high and consistent wind speeds. Since most of the land is sparsely populated desert, there is great potential to install windfarms on Peninsula de la Guajira. Accounting for national park areas and the portion of land belonging to Venezuela, there is about 2,300 square miles available on the peninsula, which could accommodate up to 18 GW of wind capacity [30]. There is similar potential for offshore wind in this region too.

It would therefore be possible to install a wind farm of 2 GW capacity within a radius of 20 miles of the existing port. Due to the intermittency of output from the wind farm, it would not be able to provide the full electricity requirements of the electrofuel plants all of the time. About 13% of the renewable electricity demand would need to be imported from the grid over the course of the year if they were sized to refuel an average of 1.1 Panamax container vessel per day with ammonia or hydrogen[4]. With this configuration, the wind farm would export about 4% of its annual generation at times of excess supply.

Although the solar resources are good in the vicinity of the port, installing a solar plant would provide limited additional benefit for the additional capital cost. This is because the solar output would often be coincidental with the peak wind output and would be wasted or exported to the grid.

SATELLITE IMAGE OF POSSIBLE 2 GW WIND FARM AROUND PUERTO BOLÍVAR CERREJÓN



[4] *See assumptions in Appendix.*

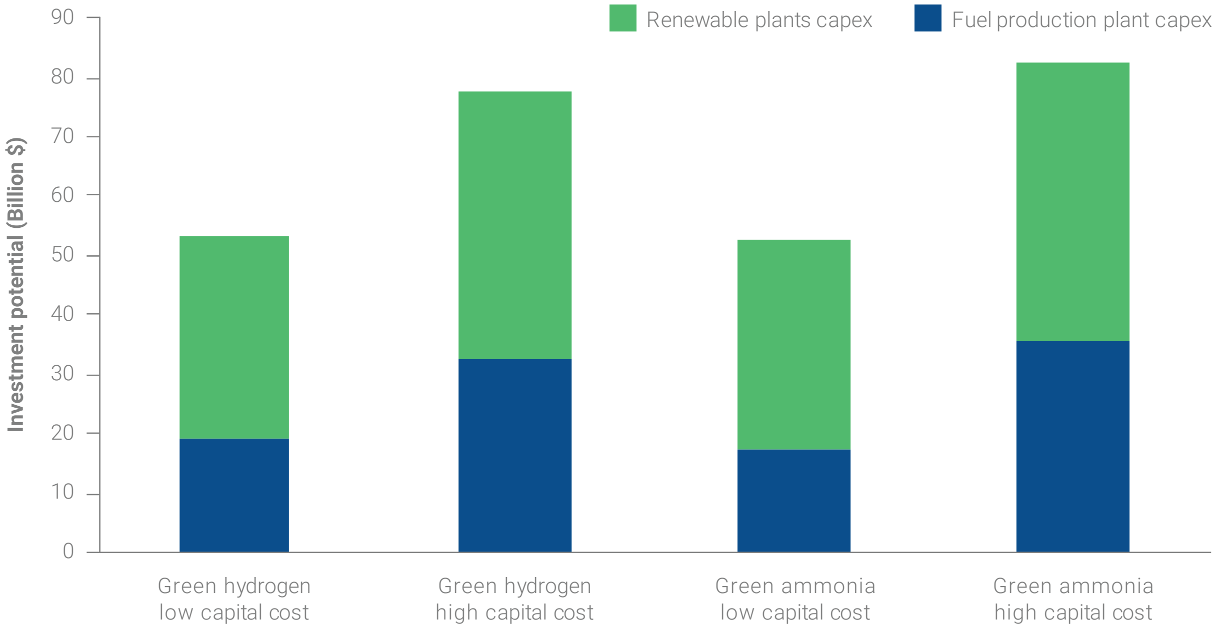
Investment potential for electrofuel infrastructure to supply shipping throughout Colombia

If all of the vessels that visited Colombia's ports in 2018 had refuelled with electrofuels [31], the average demand for green ammonia would have been about 34.6 kilotons/day, requiring an average of 335 GWh electricity per day (5.4 kilotons/day and 323 GWh for green hydrogen). About a quarter of this would have been for coal carriers. The estimated investment potential for infrastructure of this scale is between $53 and 83 billion. Of this, 55 to 70% would be for renewable electricity plants.

$53 - 83 billion

Estimated investment potential for electrofuel infrastructure to supply the ships visiting Colombia's ports

POSSIBLE RANGE OF INVESTMENT POTENTIAL FOR ELECTROFUELS INFRASTRUCTURE TO SUPPLY VESSELS IN COLOMBIA



The difference between high and low capital cost estimates in the chart above reflect the variability of investment costs in different locations around the country. Future values are not discounted.

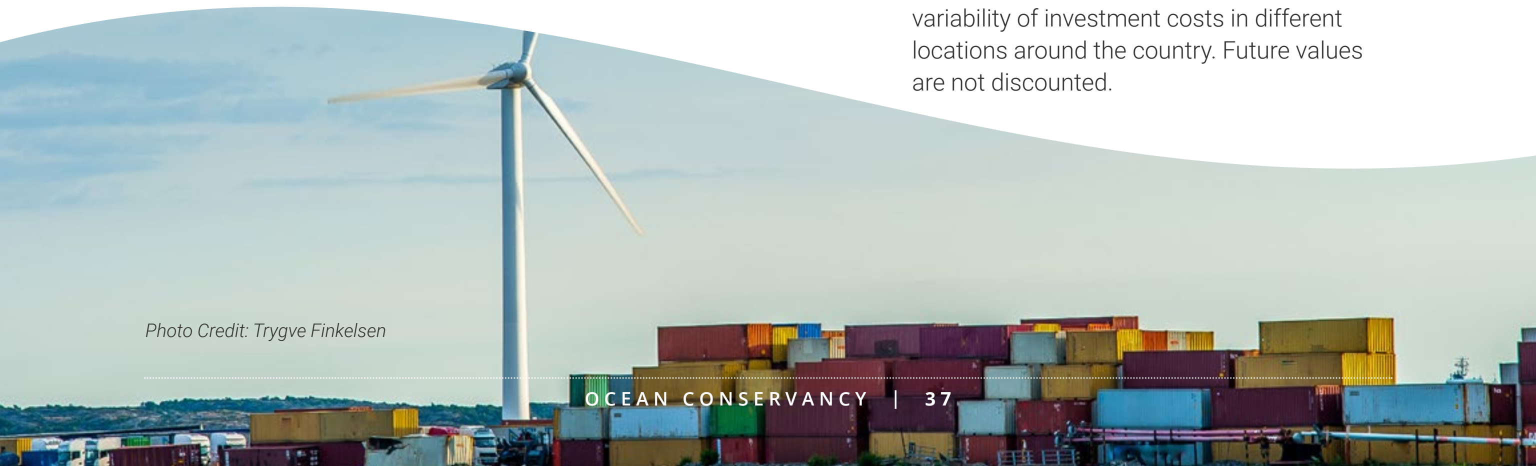


Photo Credit: Trygve Finkelsen

There are other ports in the region that could benefit in a similar way

This case study shows how a port that currently relies on throughput of fossil fuels can benefit from investing in electrofuels infrastructure, in this case to establish itself as a bunkering port, though equally electrofuels could be a commodity for export. This transition could transform local economies to be more climate friendly and sustainable.

This theme is applicable in many ports across the South & Central America region. The countries in this region together export over $100bn in fuels, more than 10% of total exports in 2018 [8]. Fossil fuel exports will inevitably decrease as the low carbon agenda is adopted across the world, and the shipping infrastructure will need to be replaced or re-purposed for electrofuels transport and bunkering.

SAMPLE OF OTHER PORTS ACROSS THE REGION THAT COULD SIMILARLY BENEFIT FROM INVESTMENT IN ELECTROFUELS

Oleoducto Central and American Port Company, Colombia

Beyond the specific case study addressed in this section, Colombia has several other ports that trade in fossil fuels and could equally be supported by electrofuels.

Port of Puerto Cabello, Venezuela

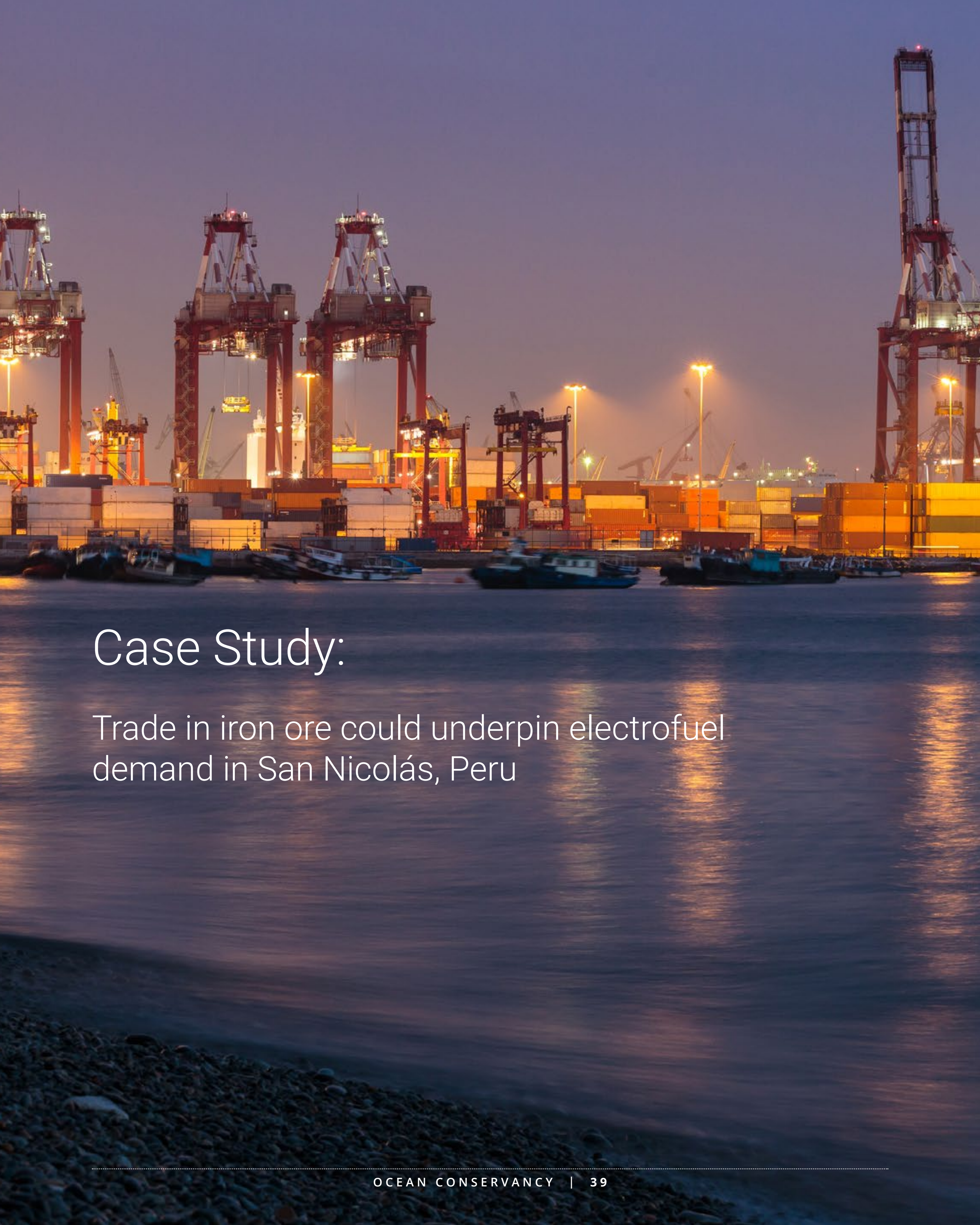
The largest port in the country and an important part of the oil industry. The prosperity of the port and the surrounding communities are heavily dependent on the oil sector and electrofuels can provide a climate-friendly alternative.

Bahía Blanca, Argentina

This port exports a number of goods including oil and has good wind generation potential. It is also close to another port, potentially providing additional demand for electrofuels.

Port of Itaqui, Brazil

Brazil is a significant exporter of fossil fuels, suggesting real benefit in diversifying to electrofuels. This port has a high throughput with exports including metals and oil.



Case Study:

Trade in iron ore could underpin electrofuel demand in San Nicolás, Peru

Peru has diverse trading relationships

Situated on the Pacific Ocean, Peru has direct trade routes to Asia and the United States. The country is an important producer of minerals which, in combination with its location, shapes the nature of its trade partners and products.

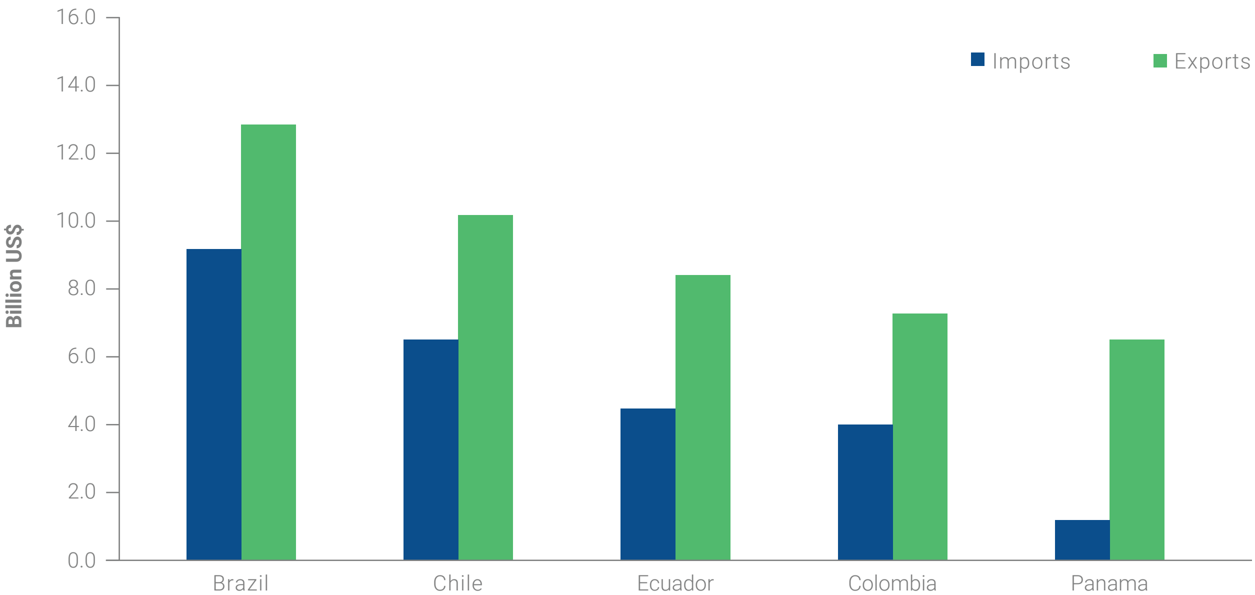
Peru trades with a diverse range of countries, with Brazil being the only regional partner in the top 5. China tops the list, taking 28% of Peru's exports and providing 23% of its imports.

In addition to Brazil, trade within the region is dominated by its relationships with its neighbours - Chile, Ecuador and Colombia.

TOP 5 GLOBAL TRADING PARTNERS IN 2018

1. China
2. United States
3. Brazil
4. Republic of Korea
5. India

TOP REGIONAL TRADING PARTNERS



Source for data: [7]

Exports of minerals could drive demand for zero-carbon vessels

Peru's main export commodities are minerals (primarily copper, gold and zinc), stone, glass, vegetables and refined petroleum, with the first three accounting for more than 60% of Peru's exports by volume. In 2019, bulk solids represented 41% of cargo transported by ships in the country by tonnage [32]. As a result, bulk carriers are the most common vessel type visiting Peruvian ports.

In the medium to long term, demand for minerals and metals is expected to be reasonably consistent, despite the anticipated economic downturn following the Covid-19 pandemic. Hence, the vessels visiting Peru's ports could provide stable demand for electrofuels in the coming years if an increasing share were zero-carbon vessels.

PERU'S TOP 5 IMPORT COMMODITIES

Machinery and electrical

Fuels

Chemicals

Transportation

Metals

PERU'S TOP 5 EXPORT COMMODITIES

Minerals

Stone and glass

Vegetables

Fuels

Metals

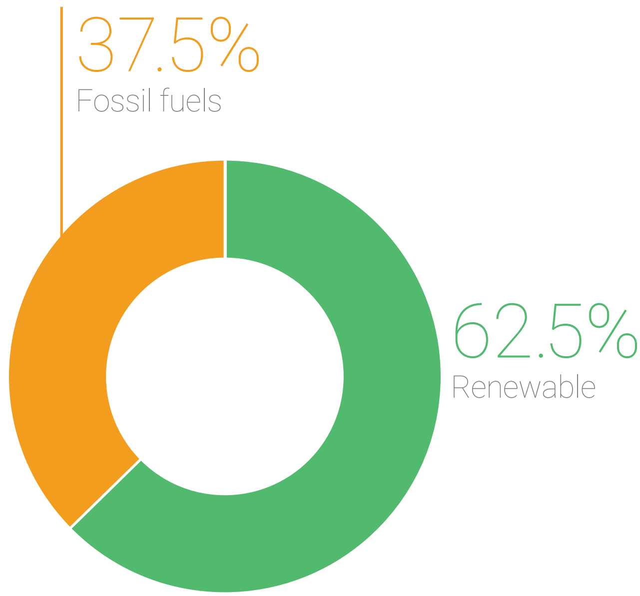
Renewables already dominate electricity supply and there is potential to install much more

At 62.5% in 2018, Peru already generates more than half of its electricity from renewable sources, mostly provided by large scale hydro plants [33]. Renewables contributed 36.8 TWh in 2018 and the government's goal is to increase this to about 50 TWh by 2025 [34].

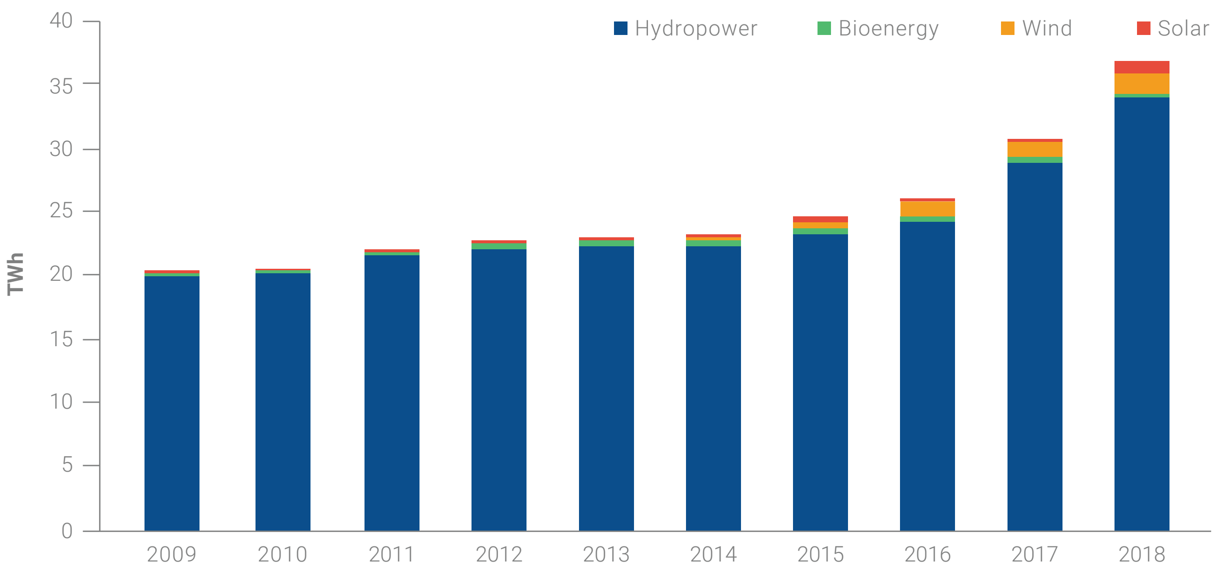
Although the contributions from solar and wind are small at present (2% and 3% respectively in 2018 [33]), there is significant scope for these to grow. A total of only 0.3 GW of solar was connected to the grid by 2018, compared with an exploitable potential of 260 GW in areas near enough to the grid [35]. The theoretical potential is five times higher if proximity to the grid is not a constraint. Similarly, 0.4 GW of wind capacity was installed by 2018; whereas the theoretical potential in the country has been estimated at 22.5 GW [36].

Peru's Nationally Determined Contributions under the Paris Agreement include 9 mitigation measures for transport, including a target to reduce greenhouse gas emissions from the sector by 30% by 2030 [37,38]. Electrofuels represent a great opportunity for Peru to deliver on this ambition.

SHARE OF ELECTRICITY GENERATION 2018



RENEWABLE ELECTRICITY GENERATION



Source for data in charts: [12,33,34]

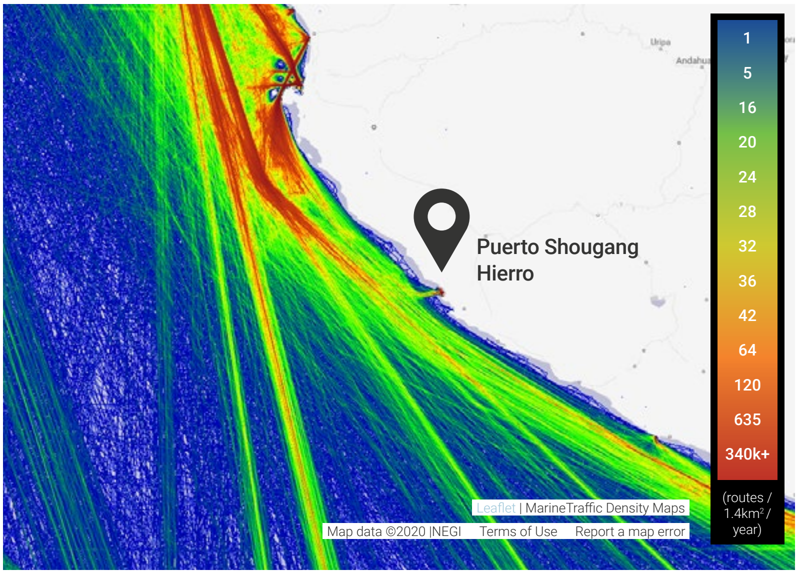
Puerto Shougang Hierro in San Nicolás has established trade routes that could support adoption of electrofuels

Puerto Shougang Hierro is located in the Marcona region of Peru, about 260 miles south of Lima. The port's primary commodity is iron ore, with the Mina Marcona mine about 10 miles away.

The ore is exclusively exported to New Orleans in the United States. Since trade is dominated by this single route, there is potential to decarbonize it completely with electrofuel infrastructure being added to the existing operations at the destination and origin ports. This would enable vessels to refuel while loading/offloading cargo, increasing their operational efficiency.

The port is also located on the main shipping lane between Chile and the Panama Canal. Therefore, there is potential for it to provide refueling facilities to passing zero-carbon vessels in addition to the current traffic at the port.

VESSEL TRAFFIC AROUND PUERTO SHOUGANG HIERRO IN SAN NICOLÁS



As well as the established trade routes to and from the port, it is also close to busy shipping lanes along the west coast of South America, potentially providing further demand from zero-carbon vessels requiring a refueling stop.

Vessel traffic data from MarineTraffic.com used with permission.

The coastal desert location at Puerto Shougang Hierro has good renewable resources

The land near the port and surrounding waters have very good potential for wind generation as well as strong potential for solar. As the surrounding land is desert, large renewable plants can be built nearby, with the electrofuel plants located at the port.

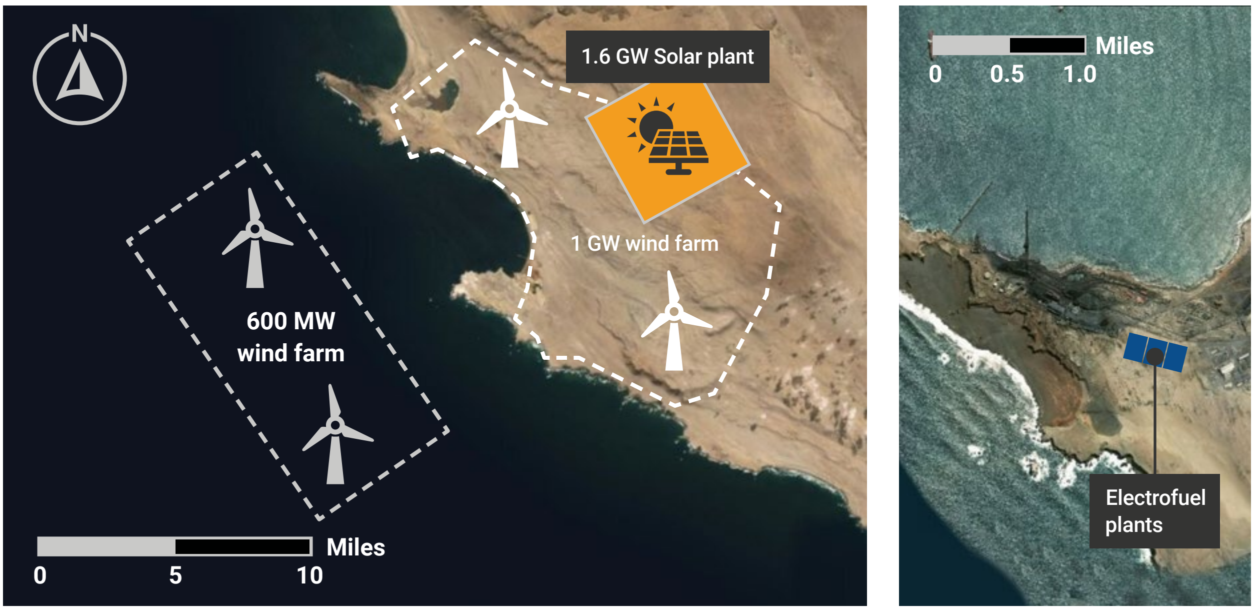
Electrofuel plants could be powered by a combination of onshore wind, offshore wind and solar plants to optimize use of space and provide diversity of sources. The figure below shows the area required for a 1 GW onshore wind farm located around the port and a 600 MW offshore wind farm just off the coast to the south west. A 1.6 GW solar photovoltaic plant is also shown in the desert to the east of the port.

Due to the variable output from the wind and solar farms, there will be periods of excess electricity supply and times when more is required to keep the electrofuel plant running at full capacity. Hence, a grid connection will be required to allow for export and import of renewable electricity. The plants have been sized so that there is a balance between export and import requirements over the course of the year.

This arrangement would provide enough electricity to produce fuel for an average of 1.1 Panamax bulk solids vessels per day[5]. At present about one ship visits the port every three days, so there would be significant potential for other vessels to stop at the port to refuel.

Multiple, diverse renewable plants can provide more consistent output of electricity and mitigate intermittent peaks and troughs from the individual sources.

LOCATION OF POSSIBLE RENEWABLE GENERATION AND ELECTROFUEL INFRASTRUCTURE AT PUERTO SHOUGANG HIERRO



Source of images: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

[5] See assumptions in Appendix.

Investment potential for electrofuel infrastructure to supply shipping throughout Peru

The chart below gives an impression of the potential level of investment that could be attracted if all of the vessels that visited Peruvian ports in 2019 were fuelled by electrofuels [32]. The average demand for green ammonia would have been about 21 kilotonnes/day, requiring an average of 201 GWh electricity per day; whereas 3.2 kilotonnes of green hydrogen per day would have been required (193 GWh electricity).

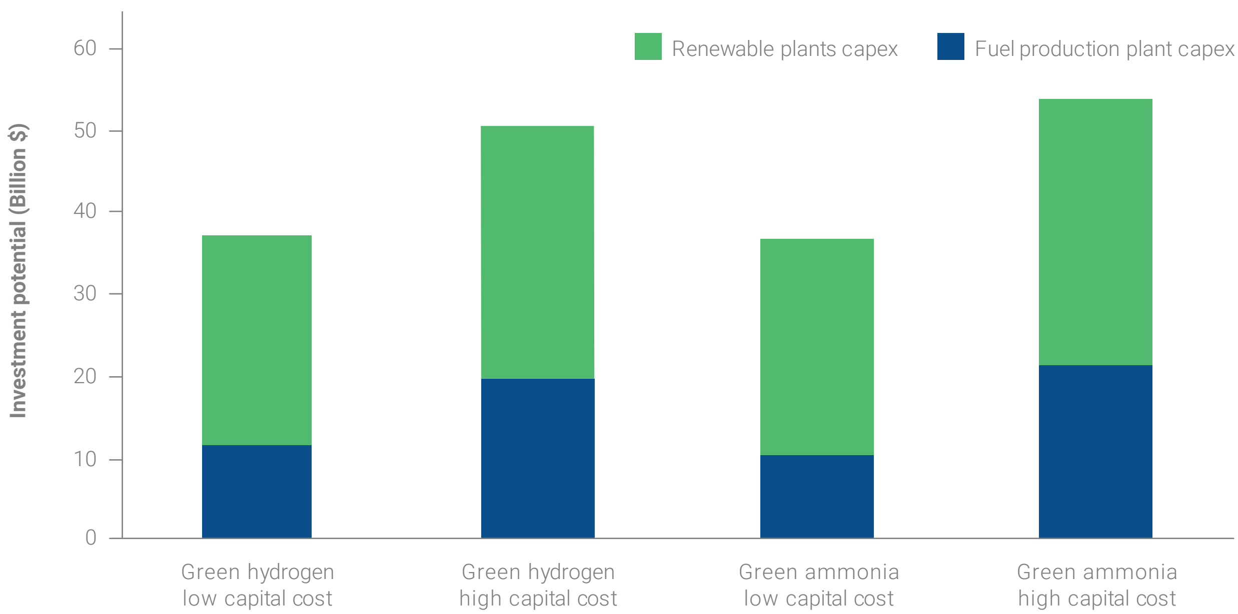
These renewable electricity requirements would be significant for Peru, at about 3.4 times the current demand from the grid. The new renewable plants for electrofuels would need to be installed in addition to existing generation plants to avoid diverting renewables from supplying electricity consumers.

The estimated investment potential for infrastructure of this scale is between $37 billion and 54 billion. Of this, 60% to 72% would be for new renewable electricity plants.

$37 - 54 billion

Estimated investment potential for electrofuel infrastructure to supply the ships visiting Peru's ports

POSSIBLE RANGE OF INVESTMENT POTENTIAL FOR ELECTROFUEL INFRASTRUCTURE TO SUPPLY VESSELS IN PERU



The difference between high and low capital cost estimates in the chart above reflect the variability of investment costs in different locations around the country. Future values are not discounted.

There are other ports in the region that could benefit from electrofuels in a similar way

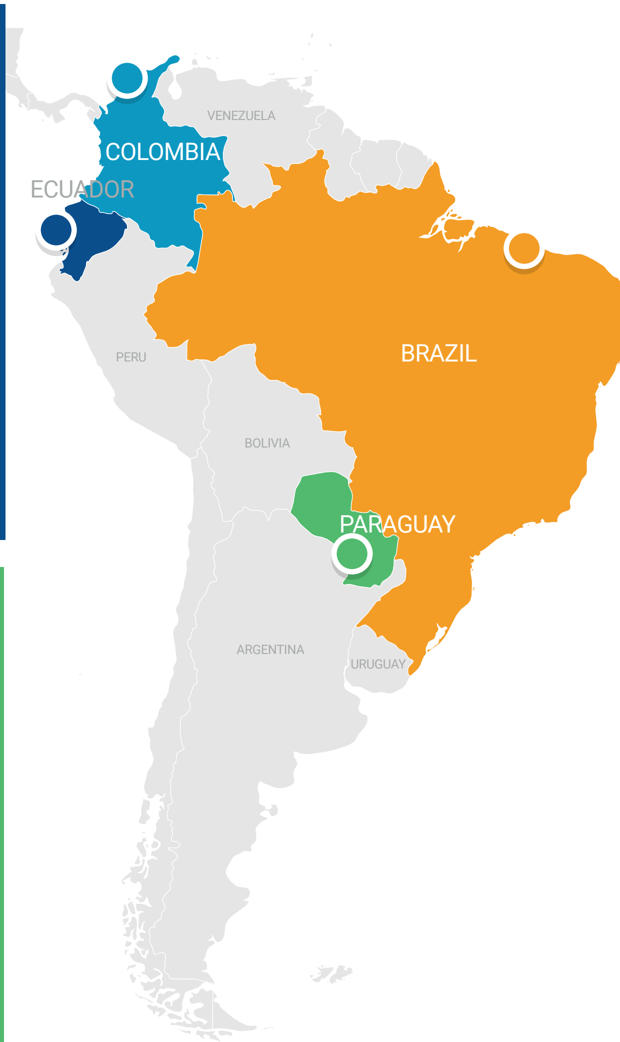
This case study highlights how ports with reliable trade and dedicated shipping routes could facilitate adoption of electrofuels. Initial adoption can be based on one or more established trade routes and the infrastructure can grow as more vessels using electrofuels are added to the fleet.

The map below shows a sample of other ports in the South and Central America region that could invest in electrofuel infrastructure to supply existing dedicated trade routes and grow from there.

SAMPLE OF OTHER PORTS ACROSS THE REGION THAT COULD SIMILARLY BENEFIT FROM INVESTMENT IN ELECTROFUELS

Port of Guayaquil, Ecuador

The largest port in Ecuador handles the bulk of the country's imports and exports. These established trading routes could benefit from having electrofuels facilities.



Contecar, Colombia

This port has a significant throughput of containers and is located on shipping lanes through to the Panama Canal, which would provide additional demand for refueling and bunkering.

Port of Asunción, Paraguay

This port on the Paraguay River is where most of the freight enters and leaves the country. While it is not a seaport, river ports with established trading routes could also benefit from electrofuels.

Port of Itaqui, Brazil

This port has the highest throughput (in tonnage terms) in Brazil by some margin. It handles a variety of commodities, providing large scope to decarbonize trade routes.

Glossary

Bunkering: Supplying a ship with fuel. A bunkering stop is where a stop is being made specifically for the purpose of refueling.

Economies of scale: The cost advantage that can be gained with increased volumes.

Electrofuel: A synthetic fuel produced using electricity.

Green: A prefix used for an electrofuel to denote that only renewable electricity was used in its production.

GW: A gigawatt of electricity.

IMO: International Maritime Organization, the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships.

Port Cluster: A group of ports located close together.

Shipping lane: A waterway route that is regularly used by commercial ships.

Spillover benefits: Free benefits that other sectors or society receive from the development of zero-carbon shipping fuels for shipping.

Supply chain: All organizations and activities involved in the supply of goods and their composite parts and materials.

Region: In this report refers to South and Central America.

References

[1] N. Ash and T. Scarbrough, “Sailing on solar: Could green ammonia decarbonise international shipping?’,” Environmental Defense Fund, London, 2019.

[2] N. Ash, I. Sikora and B. Richelle, “Electrofuels for shipping: How synthetic fuels from renewable electricity could unlock sustainable investment in countries like Chile,” Environmental Defense Fund, London, 2019.

[3] C. Midlehurst, “Ammonia flagged as green shipping fuel of the future,” *Financial Times*, 30 March 2020.

[4] R. Krantz, K. Søgaard and T. Smith, “The scale of investment needed to decarbonize international shipping,” Global Maritime Forum, 20 January 2020. [Online]. Available: https://www.globalmaritimeforum.org/news/the-scale-of-investment-needed-to-decarbonize-international-shipping. [Accessed 7 June 2020].

[5] ABS, “Pathways to Sustainable Shipping,” American Bureau of Shipping, Sping, Texas, 2020.

[6] P. Viebahn, A. Scholz and O. Zelt, “The Potential Role of Direct Air Capture in the German Energy Research Program—Results of a Multi-Dimensional Analysis,” *Energies*, vol. 12, no. 18, p. 3443, 2019.

[7] World Bank, “World Integrated Trade Solution,” [Online]. Available: https://wits.worldbank.org/CountryProfile/en/Country/LCN/Year/LTST/Summary. [Accessed 26 May 2020].

[8] World Bank, “World Integrated Trade Solution,” [Online]. Available: https://wits.worldbank.org. [Accessed 26 May 2020].

[9] ONS, “Capacidade Instalada De Geração,” Operador Nacional do Sistema Elétrico, 2020. [Online]. Available: http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/capacidade_instalada.aspx. [Accessed 10 June 2020].

[10] M. Daher, “A Previsão de Geração Solar Fotovoltaica,” Operador Nacional do Sistema Elétrico, Rio de Janeiro, 2018.

[11] Climate Scope 2019, “Brazil BNDES Finem Credit Line for Renewable Energy Products,” 2019. [Online]. Available: http://global-climatescope.org/policies/193. [Accessed May 2020].

[12] IRENA, “Renewable Electricity Capacity and Generation Statistics,” 2020. [Online]. Available: https://public.tableau.com/views/IRENARETimeSeries/Charts?:embed=y&:showVizHome=no&publish=yes&:toolbar=no.

[13] Companhia Siderúrgica do Pecém, “Pecém Industry and Port Complex,” Companhia Siderúrgica do Pecém, [Online]. Available: https://www.cspecem.com/en/about-us/pecem-industry-and-port-complex/. [Accessed 9 June 2020].

[14] CIPP, “Relatório Estatístico da Movimentação de Carga Ano 2019,” Companhia de Desenvolvimento do Complexo Industrial e Portuário do Pecém, Pecém, 2020.

[15] Porto do Pecém, “Pecém grants discounts for sustainable ships and becomes the first Brazilian port recognized by the Dutch foundation,” Porto do Pecém, 5 June 2020. [Online]. Available: http://www.complexodopecem.com.br/pecem-concede-descontos-para-navios-sustentaveis-e-se-torna-primeiro-porto-brasileiro-reconhecido-por-fundacao-holandesa/. [Accessed 9 June 2020].

[16] Governo Do Estado Do Ceará , “Estação Ecológica do Pecém,” Governo Do Estado Do Ceará , 31 May 2013. [Online]. Available: https://www.sema.ce.gov.br/2013/05/31/estacao-ecologica-do-pecem/. [Accessed 9 June 2020].

[17] ANTAQ, “Estatistico Aquaviario,” Agência Nacional de Transportes Aquaviários, [Online]. Available: http://web.antaq.gov.br/Anuario/. [Accessed 8 Jne 2020].

[18] EPE, “Energy Research Office Summary Report Year 2017,” Empresa de Pesquisa Energética, Rio de Janeiro, 2018.

[19] Ministerio de Transporte, “Estadísticas de carga,” Ministerio de Transporte, [Online]. Available: https://www.argentina.gob.ar/puertos-vias-navegables-y-marina-mercante/estadisticas-de-carga. [Accessed 15 July 2020].

[20] ANP, “Cifras,” Administración Nacional de Puertos, [Online]. Available: http://www.anp.com.uy/inicio/institucional/cifras/. [Accessed 15 July 2020].

[21] PWC, “Renewables in Argentina,” PWC, Buenos Aires, 2017.

References

[22] IFC, “RenovAr (Argentina): Scaling 'Express Edition',” International Finance Corperation, 2008. [Online]. Available: https://www.ifc.org/wps/wcm/connect/987eeec6-6259-4c00-8e21-fbf49813a47b/scaling-infra-argentina-08.pdf?MOD=AJPERES&CVID=mSCMXzz. [Accessed 23 May 2020].

[23] CNEA, “Boletín Energético 44,” Comisión Nacional de Energía Atómica, Buenos Aires, 2019.

[24] INE, “Energía, Gas y Agua,” Instituto Nacional de Estadística Uruguay, 2020. [Online]. Available: http://www.ine.gub.uy/energia-gas-y-agua. [Accessed 8 July 2020].

[25] IRENA, “Renewable Energy Policy Brief: Uruguay,” International Renewable Energy Agency, June 2015. [Online]. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_RE_Latin_America_Policies/IRENA_RE_Latin_America_Policies_2015_Country_Uruguay.pdf?la=en&hash=A76CA561F1B9FE54B25756097F5A55D20ED8EB33. [Accessed May 2020].

[26] Autoridad Marítima De Panama , “Venta De Combustible Marino A Través De Barcazas, Según Litoral,” Autoridad Marítima De Panama , Panama City, 2020.

[27] P. S. Molina, “Colombia ratifica su intención de alcanzar 1.500 MW renovables instalados en 2022,” PV Magazine, 3 July 2019. [Online]. Available: https://www.pv-magazine-latam.com/2019/07/03/colombia-ratifica-su-intencion-de-alcanzar-1-500-mw-renovables-instalados-en-2022/. [Accessed 30 July 2020].

[28] DANE, “información Para Todos,” Departamento Administrativo Nacional de Estadística, [Online]. Available: https://www.dane.gov.co/index.php/estadisticas-por-tema/comercio-internacional/exportaciones. [Accessed 4 June 2020].

[29] S. Guerroro, “El año pasado Cerrejón exportó 26,3 millones de toneladas de carbón,” El Heraldo, 2020 February 2020. [Online]. Available: https://www.elheraldo.co/la-guajira/el-ano-pasado-cerrejon-exporto-263-millones-de-toneladas-de-carbon-699359. [Accessed 4 June 2020].

[30] UPME, “Integración de las energías renovables no convencionales en Colombia,” Unidad de Planeación Minero Energética, Bogotá, 2015.

[31] Datos Abiertos, “Trafico Portuario Marítimo En Colombia vigencia 2016 a marzo 2020,” Ministerio de Tecnologías de la Información y las Comunicaciones, 2020. [Online]. Available: https://www.datos.gov.co/Transporte/Trafico-Portuario-Mar-timo-En-Colombia-vigencia-20/5r3g-zv5z/data. [Accessed 5 June 2020].

[32] MTC, “Informes y publicaciones / Transportes,” Ministry of Transport and Communications, Government of Peru, [Online]. Available: https://portal.mtc.gob.pe/estadisticas/transportes.html. [Accessed 2 July 2020].

[33] OEM, “Producción Por Tipo De Combustible,” Observatorio Energético Minero Organismo Supervisor De La Inversión En Energía Y Minería, 2020. [Online]. Available: https://observatorio.osinergmin.gob.pe/produccion-tipo-combustible. [Accessed 2 July 2020].

[34] OEM, “Evolución de potencia instalada nacional,” Observatorio Energético Minero Organismo Supervisor De La Inversión En Energía Y Minería, 2020. [Online]. Available: https://observatorio.osinergmin.gob.pe/produccion. [Accessed 2 July 2020].

[35] NREL, “Technical Potential of Solar in Peru using the Renewable Energy Data Explorer,” National Renewable Energy Laboratory, Golden, Colorado, 2019.

[36] Oxford Business Group, “Renewable energy production spurs growth in Peru,” Oxford Business Group, [Online]. Available: https://oxfordbusinessgroup.com/analysis/taking-aim-ambitious-targets-renewable-energy-production-have-spurred-growth-segment. [Accessed 2 July 2020].

[37] Gobierno del Peru, “Grupo de Trabajo Multisectorial de naturaleza temporal encargado de generar información técnica para orientar la implementación de las Contribuciones Nacionalmente Determinadas (GTM-NDC),” Gobierno del Peru, Lima, 2018.

[38] H. Levano, “Peru is systematically operationalizing its NDC,” Changing Transport, [Online]. Available: https://www.changing-transport.org/a-sustainable-transport-sector-in-peru/. [Accessed 30 July 2020].

Appendix

The table below shows the case study assumptions for potential electrofuels and renewable generation infrastructure for the case study ports in Brazil, Colombia and Peru.

Port		Porto do Pecém, Brazil	Puerto Bolívar Cerrejón, Colombia	Puerto Shougang Hierro, Peru
Fuel production	Tonnes per day	H_2: 564 NH_3: 3,464	H_2: 685 NH_3: 4,206	H_2: 322 NH_3: 1,979
Fuel plant availability factor		91%	91%	91%
Fuel plant maximum electricity demand	MW	1,400	1,700	800
Solar PV capacity	MW	0	0	1,600
Concentrated solar capacity	MW	0	0	0
Onshore wind capacity	MW	200	2,000	1,000
Offshore wind capacity	MW	2,000	0	600
Fuel plant annual electricity demand	GWh	11,160	13,552	6,377
Est. annual electricity generated – captive plants	GWh	9,179	12,103	5,975
Est. electricity imported from grid	GWh	3,620	3,214	2,450
Est. electricity exported to grid	GWh	536	425	1,418

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