EXPLORING CASE STUDIES ON POSITIVE EXTERNALITIES AND SOCIOECONOMIC IMPACTS OF RENEWABLE ENERGY INVESTMENT

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ABSTRACT

In the synthesis report of the United Nations published in COP27, it stresses the pertinence of reducing greenhouse gas emissions to meet the targets of the Paris Agreement. Nationally Determined Contributions (NDCs) facilitate this emissions reduction but are voluntary commitments with limited incentive.

Renewable energy will play a significant role in reducing global greenhouse gas emissions. This paper presents Iceland and Costa Rica, and the development narrative of their renewable energy sources. This paper argues that there are socio-economic benefits to investing in domestic renewable energy, on top of working towards climate action.

Investment in local supply chains, boosting domestic tourism, and social benefits such as labor capital and energy independence are examples of some positive externalities stemming from a domestic renewable energy policy. Although hydropower and geothermal resources have been the base of renewable capacity expansion historically, the falling costs of renewables and availability of funding should make investment in renewables more accessible to more countries.

The stories of Iceland and Costa Rica should be seen as examples, not models, of developing domestic energy sources. Further research can explore a deeper quantitative and analytical analysis of the economic benefits or investigate other countries and their development narratives.

Keywords:

Renewable energy investment, co-benefits, positive externalities, energy policy, path dependence

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1 Introduction

In the 21st United Nations Climate Change Conference (COP21), the *Paris Agreement* was signed. It was an agreement among nations to reduce their greenhouse gas emissions to limit temperature rise to 1.5°C, ideally, by the end of the century.

Achieving this target is facilitated by *Nationally Determined Contributions* (NDC). These NDCs allow countries to commit to targets aligned with their interests and level of industrial development. NDCs are submitted every five years to the secretariat of the United Nations Framework Convention on Climate Change, with the goal of increasing the ambition of each subsequent NDC (United Nations, n.d.-b).

However, the challenge with the latest set of NDCs assessed in 2022 is that these still do not meet the level of ambition needed to limit temperature increase to 1.5°C. The cumulative emissions allowed until the end of the century (so called carbon budget) to limit global warming to 1.5°C is 500Gt CO_2. Implementing the submitted NDCs up to 2030 will use up 86% of the remaining carbon budget. NDCs must therefore be over-achieved in the years until 2030, or significant reductions to CO_2 emissions must be done after 2030 (UNFCCC, 2022).

NDCs are voluntary measures for countries to signal their commitment to reducing emissions. In the documents themselves, the NDCs include targets for emissions reduction, which specific industries and strategies will be targeted in reducing emissions, and any potential “conditional” commitments depending on available financing. This approach allows countries to contribute depending on their level of industrial development and financial capacity (United Nations, n.d.-b).

While these allow countries to contribute depending on their capacity, this presents a challenge because a reduction in emissions does not have immediate economic advantages, but rather entails costs. This makes countries’ commitments to the NDCs dependent on their willingness to pursue climate action.

The energy industry is by far the greatest contributor to global greenhouse gas emissions, accounting for 73.2% of emissions in 2016 (Our World in Data, 2020). Reducing emissions from the energy industry will therefore be pivotal in meeting total emissions reductions goals. This thesis will focus primarily on the energy industry, specifically the electricity sector. Investment in renewable energy will be significant in reducing the emissions of the electricity sector but does not represent a comprehensive solution.

The research question presented by this thesis is: **Are there socio-economic rationales for renewable energy investment, in conjunction with pursuing climate action?** Alternatively, the hypothesis is that: **There are socio-economic benefits in investing in renewables, on top of the benefits resulting from climate change mitigation.**

As an example, existing renewable energy capacity in Europe has likely avoided fossil fuel import costs of up to USD 50 billion due to the rise in fossil gas prices from Russia's invasion of Ukraine. (IRENA, 2022d). This early investment in renewables has resulted in economic benefits to society, on top of their contribution to reducing emissions. This is one specific example of the positive externality of renewables – protection against price shocks from imported fuels.

The goal of the thesis is to investigate similar instances where renewables have yielded positive socio-economic benefits. The terms "co-benefits" and "positive externalities" refer to these instances where renewable energy investment has yielded benefits, aside from reducing greenhouse gas emissions.

This research will begin by defining the status quo – what have countries committed in terms of emissions reductions, and what needs to be achieved; then a review of the energy system and prominent renewable energy technologies, their limitations, benefits, and challenges; and finally, a landscape overview of the current standing of renewable energy. Providing this landscape research is important in establishing a baseline of what the prevailing technologies are, what the existing level of commitments and emissions reductions are in place, and what is the potential trajectory given the current landscape of renewable energy investment.

The study will then proceed by reviewing two case studies, Iceland and Costa Rica, and their development narratives. These two case studies were selected to illustrate the history and potential of developing domestic resources of renewable energy – though these are not meant to be prescriptive, but rather illustrative. The discussion and analysis section will go further in discussing the benefits, and their respective challenges. The case studies seek to highlight the development journeys of these two countries and are not meant to be a prescriptive solution for every country. Different countries with different geographies, available resources, and industrial capacities will have different narratives, which these two examples cannot encapsulate.

The discussion and analysis section will cover the analysis on the positive externalities of renewable energy investment. Primary attention is given to examples from Iceland and Costa Rica, with additional examples from other countries added when necessary. This section seeks to cite specific examples to build the argument for renewable energy investment. Conclusions will be derived from the case studies and the discussion and highlight these examples to address the research question.

Given the nature of this renewable energy investment, addressing the research question will depend on a case-to-case basis. Thus, the conclusions from this paper will be rather limited. In its stead, it provides specific examples of when the research question was answered for a given context. This paper can help provide compelling cases and alternative ways of investigating the benefits associated with renewable energy investment.

Limiting the depth of the study is the availability of quantifiable information on costs and benefits. It is difficult to quantify the benefits of an investment when publicly available information is limited. It is also complicated to establish cause and effect relationships between investment and outcomes arising externally. Thus, the discussion and analysis part will rely on published literature and statistics. Causal relationships between investment and benefit can thus only be implied, but not proven.

Future research can improve the number of case studies covered. Although Costa Rica and Iceland are prominent examples of countries' commitment to investing in renewables, these two are far from the only ones. Future research can be done in identifying other countries with similar narratives, or potentially recognizing which countries have the potential to follow a similar development journey.

2 Literature Review

This literature review will provide a brief look into the status quo of the NDCs, the energy system, and existing renewable energy technologies. This is meant to provide a foundational summary of the case studies and the discussion section, by having a baseline understanding of the current status of technologies and commitment to the goals of the Paris Agreement. The NDCs are used as a proxy to measure countries' commitment to the Paris Agreement. This section aims to provide an overview of the energy industry, with a particular focus on renewable electricity. This review will be limited to the most important types of renewable energy technologies used today.

Renewable energy is defined as sources of energy where the rate of replenishment is higher than the rate of consumption – this includes solar, wind, hydropower, geothermal, ocean energy, and bioenergy (United Nations, n.d.-a). Nuclear is not included in the list of renewable energy sources, as it is a depletable resource. Nuclear energy is no doubt an important low-carbon energy source, the time and cost associated with building nuclear capacity makes it a difficult technology pathway as a response to the climate crisis.

In discussing renewable energy, particular importance is given to electricity. However, it is important to note that not all energy needs rely on electricity.

Industrial processes or transportation technologies would require energy in the form of heat or mechanical energy, and not necessarily electricity. Moreover, the electrification of technologies such as internal combustion engines and residential heating systems is detached from the level of renewable electricity availability. These are cases for electrification, which will be covered below.

Further, in displacing fossil fuel sources such as natural gas and coal, it is worth highlighting that these fossil fuel sources can also be used as chemical feedstocks in industry, and not just as fuels. Petroleum, for example, is the key feedstock in the petrochemical supply chain. It is therefore an important caveat that the displacement of fossil fuel sources in this paper is limited to their use in electricity generation.

Finally, a theoretical framework for understanding the case for fossil fuel investment is reviewed. Path dependency suggests that the entrenched position of fossil fuel systems is a result not strictly through the advantages it offers, but the network effects unlocked through its continuous development. Investment in renewables thus has the challenge of having to break into the entrenched position and existing network effects, and provides insight into the persistence of fossil fuel systems.

2.1 Review of Nationally Determined Contributions

NDCs are a platform for countries to express commitment to reducing their emissions. It signals to the global community the number of emissions they're willing to undertake, under which conditions, through which sectors, and to what timeframe. NDCs allow the United Nations Framework Convention on Climate Change (UNFCCC) to take stock of what emissions reductions are expected, and to what degree (United Nations, n.d.-b).

A prominent detail to be mentioned are the "conditional" commitments of emerging economies to emissions reductions targets. These commitments are conditional upon developed countries providing climate finance to developing countries. In COP 26, it was revealed that the initial five-year goal of reaching 100 billion USD in climate finance was broken (Timperley, 2021).

In the UN Synthesis Report published in the 26th Conference of the Parties (COP27), fully implementing all the published NDCs, the best estimate for peak temperature rise by the year 2100 is between 2.1°C and 2.9°C, far above the goals of the Paris Agreement (2022). In meeting the 1.5°C goal of the Paris Agreement, the IPCC estimates the carbon budget up to 2050 to be around 500 Gt CO_2, of which, if the current NDCs are to be implemented, 86% will be consumed by 2030. This illustrates that with the current commitments, a significant increase in ambition after 2030 or an overachievement of current commitments will be needed (Liu & Raftery, 2021; UNFCCC, 2022).

These NDCs represent 94.9% of total global emissions, with some commitments also including conditional elements (primarily, financing) (UNFCCC, 2022). The current NDCs therefore are already a *best-case* estimate for the reduction of emissions as of today. As the level of commitment in NDCs are voluntary, countries have an incentive to overpromise, but little incentive to overdeliver.

Further complicating this are the conditional commitments from developing countries – countries who have contributed least to the climate crisis but are potentially the most vulnerable to it. Critically, it is these most vulnerable countries that are increasing their ambition in response to climate change, although these 78 countries only account for 7% of global emissions (UNFCCC, n.d.). Conditional NDCs are an important provision for allowing developing countries to contribute beyond their means, of which developed countries need to support (Pauw et al., 2020). These figures demonstrate the importance of the NDCs, as it allows the global community to review and take stock of commitments to reducing emissions, and from which countries.

More ambitious commitments to the NDCs relies on contributing to non-climate objectives – which can also be socially or politically appropriate (Vogt-Schilb &

Hallegatte, 2017). Making emissions reductions more socially and economically attractive is thus an opportunity to incentivize more ambitious commitments at the level of the NDCs.

2.2 Overview of the Energy Industry

This section will provide an overview of the energy industry, specifically the electricity industry and how it operates. This is far from a comprehensive review of the industry, but rather a foundational introduction into how it operates.

In counting emissions, the energy industry accounts for all emissions related to the production and consumption of energy – as thermal, mechanical, and electrical energy. Globally, electricity and heat comprise most of the emissions from the energy sector (Ritchie et al., 2020). The emissions accounted for in heating include residential and commercial heating and emissions from the industrial use of heat (for example, in the production of steel). The thermal use of energy is prominent in heavy industry, where high amounts of energy are used for chemical processes and manufacturing. Examples include the thermal reformation of nitrogen and hydrogen in the production of ammonia, and the reduction of calcium oxide in producing Portland cement.

Mechanical energy is most prominent in transportation, which accounts for 16.2% of total global emissions (Our World in Data, 2020). Reducing emissions for the use of mechanical energy, like in heating, also relies on the electrification of energy use on top of presence of renewable energy in the grid. Further emissions in the energy industry come from fugitive emissions, i.e., Emissions that are released as by-products or through leaks, maintenance, or system inefficiencies.

The electricity sector consists of three major parts – suppliers, distributors, and consumers. Suppliers consists of power plants, distributors are the grid operators that transport the electricity from supply to demand centers, and consumers are industries and population centers.

Electricity needs to be consumed at the same time it is generated, therefore supply and demand must remain balanced at any given time. To maintain this balance, either supply or demand can be adjusted to match the other. In demand side balancing, the goal is for consumers to modify their patterns of electricity use, based on grid activity (Gyalai-Korpos et al., 2020; Kies et al., 2016). An illustration of this is that grid operators can reduce the price of electricity when demand is low (at night), and vice versa, incentivizing consumers to adapt their electricity use. On the other hand, supply side balancing is when power plants are ramped up or down depending on the demand for electricity (Göransson, 2023; Gyalai-Korpos et al., 2020). This relies on power plants that are flexible enough to start or slow down at a moment's notice.

There are three broad categories for power plants. Baseload plants generate electricity consistently and represent the *baseload* demand of electricity in a particular grid. Baseload plants are often slow to start, and often run for year-round except for maintenance. Examples of baseload plants include coal and nuclear power plants. The second category of power plants is mid-merit, or load-following power plants. Mid-merit, or intermediate load plants follow the progression of electricity demand throughout the day, and thus are more flexible than mid-merit power plants. This includes natural gas power plants, and hydroelectric power plants. Finally, peaking plants are power plants that generate electricity only to meet peak demand. Peaking plants can ramp up from zero to full power in a matter of minutes-hours and are able to throttle their energy output. Peaking plants include oil-based power plants and some natural gas power plants (Breeze, 2019).

Energy storage becomes paramount in grids with a lot of variable renewable energy. This is because electricity needs to be consumed at the same time it is produced, but peak electricity demand does not always coincide with peak electricity supply. Examples of energy storage technologies include pumped hydro, and compressed air energy storage. These two technologies were developed to take advantage of price differences in the energy market, as variations in supply and demand lead to different prices. Energy storage can help balance out these inequalities by storing or releasing energy to the grid as needed.

The advantage of fossil fuels over renewable energy is that fossil fuels, by nature, are energy storage units. Storing supplies of fossil fuels is by default already storing supplies of energy. In contrast, for solar photovoltaics, the electricity generated by the solar panels needs a conversion step to become stored energy, into batteries for example. This path is the reverse for fossil fuels, which already store energy, and need conversion to become electricity. This gives fossil fuels, such as natural gas, the benefit that electricity generation from these fuels can actively respond to the demand. Analogously, energy storage (or demand side management) responds to the changes in supply from variable sources of renewable energy.

This "flexibility" of natural gas has led to renewed discussions and interest of using natural gas as a "bridge fuel" towards a renewable energy technologies (Hausfather, 2015; Kirkland, 2010; Levi, 2013; Nunez, 2014; Zhang et al., 2016). This concept of a bridge fuel suggests that natural gas – because of its lower emissions compared to coal – can be used to bridge the gap between energy supply from renewables. This idea is still however, being contested as it can lead to the expansion of more natural gas infrastructure, leading to lock-ins and path dependencies for economies moving forward in the energy transition (Kemfert et al., 2022; WWF, 2023). Continued, or even increased reliance on natural gas would lead to further lock-ins and path dependencies inconsistent with the goals of the Paris Agreement. Further investment in natural gas infrastructures could lead to potential "stranded assets" as these will eventually have to be faced out, in keeping with the goals of the Paris Agreement.

The energy transition is a complex, ever-changing topic strewed with competing interests and opposing perspectives. Achieving the goals of the Paris Agreement, however, would certainly rely on a high availability of renewable energy sources in the grid, and a combination of enabling technologies to store and use low-carbon energy sources.

2.3 Overview of Renewable Energy Technologies

Renewable energy sources have been harnessed by humanity since time immemorial. From geothermal sources being used as hot springs, to windmills used to pound grain, harnessing renewable energy has been paramount in improving human productivity. With the advent of the industrial revolution however, steam power fueled by coal became the prime mover for industrial production.

Converting renewable energy sources into electricity has been a continuous work in progress. This section will provide an overview into the most prominent conversion technologies used today, each of their strengths, and challenges. More conversion technologies exist and are being developed, and this section will only briefly cover some of these technologies.

Not covered in this section are the associated technologies needed for further emissions reductions. While the increased prevalence of renewable energy in the grid will reduce emissions by displacing fossil fuel power plants, other technologies will be needed to support this transition. Technologies such as energy storage, of which there are several different methods, will be important in supporting the development of renewables in the grid. Electrification of energy use, such as electric vehicles and electric heat pumps, is another important aspect in reducing the emissions from the energy industry. These technologies are important and are relevant to meeting the goals of the Paris Agreement but will not be the focus of this paper. Attention will be given to these associated technologies where they relate to the expansion of renewable energy and its use.

2.3.1 Hydropower

Hydropower systems use the gravitational potential energy of water to turn a water turbine to generate electricity. Hydropower systems are by far the most prevalent form of renewable energy, accounting for 59% of total renewable electricity generation in 2020, equivalent to 4,346 TWh (IRENA, 2022c).

The most well-known class of hydropower systems are called *impoundments*, where a dam is built on a river to create a reservoir of water, which can later be released to pass through turbines, generating electricity (Breeze, 2019; DoE, n.d.).

A second class of hydropower systems are called "run-of-river" facilities, which do not need to build a dam, but rather relies on high hydraulic head (high velocity or elevation difference) on end of the system to the next, to generate electricity (Breeze, 2019; DoE, n.d.).

The benefit of having an impoundment dam is in its reservoir. Because dams can hold water in their reservoir, it can choose when to release water to generate electricity. Depending on the amount of water it releases, it can also throttle its electricity output, accordingly, depending on demand. This feature can be further utilized in a subclass called *pumped hydro*.

Pumped hydro facilities have an upper and a lower reservoir. In periods of high demand, water can be passed through the turbines to generate electricity (Breeze, 2019; DoE, n.d.). But in periods of low demand, electricity from the grid is used to pump the water from the lower reservoir into the upper reservoir, to be stored for later use. Pumped hydro facilities can be particularly important for grids with a lot of variable renewable energy (VRE), as these can act as massive batteries to store energy during periods of high supply. It can also take advantage of price fluctuations, by generating electricity when the price is high, and charging its reservoir when the price is low.

However, the challenge with impoundment dams also comes from its reservoir. Building the dam requires significant investment in construction time and materials, particularly steel and concrete. Furthermore, restricting the flow of a river damages the ecosystem both upstream and downstream of the river. Riverbanks upstream of the original river will be flooded, while river flow downstream will be significantly altered. This change in land-use can in the short-term increase emissions through the decay of biomass, resulting in methane emissions. Emissions from biomass decay is a primary concern in tropical environments (Alsaleh et al., 2021; Deemer et al., 2016; Fritsche et al., 2017), where emissions from the first few years can be worse than of a similar sized coal power station. Flooding upstream can also have significant impacts to wildlife, human settlements, and the perception of nature (Breeze, 2019). For example, up to a million residents had to be relocated during the construction of the Three Gorges dam in China, the largest hydropower facility in the world (Gan, 2020).

Run-of-river facilities avoid this issue by not having a reservoir. Instead, these facilities construct a canal alongside the river, diverting some of the water flow, passing it through a turbine, and later joining the river downstream. This results in faster construction times, less materials, and no flooding. However, the limitation of run-of-river facilities is that they require the river to either have a high elevation difference, or a fast-moving flow. Additionally, these limit the potential size of run-of-river facilities significantly and limits their ability to store water.

An additional concern with hydropower is the use of water. As opposed to other power generation sources, potable water is a necessity for agriculture and human use. Periods when it's most economical to produce electricity may not coincide with the right-of-use for the available water. Droughts and periods of low-water supply make this even more challenging, as it restricts the ability of hydropower plants to generate electricity. Conversely, periods of high-water supply can bring challenges of flood control especially in tropical areas. In the Philippines for example, typhoons can inundate the country with an abundance of rainfall. This surplus of water increases water levels in bodies of water, including dams. A sudden increase in water supply can overwhelm dams and require them to release water, causing flooding downstream. (Valenzuela, 2020).

Furthermore, when the river passes through multiple jurisdictions or national boundaries, conflicts can arise over who right of use of water (Breeze, 2019). Examples include the Grand Ethiopian Renaissance Dam (GERD), which is being contested by the governments of Sudan and Egypt because of its impacts on the Nile River (BBC, 2021); the disruption of water flows from the Euphrates river to Syria after the construction of the Ataturk dam (DW, 2021); and the dispute over sedimentary flows over the Mekong river from China and Laos through Cambodia and Vietnam (Reuters, 2022).

Hydropower is an exceptional technology in providing a predictable, flexible, and enormous supply of renewable energy. However, because of the potential impacts of climate change on regional and local weather systems, the amount of precipitation and – and thus water availability for hydropower, can change drastically at a regional level in the coming years (Majumder & Saha, 2016; Schaefli et al., 2007; Wasti et al., 2022).

2.3.2 Wind

Windmills generate electricity by converting mechanical energy from wind to electricity using turbines. The kinetic energy stored in wind is given by the equation:

$$KE = \frac{1}{2}\rho A v^3$$

Where ρ represents air density, A represents the cross-sectional area of the turbine, and v represents air velocity. The term v^3 denotes that the energy is proportional to velocity cubed, making windmills particularly reliant on the velocity of incoming wind. Wind flow can be interrupted by geographical features such as hills and trees, and thus higher velocity winds are often found vertically far from the surface (Breeze, 2019).

Windmills can be classified into two categories based on design. Vertical Axis Wind Turbines (VAWT) and Horizontal Axis Wind Turbines (HAWT). HAWT is the most used windmill design, because of its higher efficiency for generating electricity. HAWT, however, relies on non-turbulent air to maintain its efficiency, therefore limiting its use to areas with non-turbulent air. Turbulence is the chaotic property in the direction of flow, caused by changes in direction in the flow of air, such as those caused by geographic features. VAWT overcomes this by rotating along a vertical axis, and thus able to receive the flow of air from any direction. VAWT are more flexible in their deployment but are much less efficient in generating electricity (Breeze, 2019).

The geometry, rotational speed, and size of the blades play an important role in the efficiency of a wind turbine. The angle of the wind turbine blade, for example, can be adjusted to get the optimum amount of energy depending on the wind speed. Additionally, because wind speed can vary across the area of the wind turbine, the angle of the blades can be adjusted along the hub as it rotates. As wind turbines rotate faster, these can also generate more noise (and stress from the mechanical vibration), and the angle can also be adjusted accordingly (Breeze, 2019).

Although wind is intermittent, accurate weather forecasting and models can optimize and predict wind generation capacity ahead of time. In contrast to solar energy, a predictable supply of energy can be generated from wind across seasons and throughout the day. There will also be seasonal variations in the energy generation of wind, but to a lesser degree than solar and hydro, especially in latitudes further from the equator. Nonetheless, wind is still an intermittent resource, and thus a great degree of variability in generating electricity (Breeze, 2019).

However, windmills come with their own set of challenges. Foremost is the disruption of land and air use, leading to fatalities of avian populations (Aishwarya et al., 2016; Wang & Wang, 2015), and concerns of ruining landscape views (Lo, 2012). Furthermore, the materials and manufacturing techniques in building wind turbines make them difficult to re-use and recycle, leaving most windmills turbines to be landfilled or incinerated after its lifetime (Larsen, 2009).

Another unique feature of wind power is with regards to land use. As opposed to most energy generation technologies, land used for windmills can still be used for other purposes (such as farming). Thus, in terms of actual land use, wind has one of the smallest actual footprints when compared to other technologies, at 0.4 m^2 land used versus 15m^2 of land per MWh in a year for coal (Ritchie, 2022).

Wind thus represents a unique opportunity in that land used for wind turbines can be used to generate electricity, whilst being used for other purposes. Another unique advantage of windmills is that these can be placed offshore. This further reduces the land-use burden of windmills, especially in countries with limited wind resource availability on land. While offshore wind turbines can be significantly more expensive, these offer better flexibility in terms of land-use and the aforementioned challenges than onshore wind turbines (Breeze, 2019).

2.3.3 Solar

There are two mainstream paths to generating electricity from solar power. First is through *Photovoltaics* (PV), and the second is through *Solar Thermal Generation* (Breeze, 2019). Rooftop solar collectors can also be used to collect solar energy for direct heating.

Solar PV converts solar energy into electricity through the *photovoltaic effect*, a phenomenon which generates electricity by passing light through semi-conductors.

Solar thermal generation (or concentrated solar plants, CSP) relies on using heat from sunlight and converts this thermal energy into electricity. This can be done using mirrors or lenses, which concentrate sunlight onto a receiver to collect sunlight. There are several ways to convert thermal energy into electricity, with the *Rankine Cycle* being the most used- where the heat is used to convert water into steam, which is then passed through a turbine which turns a generator (Breeze, 2019).

In both these systems, the main source of energy is direct access to sunlight. While both systems work with varying amounts of sunlight, CSP plants perform better in high temperature conditions, while solar PV can still perform in areas with lower surface temperatures. In terms of energy storage, solar PV needs to convert the electricity into other forms of energy for storage (such as through lithium-ion batteries), while CSP plants can store thermal energy (for example, using phase-change materials) directly, before consumption. This allows solar thermal generation plants to continue to supply electricity, even after daylight (Breeze, 2019).

Solar power plants benefit from a high degree of predictability in generating electricity – as these can be derived from available daylight hours and other variables such as cloud cover. Another benefit of solar power is that these can be installed on rooftops – generating electricity at potentially very low land-use footprints. Rooftop solar also represents a great degree of distributed electricity generation, along with its associated effects to the grid (Breeze, 2019).

The challenge with solar panels is the evident relationship to daylight hours. This problem is exacerbated in latitudes away from the equator, as decreasing daylight hours due to the change in seasons means that a seasonal level of load-balancing must be implemented to keep the grid balanced. Heating demand will be highest in winter, coinciding when solar energy supply is at its most limited. Thermal energy storage in solar thermal plants can mitigate the day-night variability of solar energy but is inadequate to account for seasonal variability. Compressed air storage, hydrogen production, lithium batteries, and pumped hydro are potential technologies for seasonal storage, but only pumped hydro storage presently exists in a large enough scale (Deane & Gallachóir, 2015; Guerra et al., 2020).

Additionally, huge amounts of waste (and potential raw materials) are expected to be generated from the end-of-life of solar panels. Recycling capacity for solar panels will need to keep up with the decreasing costs of production to minimize this projected amount of waste (Atasu et al., 2021; IRENA, 2016).

Apart from the advantages mentioned, solar panels also have the distinct ability of being placed upon commercial and residential rooftops. Placing solar panels on rooftops also has the compounding benefit of reducing energy demand for cooling (Salamanca et al., 2016; Shen et al., 2022).

2.3.4 Geothermal Power

Geothermal power plants, like coal power plants, rely on the *Rankine cycle* to generate electricity. However, instead of using fossil fuels, these power plants generate steam using geothermal heat. This constrains geothermal power plants to locations with ample supply of geothermal energy (Breeze, 2019). The *Pacific Ring of Fire* is the colloquial term used to describe the vast geothermal activity located in a ring around the Pacific and is also where most geothermal plants are located.

Steam and thermal energy can be collected from geothermal wells, where geothermal energy from the Earth's core finds its way to the surface. In collecting this energy, geothermal plants can either collect the water/steam directly or use a heat exchanger to collect heat from underground. In both processes, the collected heat is used to generate steam, which then runs a steam turbine to generate electricity. In the case of the former, the collected steam can be reinjected to mitigate the pressure decline from the collection of steam (Breeze, 2019; Gunasekera et al., 2003). Foregoing the re-injection of steam back into the surface can lead to decrease in productivity of the well over-time- making it a limited resource.

Geothermal plants produce a small amount of emissions, but not through the form of combustion (Fridriksson et al., 2017). Because geothermal plants rely on collecting heat energy through geologically active formations, exhaust gases from underground are often released during the collection of thermal energy. However, the estimate for emissions of geothermal plants are only up to 1/4th the emissions from natural gas (Fridriksson et al., 2017). Additionally, the International Geothermal Association considers these emissions as part of natural background emissions from geothermal areas (Ármannsson, 2003). It is likely that these emissions would have been released over time, even without the presence of the geothermal plant. Geothermal plants are renewable sources of energy because the energy collected would have otherwise been released through natural geological processes.

The consistent, predictable quality of geothermal power yields high-capacity factors of up to 90% (Fridleifsson, 2003)- in contrast to the other, more variable types of renewable energy. Capacity factors indicate the percentage of energy produced by a power plant, over a time period, with 100% being fully operational all the time, and 0% completely deactivated.

Furthermore, geothermal energy can also be used in district heating applications (Breeze, 2019). Instead of generating electricity, the collected heat energy can be used directly as heating, for commercial or residential purposes.

However, a limitation of geothermal energy is its reliance on geographic location. There are very limited resources of geothermal energy in continental Asia, Central and South America, and parts of Africa (Breeze, 2019). Discovery and exploration of geothermal wells is also considerably more expensive than other renewables and can take years to get an accurate estimate of available resources.

2.4 Summary of Renewable Energy

A variety of technologies exist for collecting renewable energy. These are by no means exhaustive but highlight the most prevalent forms of technology in use today. Of these, hydroelectricity is by far the largest component, accounting for 53.89% of total renewable electricity generation, followed by 23.48% of wind and 13.02% solar in 2021. Most of the installed wind and solar were only built in the last decade, with solar being the most built renewable source in recent years. The graph below shows the distribution of renewable energy generation by technology type (BP, 2022). As of the end of 2022, the world had a combined capacity of 3,372 GW of renewable energy generation capacity (IRENA, 2023).

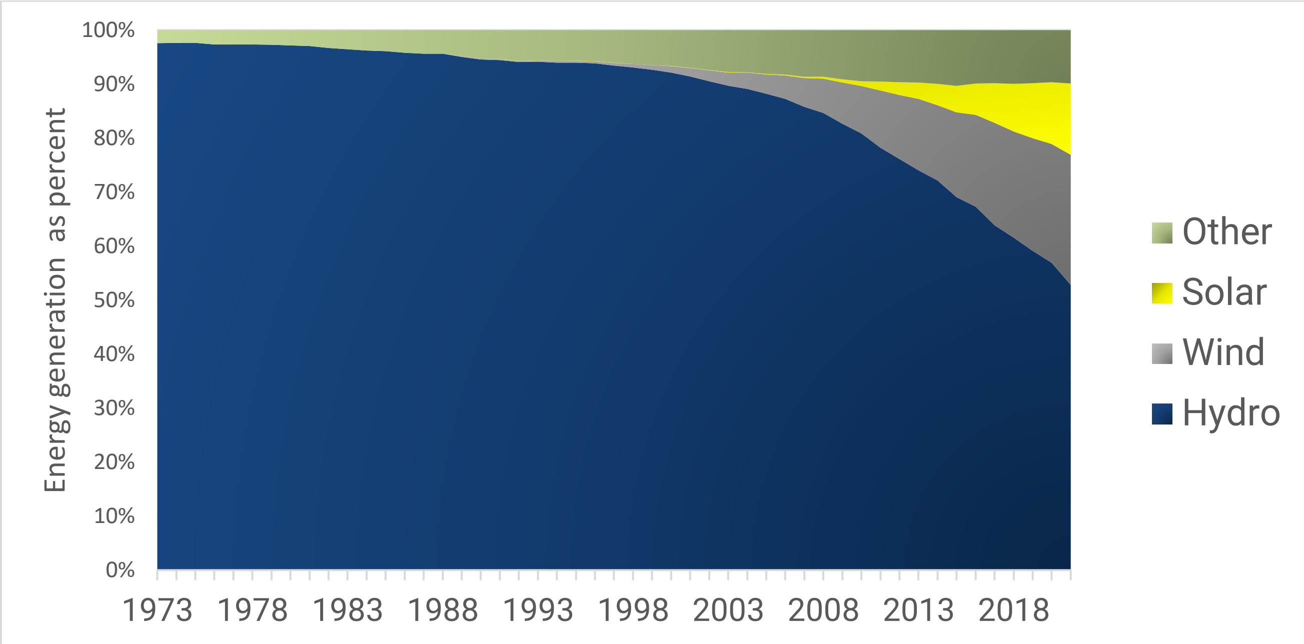


Figure 1 Renewable energy generation by technology, as percentage of total renewable energy generation, 2021. Source: BP Statistical Review of World Energy 2022.

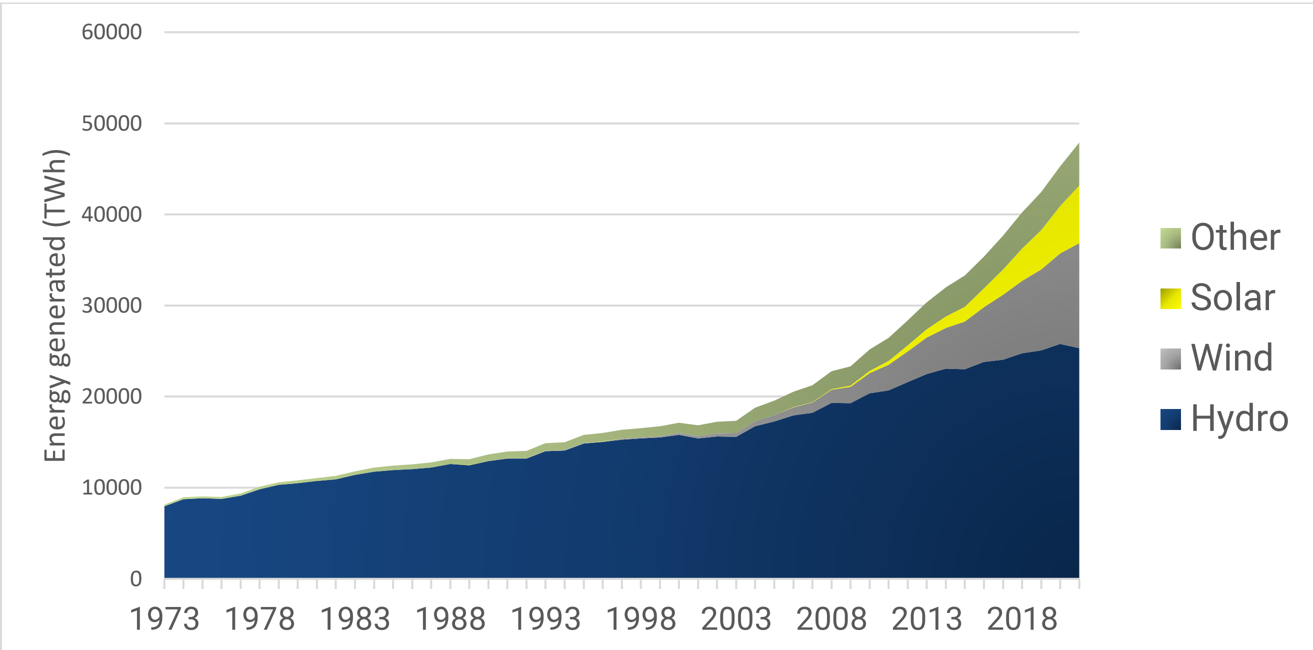


Figure 2 Total renewable energy generation in 2021, by technology. Source: BP Statistical Review of World Energy 2022.

In 2022, renewables accounted for over 80% of all newly built electricity generating capacity worldwide. Of the 295 GW of renewable capacity added worldwide in 2022, solar contributed and wind contributed192 GW and 75 GW, respectively (IRENA, 2023).

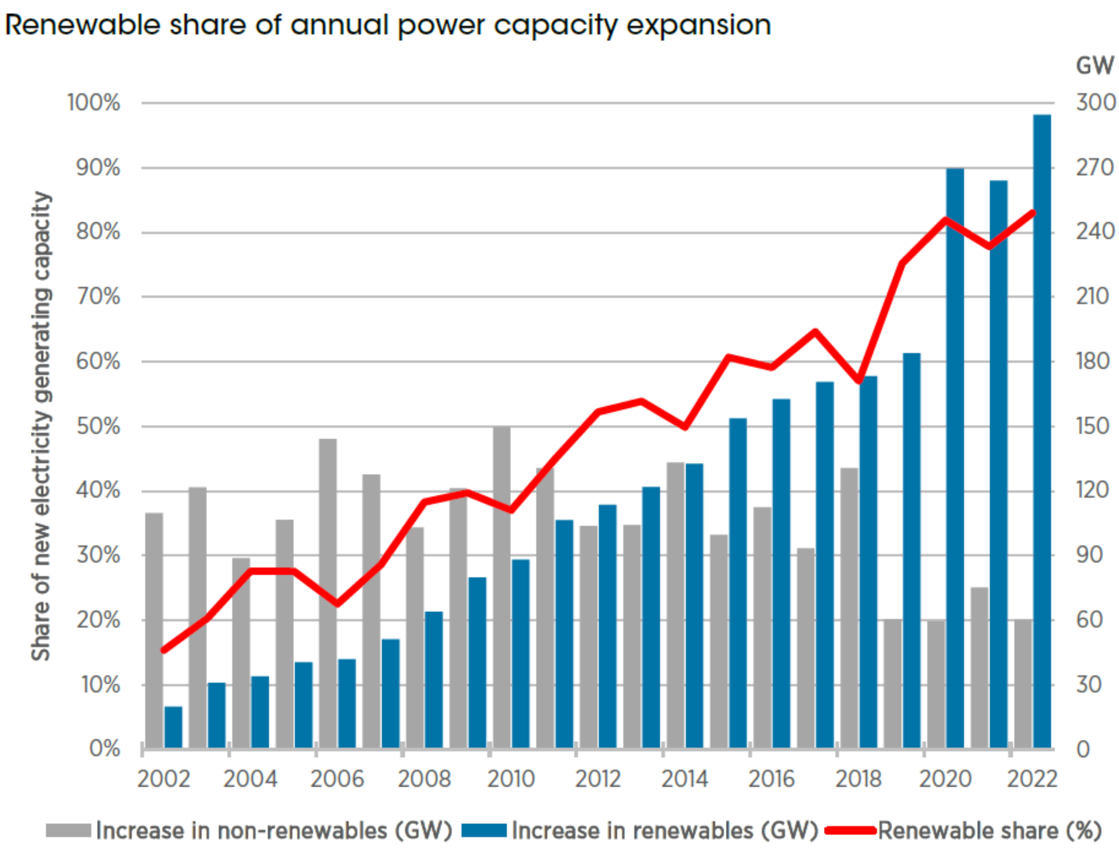
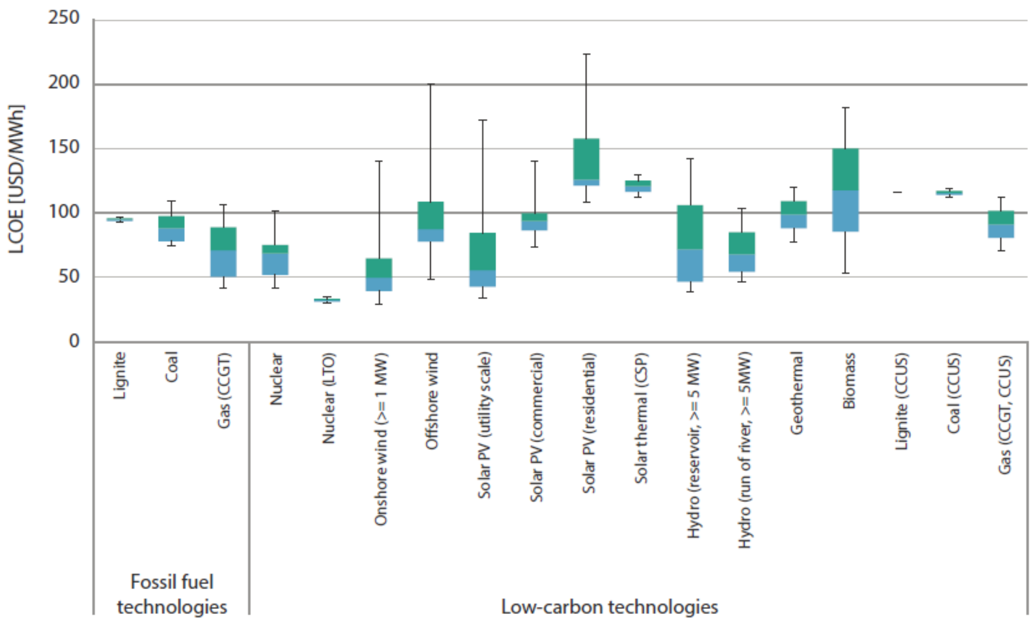


Figure 3 Newly built electricity generating capacity, 2002-2022. Source: IRENA Renewable Energy Statistics 2023

This is in part due to increased ambition of countries worldwide, but also the falling costs of renewable technologies. With adjusted 2021 USD values, solar panel costs have fallen from $5.66/W in 2000 to $0.27/W in 2021 (Our World in Data, 2021).

The levelized cost of energy (LCOE) is a metric used in comparing the lifetime costs of building, operating, and maintaining power plants. It considers all the expected costs of a power plant, including its capacity factor and potential downtimes, and assesses it at a net-present value. It is a helpful metric in comparing different electricity generating technologies but does not paint a whole picture of the market. The two succeeding graphs show the cost competitiveness of renewable energy technologies as compared to fossil fuel technologies. The cheapest RE technologies are already as cheap, and sometimes cheaper, than the cheapest fossil fuel technologies, without accounting for subsidies or emissions pricing (IEA, 2020; IRENA, 2022d; Lazard, 2023).



Note: Values at 7% discount rate. Box plots indicate maximum, median and minimum values. The boxes indicate the central 50% of values, i.e. the second and the third quartile.

Figure 4 Boxplot comparison of levelized cost of electricity, by technology, with a 7% discount rate. Source: IEA Projected Costs of Generating Electricity 2020

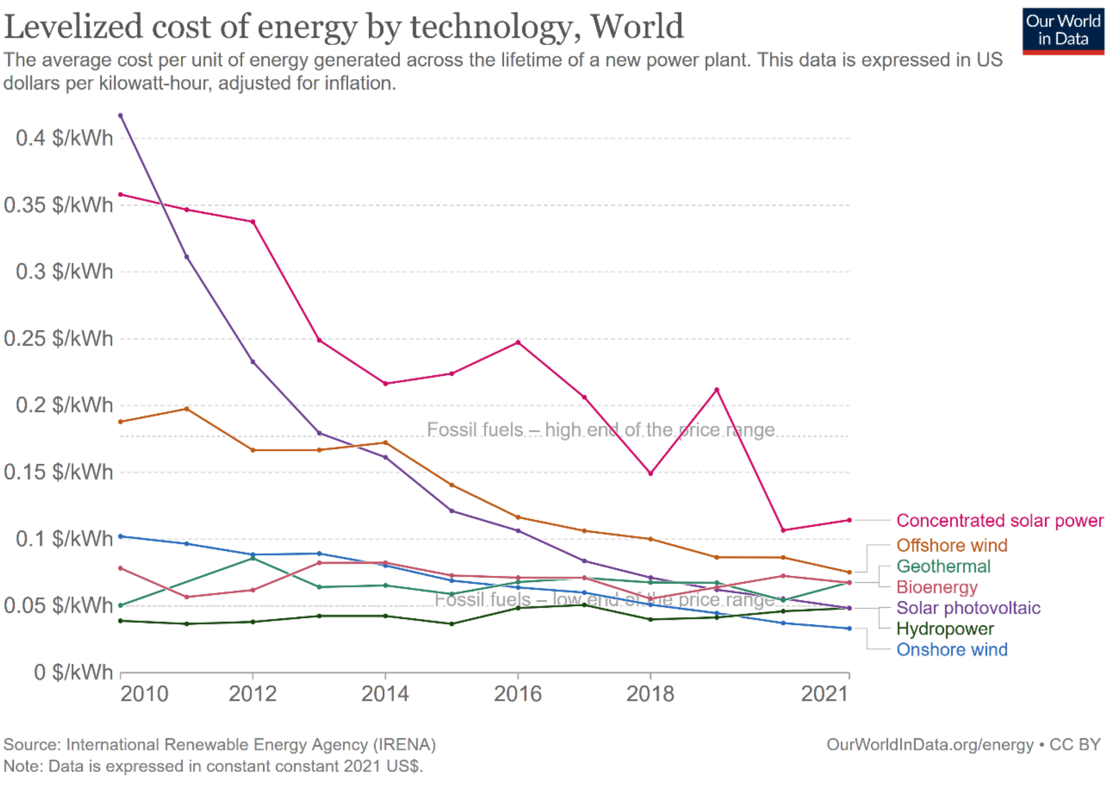


Figure 5 Levelized cost of energy for different technologies through time, by technology. Source: Our World in Data | IRENA Renewable Energy Statistics 2021

However, even with all the progress made, this is still insufficient to meet the energy demands of 2050 in line with the Paris Agreement. Share of renewables in electricity generation needs to exceed 88% in order to align with a 1.5°C scenario, up from today's 26-28% (IEA, 2021; IRENA, 2022e).

The pace of progress in advancing renewables must only accelerate from here. Cost reductions and advances in technology will make renewables available to a broader set of economies and grids. Renewables alone will not solve the climate crisis but will make an important contribution to reducing greenhouse gas emissions.

Apart from the uptake of renewable energy, energy efficiency, and electrification of energy use will also play an important role in the reduction of greenhouse gas emissions.

Energy efficiency – as the name implies, is the shift towards the more efficient use of energy. This includes redesigning buildings to be more energy efficient through heating and electricity use, and the upgrading of industrial facilities to newer, stricter standards of energy use. Because of the limited nature of the carbon budget, replacing fossil fuels with renewables alone will not be enough if current energy consumption trends are continued – after all, producing solar panels and manufacturing wind turbines also take up energy and cause emissions. It is with the reduction of polluting energy sources and improvements in the use of energy that can help reduce the carbon footprint of the energy industry.

Electrification of energy use is the conversion of technologies – which would otherwise use fossil fuels, to electricity. Examples include the transition from internal combustion engines to electric vehicles, gas heating to electric heat pumps, among others. Increasing only the use of renewables would have very little impact on the transport sector without electrification. Alternatively, dependence on natural gas would change very little if natural gas was still the fuel of choice for domestic and industrial heating. Even countries such as Costa Rica for example, with a near 100% renewable electricity grid, relies on fossil fuel imports because of its transportation sector. Further, path dependence will still be a concern if fossil fuels such as natural gas and oil continue to be used, even with increased renewables and energy efficiency.

All three of these facets, and more, are important to ensure the reduction of greenhouse gas emissions in meeting the goals of the Paris Agreement. Discussing the different elements of all three dimensions is beyond the scope of this paper, but it is important to highlight their relevance.

However, given the scope and progress made in advancing renewable energy technologies, why do fossil fuels continue to be so persistent in the global economy? If renewable energy technologies are cost-competitive and offer such positive externalities, how are these still not the prevalent form of energy production? Understanding the case for renewable energy investment also involves understanding the nature of why fossil fuel energy systems are prevalent.

It is noteworthy to emphasize that fossil fuel systems are prevalent not by nature, but by design. The next section will offer a theoretical framework for understanding the growth and scale of fossil fuel technologies, the barriers for renewable energy, and a positive outlook on overcoming them.

The diffusion of renewable energy technologies relies also on the displacement of fossil fuel technologies in power generation. The narrative of renewable energy growth is therefore incomplete without the history of how fossil fuels found their entrenched position in today's energy landscape. The consensus and threat of climate change exists, and the abolition of fossil fuels play a prominent role in mitigating its effects.

2.5 The Nature of Path Dependencies

Path dependencies offer a theoretical explanation for the persistence of fossil fuel technologies. Path dependencies or "lock-ins" refer to the continued reliance on a technology pathway not by virtue of its advantages over alternatives, but through its entrenched position in an existing system (Goldstein et al., 2023). It offers a theoretical background for understanding the deeply rooted nature of fossil fuel systems.

Technological lock-in stems from improved economies of scale as it becomes more prevalent in a system. Unruh provides several historical examples of technological lock-ins from the use of alternating current in the electric grid and the dominance of internal combustion engines in automotive transport (2000). A common thread in these historical cases is that competing alternatives where not necessarily inferior versus the technology pathways that eventually prevailed, but rather the historical development and improved economies facilitated these technologies to become dominant. When a certain technology pathway gains a lead – whether through innate advantages or historical coincidence, the benefits provided by improved scale can make it difficult to be overcome by the alternative pathways.

Moreover, network effects play a significant role in magnifying the effects of scaling. Network externalities benefit from the increased scaling of a particular pathway, where each successive participant in the network improves the network, further inviting successive participants (Unruh, 2000). Unruh provides the example of the automobile, where each subsequent participant in the automobile supply chain – tire manufacturing, petroleum refining, road construction, service stations, provide complex interdependent industries which all benefit from the network effect (2000).

Different policy actions can be taken to prevent further carbon lock-in, but requires a level of critical mass and adoption in order to move away from the entrenched path dependencies (Seto et al., 2016; Stein, 2016; Unruh, 2002). It is worth understanding that the current reliance on fossil fuels for energy is a consequence of both technological advantages and path dependencies. Exogenous and forces – such as through policy levers – will be critical in breaking away from carbon-based path dependencies (Unruh, 2002). In 2022, despite the incredible growth in energy share of renewable energy technologies, coal, oil, and natural gas still accounted for roughly 80% of world primary energy consumption (Energy Institute, 2023). This suggests the scale of the technological lock-in, that whilst scholars already understand the scale and challenge of the climate crisis, lock-in has persisted, and will continue to exist as long as economies are reliant on fossil fuels.

Socio-economic interdependencies are also important in the discussion of lock-in. The economics offered by the fossil fuel sector has wide reaching effects on employment and research. Economic opportunities from the fossil fuel industry motivates a shift in research and academics away from alternative technologies. The entrenched position of the fossil fuel energy system thereby means there would be less available engineers, researchers, and scientists to work on alternative solutions. This presents a co-evolutionary feedback process by which academic research is directed towards these entrenched technologies, motivating further efforts into academic research.

Breaking from path dependencies is particularly important in the context of the energy system at large, especially in economies in the early stages of industrialization. Emerging economies have the opportunity to steer the development of their energy systems, while their industries are relatively nascent (Fouquet, 2016).

This also suggests that while lock-in in fossil fuels has been a historical development that has taken decades to follow, network and lock-in effects of investing in renewables may offer the similar externalities in its development. Investments in the supply chains for renewables will spur developments in new technologies, further incentivizing investment, and further development. Cross-industry interdependencies would also arise, like the case of the automobile, where developments in electric vehicle infrastructure would trigger advancements in grid and charging infrastructure, benefitting the deployment of renewables, and further advancing the use case for electric vehicles. This optimistic virtuous cycle, however, may not yet be at the critical mass needed to develop further dependence on renewable energy systems. Nonetheless, historical lock-in in fossil fuels suggests that future lock-in in alternative technologies may also be possible, given the right scale, time, and advantages.

This discussion on path dependencies offered a theoretical outlook into the nature of the energy system. Lock-in in carbon-based technologies has been a historical precedent and will need considerable effort to disentangle and transition away from (Djelic & Quack, 2007; Fattouh et al., 2019). This also illustrates the case for further investment in renewables, in that each unit of investment in renewables would have sequential networks effects in making them better than their fossil fuel counterparts.

This is by no means a singular and complete discussion of path dependencies and the fossil fuel energy system. What this review presents is a baseline understanding and a recognition that although the existing techno-economic landscape for fossil fuels is positive, that this will not always be the case. Its entrenched position and improved economies of scale has allowed it the leverage of being the dominant form of energy source. Continued investments and policy actions in supporting renewables can help remove the effects of lock-in in the fossil fuel energy system.

3 Case Studies

This section will consider Iceland and Costa Rica, and the development narratives of their renewable energy infrastructures. Although countries are unique, shared lessons can still be derived from the development stories of these countries. These case studies seek to highlight the development journey of these two countries, while the discussion and analysis section will seek to identify the co-benefits and positive externalities from the case studies.

Iceland and Costa Rica were selected as case studies because of the use of 100% renewable electricity, coupled with near universal electricity access. Both countries are exceptional models for the uptake of renewable energy, and thus serve as interesting case studies for the successful use of renewables in the electric grid. The narrative of these two countries shares similarities but are also rooted in fundamentally different approaches. While both countries have abundant renewable energy resources, it should not take away from the success of these countries for investing in their domestic capacity.

It must be mentioned however that these case studies should not act as a model for renewable energy development. Different contexts, resources, and geopolitics all play a role in the development of each country and would thus require different energy policies alongside them. These stories, however, can show the different possibilities and pathways for climate-responsible energy policy. These case studies are not guides, but examples, for the development of renewable energy.

Another caveat to be mentioned is the prevalence of hydropower in these examples. Hydropower is by and far the dominant form of renewable energy today and has been for decades. Thus, examples of countries with a developed market of renewable energy will be strewed with examples of hydropower. This is not to say that hydropower *is* the way to develop an economy with a high allocation of renewables, but rather an admission of the current technology reality. As solar, wind, and other renewable technologies become more cost effective, more and more countries should be able to take advantage of their renewable resources, which was once restricted to countries with large amounts of hydro resources. These case studies should therefore be looked at as examples from the past, with wider future possibilities due to lower costs of other renewable energy technologies.

Finally, it must be noted that renewable energy deployment is only one metric out of many of the contributions of a country to climate action. This study focuses particularly on renewable energy deployment, and potential ways to increase it, but does not advocate that it be the only metric to be used. For example, although hydropower is a low-carbon source of renewable energy, changes in land-use due to upstream flooding or displacement of local communities and wildlife are not reflected in energy mix statistics (Aguiar et al., 2016; VanCleef, 2016). It is therefore important to mention that renewables are but one piece of the puzzle in mitigating the effects of climate change. It is the focus of this paper but should not be the *only* focus for policy makers.

Ultimately, this case study hopes to dispel some misconceptions about renewable energy investment. Richer countries are not necessarily keener to invest in renewables, and neither are renewable resource rich countries. This paper advocates that a more comprehensive approach be taken in assessing renewable energy investment, including potential positive and negative externalities.

3.1 Iceland

Iceland is an island nation in the Atlantic, situated between Norway and Greenland. As of 2021, it has a population of around 370,000 with a GDP per capita of around USD 68,700 (World Bank, n.d.-c). Iceland is consistently ranked near the very top of the human development index – a measure of a country's development based on life expectancy, education and purchasing power of individuals (UN Development Programme, 2022).

However, this was not always the case. Iceland's economy was historically reliant on fishing, and was once one of Europe's poorest economies (Lee & Logadóttir, 2012; Logadóttir, 2015). In the 1960s, fishing accounted for half of Iceland's foreign currency earnings, making fishing its primary source of export revenue. During this time, Iceland's primary energy source were imported fossil fuels (Lee & Logadóttir, 2012; Logadóttir, 2015). In 1970, Iceland's GDP per capita was USD 2576.4 (in 2023 values). This would be on par with 2021 GDP per capita values for Papua New Guinea, Bangladesh, and Ghana USD 2672.9, USD 2457.9, and USD 2363.3 (World Bank, n.d.-d).

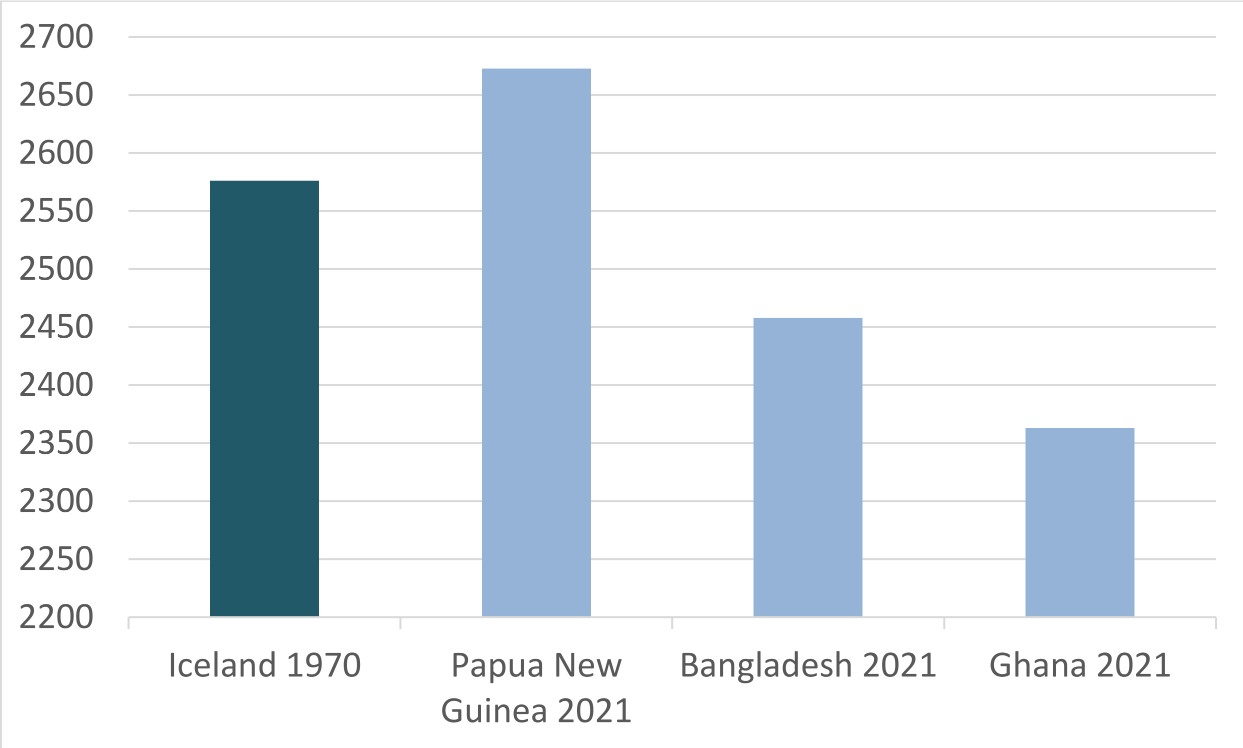


Figure 6 GDP per capita of Iceland in 1970, and countries with similar GDP values in 2021. Source: World Bank Open Data

Renewable energy has a long history in Iceland, with its first hydropower facility coming online in 1904 in Hafnafjörður (Renewable Energy Cluster, n.d.). However, for most of the 20th century, Iceland's economy lacked a strong industrial base, and with an economy dependent on agriculture. Thus, there was little market demand for the development of renewable energy.

The oil crisis of the 1970s was one of the prompts for Iceland to transition their energy policy. Without domestic energy resources, Iceland was particularly vulnerable to price shocks from importing fossil fuels. In 1974, Iceland's minister for energy presented a report on replacing the consumption of imported oil with domestic sources of energy. The report suggested the use of geothermal energy for space heating, thus reducing the need for foreign fossil fuels (Melsted, 2021).

Reykjavík, due to its concentration and availability of resources, had its first urban geothermal utility built by 1944. Other areas of Iceland, due to remoteness or lack of access to geothermal sources, were unsuccessful in transitioning to geothermal sources during this time. Instead, these other townships shifted from coal to oil for residential heating. While both coal and oil are imported fuels for Iceland, oil heating had the benefit of decreased smoke pollution in the household. Oil had thus replaced coal as the primary heating source, where geothermal had earlier been unavailable. The energy crisis of the 1970s, however, became a significant catalyst for the rest of Iceland to transition to geothermal heating as the cost of geothermal heating in Reykjavík was considerably lower than the cost of oil heating in these townships. Along with the prevailing thought that oil prices will not go down, the desire to transition from imported fossil fuels to domestic resources was the driver in motivating Iceland's transition to geothermal heating (Melsted, 2021).

In 2021, more than 90% of residential heating needs are met with geothermal sources, with high temperature heat (>100°C) being used for domestic heating, and lower temperature heat (>30°C) for heating sidewalks and roads (CBC, 2013).

This transition to geothermal sources did not occur only because of the 1970s oil crisis but was borne of a desire for energy independence. The high price of imported oil became a catalyst for transitioning to domestic supplies of energy but was not the sole inspiration. Transitioning to domestic energy supplies had already been considered as early as the 1930s (Melsted, 2021). The oil embargo of the Organization of Arab Petroleum Exporting Countries (OAPEC) in 1973 only sought to accelerate this transition.

However, the transition to geothermal energy did not happen because of a need for climate action, but rather, geothermal was an available domestic resource, which simply happened to also be renewable (Melsted, 2021). Iceland's intentions for its energy transition were fueled less by climate aspirations, but more of seeking energy independence.

In diversifying its economy, Iceland leveraged its renewable resources to attract energy intensive industries to invest in Iceland. Investment in these industries will be coupled with the development of hydropower resources. In 1969, the ISAL Aluminum smelter in Hafnarfjörður began operations using hydropower from the Þjórsá river (*ISAL*, n.d.).

To attract investment, Iceland offered low electricity prices, tax, and investment incentives to aluminum smelters, as well as tariff free access to the rest European market (Lee & Logadóttir, 2012). As aluminum is a very energy intensive process, developing the aluminum industry in Iceland also meant developing an energy industry capable of supplying bountiful, low-cost electricity. Due to the lack of fossil fuel resources in the country, developing a strong domestic energy industry meant tapping into the renewable resources of Iceland (Lee & Logadóttir, 2012). Aluminum was thus the consumer to which renewable energy production would be based on.

Developing these renewable resources did not go unchallenged. Due to its remoteness, Iceland's natural landscapes remained mostly untouched. Building dams and geothermal plants meant developing infrastructure to access these sites and altering the natural landscape. Furthermore, dams and hydroelectric stations can alter the natural flow of rivers and potentially impact the migration patterns of birds and grazing areas for local farmers (Lee & Logadóttir, 2012). Overreliance on hydropower can also lead the electricity grid vulnerable to droughts. Overcoming these challenges was aided by a centralized master plan for energy policy, of which included working groups dedicated to studying the impact of development on wildlife, geological formations, employment, among others (Steingrímsson et al., 2008).

In 2022, the aluminum industry contributed to 23.1% of Iceland's exports, with fishing contributing now only 20.0% and revenue for tourism at 25.6% (Statistics Iceland, n.d.). Iceland has highest energy production capacity per capita at 55,000kWh per year, with almost 66% of this electricity consumed directly by the aluminum industry. For comparison, the EU average is 6,000 kWh per year (Government of Iceland, n.d.; Orkustofnun, 2019). In 2020, more than half of Iceland's exports makes its way to European markets, of which The Netherlands, Spain, and the United Kingdom are its largest buyers (World Integrated Trade Solution, n.d.).

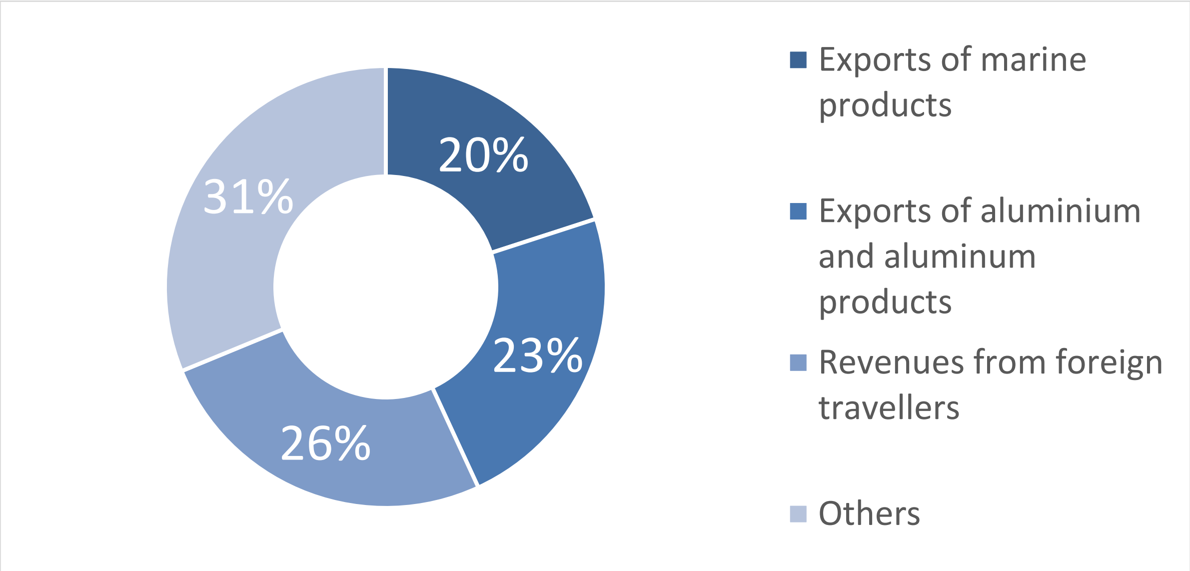


Figure 7 Iceland's 2022 exports, by sector. Source: Statistics Iceland

Iceland's geography grants it bountiful renewable energy resources. Iceland is then able to capitalize on it by developing an energy intensive industry that can help Iceland export some of this renewable electricity through value addition.

Because of the global interest in reducing emissions, aluminum producers in Iceland market the renewable source of their electricity production as a unique selling point. This makes renewable energy not only a source of affordable, and reliable electricity (from the view of the aluminum smelters), but also a unique selling point to their customers. One of the largest aluminum smelters in Iceland specifically markets their aluminum as being low carbon, along with the requisite certificates (Century Aluminum, n.d.; *Nordural*, n.d.).

Renewable energy cannot be singularly attributed for Iceland's development story. The geopolitics of the area, leadership of its people, and market forces during its time have all immeasurably contributed to the success of its economy. However, the story of its renewable energy development can act as an inspiring case study of the potential for renewable energy, outside of the benefits of climate action.

It is important to emphasize that while hydro and geothermal energy sources proved successful for Iceland, this does not indicate that it should be a model to be followed. Rather, Iceland's case can be a useful example of the co-benefits of investing in domestic energy sources. Further, Iceland's case emphasizes that not only wealthy countries can benefit from renewable energy investment, as Iceland itself was a developing country when it exploited its domestic energy sources.

With the continuing trend of decreasing cost of solar panels and wind turbines, more countries should be able to exploit their domestic energy sources. Accompanied with supporting regulatory frameworks and funding schemes, more and more emerging economies should be able to take advantage of their own resources.

3.2 Costa Rica

Costa Rica is a country in Central America, located between Panama and Nicaragua. In 2021, it recorded a population of 5.1 million, with a GDP per capita of USD 12,400 (World Bank, n.d.-b). It is classified as an upper middle-income country, with food and agricultural products as its primary exports. The services sector of Costa Rica makes up 67% of its GDP, away from what once was an agriculturally dominated economy (World Bank, n.d.-d).

Electricity supply in the country has for the longest time historically been dominated by renewables. Hydroelectricity provides most of the country's electricity supply, with other renewables recently contributing more and more to Costa Rica's electricity supply.

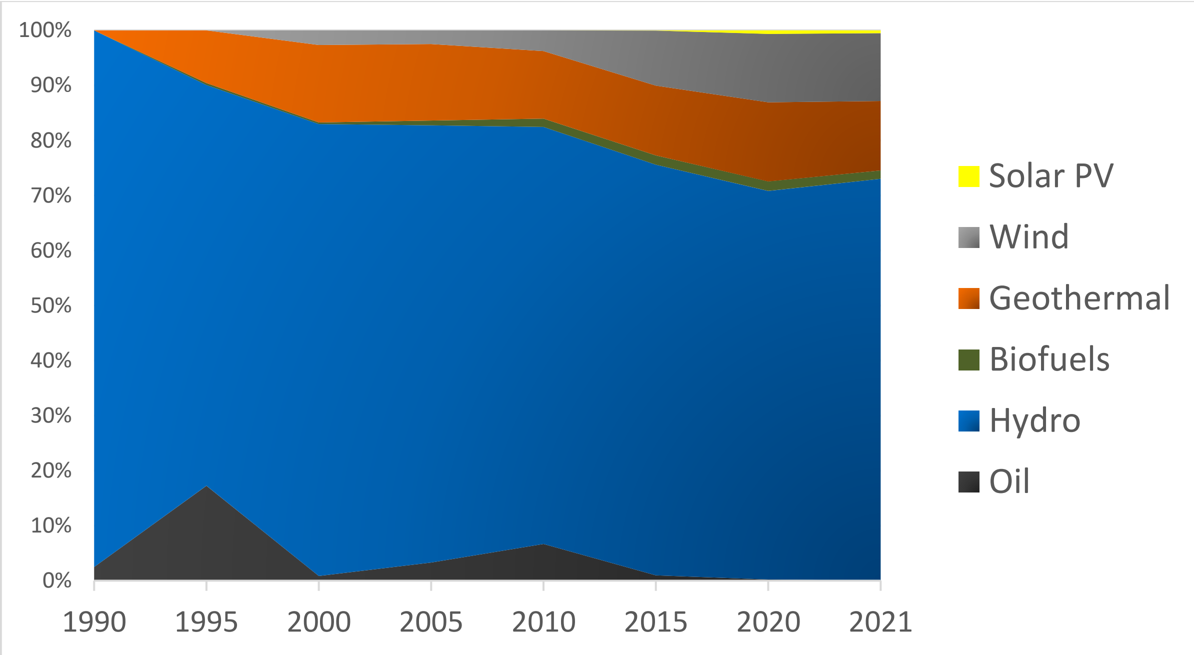


Figure 8 Share of Costa Rica's electricity generation, by technology. Source IEA Electricity Information 2022.

As visualized above, hydropower continues to be the dominant electricity provider, but other forms of renewables are now catching up. Even more impressive with Costa Rica's electricity profile is its high diversity of renewable sources. While hydro plays an extensive role in supplying Costa Rica's electricity, it is far from the only renewable resource it uses. Geothermal sources have supplied a notable portion of Costa Rica's supply from 1995 onwards, and Costa Rica has continued to diversify its electricity mix since.

In the graph below, it can be seen that renewables have made up at least 80% of electricity generation in the country for 30 years, with recent years exceeding 99% of electricity generated by renewables (IEA, n.d., 2023). This is in line with Costa

Rica's National Decarbonization Plan (NDP), a comprehensive commitment to be carbon neutral by 2050 (Government of Costa Rica, 2018; Inter-American Development Bank, 2020).

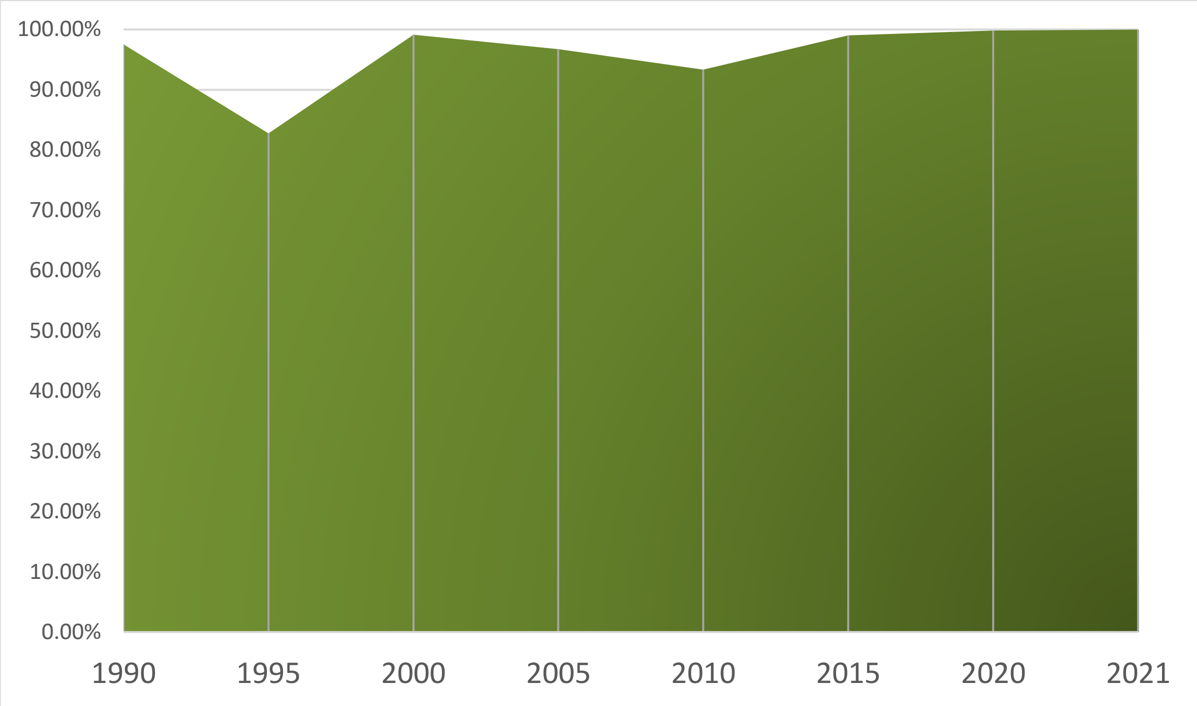


Figure 9 Share of Costa Rica's electricity generation of which are renewable. Source IEA Electricity Information 2022.

An important note to mention is that Costa Rica's electricity and energy consumption look very different. Although electricity generation is laudable, Costa Rica has a long way to go to decarbonize all its energy consumption. The non-renewable part of energy consumption can come from fossil-based transportation, cooking, and industrial processes. Transportation is of particular note, as it emitted the equivalent of 5.7Mt of CO_2 in 2018, equivalent to roughly 40% of Costa Rica's emissions (Groves et al., 2020).

All this is coupled with Costa Rica's financial position. In terms of GDP per capita, it is on par with countries such as Bulgaria and Malaysia, while Costa Rica has significantly lower emissions (World Bank, n.d.-b). In addition, Costa Rica has one of the most developed electricity markets in its region. With this amount of surplus electricity, Costa Rica can not only be self-sufficient in terms of electricity supply (and thus, relative energy independence), it is also able to sell its excess electricity to its neighbors. This electricity export thereby converts its natural resources such as rainfall and geothermal sources into government revenue (IRENA, 2022f).

Costa Rica's unique energy journey can be traced back to the creation of the Costa Rican Institute for Electricity (Instituto Costarricense de Electricidad - ICE). ICE was founded on a grassroots foundation close to civil society, as opposed to U.S. based capitalist interests that preceded it. Alongside abolishing the military, the 1948 Costa Rican civil war paved the creation of the ICE, with the goal of providing sustainable electricity access for all Costa Ricans (Wilde-Ramsing & Potter, 2006). Even in 2021, Costa Rica has the highest rate of citizens with access to electricity across Central America (IRENA, 2022f). More than just developing energy resources, ICE's investments in renewables also led to the development of skills and expertise in operating hydropower facilities in Costa Rica. The development of renewables in Costa Rica is also deeply embedded in the development of Costa Rica and its people.

The development of Costa Rica's energy policy was thus inspired by an aspirational goal of providing equitable, and social access to electricity. In stark contrast to its capitalist predecessor EBASCO (Electric Bond and Share Company), ICE was founded on the principles of social democracy and an interest in harnessing local energy sources. Context is necessary in viewing this journey, as Costa Rica did not only abolish its military in 1948, but also had the goal of providing free healthcare and free education to all its citizens (Chavez, 2023; McDonald, 2014). The embeddedness of the ICE within Costa Rican social democracy has guided it to pursue long term, sustainable, and domestic supplies of electricity (Chavez, 2023; McDonald, 2014; Wilde-Ramsing & Potter, 2006).

Using domestic supplies for energy resources also has the benefit of strengthening local supply chains and skilled labor. Costa Rica's achievement of powering itself using renewable energy is a testament to the skill and expertise of ICE and its management of renewable supplies. In a period where fossil fuel plants were considered "simpler" to operate, the investment required to build labor capital in "complicated" renewables has paid off with the reliable and affordable supply of electricity for Costa Ricans (McDonald, 2014). Investing in domestic resources means developing local skilled labor, which is by itself a co-benefit. Luckily, Costa Rica chose to invest in renewables.

Costa Rica's journey of investing in renewables can be an example for emerging economies around the world for investing in domestic resources. Costa Rica ranks 6th in terms of annual precipitation, yet has a higher percentage of renewable energy than the number one, Colombia (Ritchie et al., 2022; World Bank, n.d.-a). Values for annual precipitation no doubt has an influence in the hydropower potential of a country, nevertheless, the correct policy instruments and incentives play an important part in encouraging hydropower investment. Moreover, Costa Rica achievement stands in comparison to its regional peers, where Costa Rica has the highest electrification rate and also the highest installed capacity of energy generation (IRENA, 2022f). It would thus be unfair to claim that Costa Rica's success lies in its geography, rather, it is through both geography and directed policies that Costa Rica was able to develop its domestic resources.

Further, the rapidly decreasing costs of renewable energy technologies should only encourage other emerging economies to invest in their domestic resources. As hydro has done for Costa Rica, so too can solar and wind technologies do for Africa and Southeast Asia. Other emerging economies may not have the same hydro resources such as Costa Rica, yet have large potentials for solar, wind, and geothermal resources which are becoming only ever more economical.

4 Discussion and Analysis

This section will discuss and review the case studies and their implications. The focus of the case studies has been how well renewables play into the energy system of these countries, while this section will discuss the broader benefits and challenges of renewables. It must be reiterated that renewables are but one part of the bigger picture when it comes to reducing global greenhouse gas emissions. Further, using renewables as a percentage of the energy mix is a singular, quantifiable approach, and is not sufficient for a deeper discussion of the topic.

In discussing the social and economic benefits of renewable energy investment, particular importance has been given to the benefits of investing in domestic capacity. In both the cases of Iceland and Costa Rica, these countries chose to invest in domestic supplies first, and renewable sources second. The decision to invest in renewables was a consequence of their relative abundance and availability, not through the choice of investing in climate action.

For Iceland, the primary driver for its energy transition is to reduce its reliance on imported fossil fuels for heating (Melsted, 2021). Further investments in renewable capacity happened as a byproduct of diversifying its economy. In Costa Rica, its vast hydropower resources was harnessed as part of ICE's goal of providing equitable electricity access to Costa Ricans, as opposed to the capitalist interests of its predecessors (McDonald, 2014; Wilde-Ramsing & Potter, 2006). In both instances, renewables happened to be the domestic resource available. For Costa Rica however, environmental stewardship had a larger role in its choice of investing in renewables than Iceland. Nonetheless, both countries' investment has yielded economic benefits on top of the initial goals of energy independence.

Recognizing this technologically agnostic reality is a stark reminder into how fossil fuels became so widespread – fossil fuels were economically attractive and technologically available, providing a compelling argument for investing in these technologies. However, it is also the reality that fossil fuels have negative externalities associated with their use – land, air, and water pollution, and the emission of greenhouse gases (Allen et al., 2011; Armaroli & Balzani, 2011; Bach, 1981; Barbir et al., 1990; IPCC, 2022). This paper acknowledges that a lot of the benefits arising from renewable energy investment stems from investment in domestic industry and capacity – not only renewable energy per se. Investing in domestic forms of fossil fuels would also yield some of the positive externalities of renewable energy investment, along with the negative externality of greenhouse gas emissions.

The case for renewable energy investment is therefore parallel to the case for investment in domestic energy sources, along with the benefit of climate action. Regardless, there are also unique advantages to investing in renewable energy not available to fossil fuels, which will be covered below. It is an important reality to keep in mind but should not take away from the case of renewable energy investment.

A key limitation of this discussion section is quantitative analyzing the actual economic or social benefits of each renewable energy investment. Because investments are made on a case-to-case basis with a high level of confidentiality, available data for investment decisions are difficult to assess. Further, quantifying the effects and benefits of a project or a policy is far beyond the reach of this work-requiring a deeper understanding of each case study than published material would allow. As such, this section can only assess positive externalities at a high level of each renewable energy project or renewable energy policy. Instead of taking a deep dive into specific projects and specific cases, a larger scope and breadth will thus be taken by the analysis.

Moreover, this analysis relies heavily on already published information and available data. The value provided by this section is in collating and discussing the arguments cited in this work. Additional insights are also offered throughout this section, expanding on the knowledge already made available.

4.1 Social Benefits

4.1.1 Security of Supply

Investment in renewable energy can be seen first and foremost as an investment in domestic energy sources. The importance of a domestic supply of energy cannot be understated, especially in light of Russia's invasion of Ukraine. In 2021, the European Union imported 45% of its natural gas from Russia (IEA, 2022). In September 2022, this number dropped to 8% (European Commission, 2022). This rapid decrease in supply did not only lead to higher prices for gas (up by almost 300% for August), but also reducing natural gas consumption to preserve remaining stock (Cooban, 2022; Wilkes et al., 2022). Rationing of natural gas supplies hurts consumers indirectly through increased energy prices and limits essential inputs to industrial production. In Germany for example, plans to ration natural gas supplies to industry threatened production in a chemical manufacturing facility – potentially causing economic and supply chain issues down the line (Beard, 2022). Gas rationing has the tangible effect of reducing industrial output, and the speculative effect to the perceived vulnerabilities of the industry.

The resulting energy crisis in the EU exposed its overreliance on imported Russian fossil fuels. In May 2022, the EU announced its REPower EU plan, a comprehensive energy strategy with the objective of reducing EU reliance on Russian gas, diversifying energy supply, reducing energy consumption, and investment in domestic renewable resources (European Commission, 2022). This strategy highlights a key benefit of renewables – investment in renewables means an investment in domestic forms of energy.

Although some countries have domestic sources of fossil fuel energy, almost all countries have some quantities of domestic renewable energy. Production of the world's fossil fuels is concentrated among the top few producers, whilst available sources of renewable energy are shared worldwide.

The cases of Costa Rica and Iceland highlight the business case for investing in renewable energy – these are domestic resources available to almost all countries. While historically, hydro and geothermal sources were the most economical forms of renewable energy, the decreasing costs of solar and wind can make investment in these renewable sources available to more countries. As both the cases show, emerging economies can also take advantage of these resources. In Southeast Asia and Central America for example, renewable energy potential for electricity generation far exceeds the energy demand of each region (IRENA, 2022b, 2022f). In ASEAN for example, local renewable sources, when properly implemented, can provide cost-effective alternatives to non-indigenous sources of fossil fuels (IRENA, 2022b). The transition to renewable sources is however, not only in increasing renewable energy production, but also the retirement or conversion of fossil fuel power plants – which entails its own socio-economic costs.

Energy security can be considered as a social co-benefit because of its effect on local energy prices. In Iceland for example, transitioning from imported fossil fuel for heating to geothermal sources for district heating resulted in decreasing and equalizing the cost of heating in the country (Melsted, 2021). Equalizing the cost of heating is a social benefit as it provides equitable access to heating, irrespective of social status. Oil heating outside of Reykjavík for example, would only be accessible to those who could afford it, whilst the rest of the population had to use lesser, potentially more polluting forms of energy for heating. Providing, equitable, available, district heating meant that most people had access to the same quality of heating supply. And at the core of this equitable access to district heating, was domestic energy supplies.

However, having domestic energy resources does not necessarily mean equitable access to energy. Rather, it is the affordable, secure, and available supply of energy – afforded by domestic supplies, instead of buying from the global market, that is key to equitable access to energy.

Melsted (2021) in his paper, acknowledges that “Iceland’s geothermal resources were not simply used because they existed; they were actively developed.” This is an important statement to emphasize in the discussion of domestic energy potential because these energy sources will not become viable by themselves. Policy incentives, skilled labor, financial resources, among others, are needed to explore and plan and build these renewable energy infrastructure. As in the case of REPower EU and Iceland’s own transition, perhaps a catalyst event is needed to push policy towards more independent and local forms of energy.

The importance of having domestic energy sources cannot be understated. Pakistan for example, has incredible resources of renewable energy, yet suffered from rotating blackouts as a result of the 2022 energy crisis (Stapczynski et al., 2022; World Bank, 2020). The price of liquefied natural gas (LNG), the form of gas used for cross-oceanic trade, markedly increased after Russia’s invasion of Ukraine. Because of the EU’s reliance on natural gas and the sudden reduction of its supply, the EU bought global LNG supplies at significantly higher prices. These higher prices resulted in the EU bidding out poorer countries, such as Pakistan, Thailand, Bangladesh for those LNG supplies. Exacerbating the effect of the energy crisis was the relative appreciation of the US dollar, the currency of global LNG trade (Stapczynski et al., 2022). The diversion of global LNG supplies from these emerging economies to the EU underscores the importance of energy security – both for the EU, and for emerging countries such as Pakistan. The EU endured much higher prices for energy and had to ration its existing supplies, Pakistan and Bangladesh suffered rotating blackouts for its schools, hospitals, and homes (DW, 2022; Stapczynski et al., 2022).

This example illustrates the social case for investing in renewables. Not only are renewables cost competitive with fossil fuels (especially in times of inflated fossil fuel prices), but also contribute to the social welfare and security of a country. Although the blackouts in Pakistan and Bangladesh are also systemic national issues related to its electricity grid, the diversion of LNG supplies from these countries could only have contributed to worsening the problem. Each unit of LNG diverted from South Asia represents a unit of time where hospitals had no lights, schools were in the dark, and people struggled to work. This is not to imply that investment in domestic renewable energy will solve these systemic issues, but rather the overreliance on imported fossil fuels underscores these vulnerabilities.

Investment in renewable energy can help alleviate this challenge, and thus be an investment in the social welfare of a country. Diversifying energy supplies through local renewable energy means increased security of supply, and a more resilient electricity grid. In this example, the EU, Pakistan, and Bangladesh would all benefit from increased renewable investment, as less demand for LNG can reduce competition for these limited supplies.

Security of supply also has an apparent political benefit, especially at the level of geopolitical level. A key event that triggered the 1973 oil crisis was the Yom Kippur War of October 1973 – where the Organization of Arab Petroleum Exporting Countries imposed an embargo on the sale of oil, after perceived Western intervention of their invasion (Mitchell, 2010; Myre, 2013; Paust & Blaustein, 1974). A similar case can be found in Russia's invasion of Ukraine, where Russia reduced its exports of gas and oil, seen by some as a response to sanctions imposed upon Russia (Pandey, 2023). In these two historical cases, energy exporting countries leveraged their control over oil and gas supplies as a tool to lobby for their interests. Specifically in the 1973 oil crisis, Mitchell writes that "The Arab producer states were trying to create a linkage, to set up an equation between the price of oil and the policy of the Unites States regarding the Palestine question" (Mitchell, 2010). OAPEC threatened the supply of oil, to force the US (and its allies) to reconsider its position in the war.

Transitioning from a fossil based energy system to a renewables based system reduces the bargaining power of the few oil and gas exporting countries. However, new strategic resources may potentially arise from the energy transition– for example control over lithium supplies for the manufacturing of batteries. Nevertheless, diversifying energy sources through the use of domestic renewable energy can be promising solution towards an independent energy policy.

4.1.2 Liberalized energy access

A secondary co-benefit of renewable energy investment is the benefit of investing in domestic industries. The supply chain for fossil fuels begins at the exploration stage, where companies look for economically viable resources of fossil fuels to be extracted and ends at the point of consumption. Countries which import fossil fuels miss out on the entire upstream supply chain, as they can only participate at the downstream end of import and consumption. In contrast, countries which invest in renewable energy can capture more of the value-adding industries as their facilities have to be built and constructed on the countries themselves. In the case of hydropower facilities, planning, construction, and operation of the hydropower plant must be done at the ground level, benefiting the local economy. This is in stark contrast to the fossil fuel supply chain, where the only potential benefactors are the countries with available fossil fuels.

The supply chain for renewable may also be not wholly domestic. Manufacturing of wind turbines, minerals needed for solar panels, and others, will still be concentrated in some key countries with the competitive advantage. The main distinction is that these supply chains have the potential to be more diverse, whereas the supply chain for fossil fuels will necessarily be restrictive. Barring any new discoveries of oil and gas resources of more economical means of extraction, only a limited few will really benefit from the fossil fuel supply chain. Thus, renewable energy should be seen as a way for countries with limited resources of fossil fuels as an opportunity to take a more assertive position in the energy sector. Unlike fossil fuel exploration, renewable energy manufacturing is not as geographically restrictive – allowing more countries to take part of the upstream supply chain than in the oil and gas industries.

This liberalization of energy access can also be found at the more local level. Whereas previously, the energy generation industry is only accessible to those with large capital, access to renewables can make the cost of entry to energy generation lower (Nicolli & Vona, 2019). Promoting entry to the energy market for smaller generators can be extremely beneficial as it reduces monopolistic influences of the previous energy players and promotes competition. Even more fundamentally, where energy consumers where previously a “captive market” with regards to where they can get electricity, being able to install rooftop solar panels allows consumers an alternative to buying electricity from the grid (Pacudan, 2018).

The lower barrier to entry for renewables versus fossil fuels can be extended even further at a more grassroots level. Providing grid access to remote communities can be expensive and difficult to maintain, especially if these communities are in difficult terrain or on isolated islands. Renewables can offer a cost-effective decentralized solution to providing universal electricity access, as has been made possible in several locations (Bhattacharyya & Ohiare, 2012; Hossain et al., 2015; Nouni et al., 2008; Singal et al., 2007). The fossil fuel solution for providing electricity access to these communities would be through generator sets running on diesel – which would still have to be supplied to maintain a consistent supply of electricity. Renewables on the other hand, can provide an alternative, independent solution for electrifying these communities. Solar panels and the associated battery systems could work in these areas without the need for fuel. Additionally, solar panel systems have very little moving parts when compared to a diesel generator, requiring much less service and maintenance to keep operational. And finally, solar panels are non-polluting, providing a safer and healthier alternative to combustion diesel generators.

Costa Rica’s success in developing its domestic renewable energy sources can be traced to ICE’s embeddedness in Costa Rica’s social democracy (Wilde-Ramsing & Potter, 2006). In Wilde-Ramsing and Potter’s article, they assert that ICE’s connectedness to civil society and the direction set by the government allowed it to have not only some the cheapest electricity prices in the region, but also the highest electricity access rate (2006). Furthermore, they credit ICE with the success to which Costa Rica has invested in renewables, while neighbors in the region rely on fossil fuels.

The ICE was also instrumental in securing the intellectual and technological expertise needed to serve the electric grid. From the strict selection in employment, to the attractive workplace incentives that ICE provided to its employees, was critical in operating, maintaining, and expanding Costa Rica's hydropower fleet (Wilde-Ramsing & Potter, 2006).

Costa Rica illustrates the case for the social dimension when investing in the domestic energy industry. The benefits yielded through the ICE's embeddedness in civil society would not be as pronounced if it had to rely on fossil fuel imports, than through domestic forms of energy. It is precisely through ICE's decision to invest in domestic capacity that these benefits are present. Access to electricity in remote areas for example, is facilitated by small-scale hydro facilities (Richmond-Navarro et al., 2019).

This social dimension is not strictly exclusive to renewable energy, as fossil fuels could also provide the aforementioned benefits, to some extent. The baseline capabilities of coal power plants and the flexibility of oil and gas power plants can offer higher "quality" of electricity, which can be more economical. Quality of electricity is defined as the consistency and reliability of supply of electricity. Solar, wind, and hydro, are all still vulnerable to the changing weather, which can be a challenge to the quality of electricity available. However, the advantage of fossil fuels can hardly be the case for countries which have to import them, as the (affordable) security supply can hardly be guaranteed.

Liberalization of energy access also has significant effects to different social dimensions. While only a limited number of countries have economically viable quantities of fossil fuels, most countries have some availability of renewable energy sources. Transition to renewable energy sources would therefore also translate to a change in geopolitics, changing the relationships between countries reliant on fossil fuel trade (IRENA, 2019). This change in international dynamic also extends to the mining, manufacture, and development of materials and technologies pertinent to the energy transition (Gielen, 2021).

4.2 Economic Benefits

4.2.1 Balance of Trade

As in the example of Iceland, a co-benefit in investing in renewables is the potential to attract investment in renewable based industries. Having a reliable base of renewable electricity provides an incentive to industries targeting to sell in low-carbon markets. Iceland's renewable capacity (and investment incentives) have attracted aluminum smelters to build their facilities in Iceland, and these smelters have in turn marketed their products as low carbon based. This effectively allows Iceland to export its renewable electricity, in a value-adding way. Since Iceland has no connection to the continental European grid, aluminum can be the medium to export their renewable capacity.

Exporting renewable capacity in the form of value-added products boosts the economy of the host country by encouraging long-term investments and the accompanying policies. Countries with large potential for renewable electricity will no doubt benefit from the interest in a low-carbon economy, but how can be manifested in different ways. Countries can either export their resources directly as electricity or develop them further down the value chain. Surplus renewable electricity is a valuable resource and exporting it as electricity or through value-adding commodities can generate revenue for the host country.

Not all countries will be able to have surplus renewable electricity, however. What is available for most countries is the ability to abate the import of foreign energy – which will come with associated costs, through harnessing domestic supplies of energy. This has not always been economically possible due to costs and technological constraints, but the decreasing costs of renewables and access to international funding should make harnessing local energy supplies more economical.

Exporting energy supplies through commodities – such as aluminum, is a co-benefit for the host country as they can capitalize on the build-up of domestic supply chains and labor capital. This can be more beneficial than the outright export of electricity, as the host country gets to retain the skills and assets through the supply chain.

In contrast to fossil fuel supplies, all countries have some amount of renewable energy. Developing these renewable energy supplies is in turn an investment into local supply chains and labor capital. The aggregation of skilled labor can potentially be transferred to adjacent industries (such as manufacturing and engineering services) as a co-benefit. ICE's domestic talent and skills allowed it to steer and grow Costa Rica into the regional leader of renewable energy it is today.

Reducing reliance on imports is also an important part of the balance of trade equation. As illustrated in the discussion of *Security of Supply*, an overreliance on imported fossil fuels can be very expensive in the case of EU, and socially damaging as in the case of Pakistan and Bangladesh. Moreover, reducing imports of fossil fuels can also reduce the stress on countries' foreign reserves, especially in times of crises. Buying imported goods is often denominated in reserve currencies, particularly the US dollar. Diversifying the energy mix through the use of renewable energy would reduce the need to import fossil fuels, reducing the pressure on foreign currency reserves. Sri Lanka's economic crisis had the unfortunate consequence that it could not import fuel for transport, because of the depletion of its foreign currency reserves. Public transport, emergency services, and supplies of food would be severely restricted without access to fuel (Perera, 2022). Investing in renewables (and transitioning to a renewables-based transport, such as electric vehicles or using green gases) can improve the balance of trade, particularly in reducing the reliance on imported energy.

In exporting energy supplies, a similar energy intensive commodity with the potential for export is green hydrogen. Hydrogen as a commodity is already currently used for chemical processes but is currently primarily sourced from natural gas. *Green hydrogen* is the term used to describe hydrogen which is produced using renewable electricity. Countries with high resources renewable electricity are thereby candidates for producing large amounts of green hydrogen in the future (IRENA, 2022a; McKinsey and Company, 2022).

In the case of hydrogen, countries worldwide are looking at the potential to export hydrogen as a commodity. Hydrogen is already being consumed as a feedstock for chemical processes such as fertilizer production or the hydrogenation of food. Electrolysis using renewable electricity is one such pathway to reducing those emissions, as it produces no by-products by itself. Electrolysis splits water molecules into hydrogen and oxygen using electricity, producing no emissions. The demand for hydrogen exists, and there is legislative pressure in reducing emissions. The market for low-carbon hydrogen will therefore exist, and some countries can benefit from this transition by becoming the exporters of this renewable fuel(IRENA, 2022a).

Another economic benefit of renewables exists in the market for carbon emissions trading. Emissions trading markets exist to incentivize companies to reduce their emissions. Companies who wish to meet certain emissions targets, but are unable to do so, can opt to buy carbon credits from companies which have an excess. Companies with high emissions therefore need to pay extra to continue operating, while companies with low emissions generate revenue through the low emissions of their operations. The European Emissions Trading System (ETS) is an example of one such market which operates in the EU (European Commission, n.d.-b). Countries located with a high share of renewables are thus able to benefit indirectly from the ETS, as their industries can earn revenue through renewable energy.

Similarly, the EU proposed carbon border adjustment mechanism (CBAM) aims to put a price on the carbon footprint of imported materials. The CBAM will cover carbon intensive materials such as cement, iron and steel, and fertilizers, with the aim of taxing materials with a high carbon footprint (European Commission, n.d.-a). Such a taxation scheme hopes to incentivize production pathways with lower carbon emissions, thereby benefiting industries which use renewable energy.

These two are, however, examples of legislative pressure instead of pure economic benefit. Nonetheless, legislative pressure was also present in incentivizing renewable energy investment in Costa Rica and Iceland, and only then did positive economic externalities materialize. While these examples of legislation are not by themselves positive externalities of renewable energy investment, these are certainly important in steering the direction of investment. Attracting aluminum industries would have been difficult for Iceland without the associated policy frameworks. Thus, these policy incentives can be part of a wider range of economic incentives for renewable energy investment.

4.2.2 Tourism Growth

An overlooked potential benefit of renewable plants is their benefit to tourism and conservation. Renewable energy sources can sometimes exist in very remote areas, and tapping into those renewable energy sources means building out the supporting infrastructure to reach and construct the power plants, electric grid infrastructure, and access to human capital. This means that to tap into renewable sources in far-away locations, transport infrastructure will be built in order to support those facilities.

A co-benefit of the expansion of transport infrastructure is providing access to more people to what was once a remote location. A beautiful waterfall in the middle of nowhere would continue to be a beautiful waterfall in the middle of nowhere if there were no means to access it. Roads, rail, telecom infrastructure, running water – all these supporting infrastructures that accompany big renewable projects help tourists access these what remote locations.

An example is the Blue Lagoon geothermal spa in Iceland, an offshoot of the nearby Svartsengi Geothermal power plant. The Svartsengi geothermal power plant collects water from geothermal wells underground and passes it through turbines to generate electricity. After passing through the turbines, the water, still at a relatively high temperature, is passed through heat exchangers to provide district heating. The power station generates 75 MW of electricity and 150MW of thermal energy (Verkis, n.d.).

Because of the high mineral content of the water in the geothermal well, reinjection back into the well is not possible. Thus, the effluent brine is made to collect in pools at the surface. The high concentration of silica in the water gives the pools its bluish tint.

In 2017, up to 1.3 million tourists visited the Blue Lagoon, in a year when 2.2 million foreign visitors went into the country (BBC, 2017; Icelandic Tourist Board, 2022). This certainly unique geothermal plant is a key tourist attraction, with an EBITDA (earnings before income taxes, depreciation, and amortization) of 39.6 million euros, and a total tax revenue of 4.6 billion Icelandic Krona in 2018 (Blue Lagoon Iceland, n.d.).

A similar idea was conceived in Norway, where a hydropower plant was built specifically with tourism in mind. The Øvre Forsland power station is located in the North of Norway, designed to be a hydropower plant and a tourist attraction at the same time. The power station is capable of generating 33GWh per year, or the energy needs of 1,700 Norwegian households (Voith, n.d.). The power station not only generates electricity for Norway but can also generate tourist revenue in the local area.

A similar story can be told of the Niagara Parks power station – a hydroelectric power plant in the Niagara River. Of the 14 million tourists who typically visit Niagara Falls every year, 8 million visit the Niagara Park (Leader, 2021). In 2019, the Niagara Parks generated 96 million Canadian Dollars, besides the revenue generated from the different power stations along the river (The Niagara Parks Commission, 2019).

Similar restorations, however, exist elsewhere using fossil fuel power plants. The Battersea Power Station in London for example, was a coal fired power plant operating until 1989, which has now been converted into mixed-use commercial and residential space (Moore, 2022). What is unique however with renewable installations is that these can operate both as tourism sites and power plants at the same time. In the case of the Battersea Power Station, it was preserved because of its cultural significance and heritage to the city of London – less so because of its significance as a power plant. In the cases of Niagara parks and the power station of the Blue Lagoon, part of their touristic significance is the fact that these are existing, operating, renewable power stations. Renewables are non-polluting and are therefore safer to operate alongside crowds and tourists – a quality not available to most coal, gas, or oil power plants. Further, the low-carbon nature of renewables and their location in nature allows them to market themselves as “eco-tourism” destinations, which can be coupled alongside tours of the surrounding nature, hikes, among other outdoor activities, such as the Øvre Forsland power station.

Tourism is a particularly important benefit in renewable energy investment that cannot be overemphasized. When compared to the other cases, fossil fuel power plants will by themselves have similar benefits, especially when relating to cost. However, the unique advantage of renewables when it comes to tourism has very little equivalent when compared to fossil fuel power plants. Fossil fuels by nature are volatile and polluting, making them ill-suited as tourist destinations even at the best conditions.

A caveat that deserves to be mentioned is that tourism can also be a barrier to renewable energy development. Tourism may not always be welcomed, especially if the area in question is of particular importance to the locals. Spiritual, ecological, or cultural heritage may take precedent over developing a natural resource. An example is the hesitance of traditional Japanese hot springs owners to allowing geothermal exploration, as these can compete with their operations (Tabuchi & Lee, 2023).

Costa Rica's investment in renewables and its commitment to environmental stewardship has allowed it to market itself as an eco-tourist destination (Costa Rica Tourism Board, n.d.). Coupled with national policies such as the National Decarbonization Plan, a binding commitment for Costa Rica to be carbon neutral by 2050, and its reforestation initiatives lends it credence as an eco-tourist destination. Its tourist destinations lie mostly in its protected natural parks and biological reserves, but it is difficult to separate its environmental awareness and its renewable resources. It would be inapt for fossil fuel consuming countries for example to market themselves as eco-tourist destinations, if they continue to consume oil and gas.

Tourism accounted for 4.8% of Costa Rica's GDP and employed 170,870 people in 2019. Not all this tourism revenue can be attributed to eco-tourism, however. Nonetheless, its international reputation as an eco-tourist destination is certainly a net benefit for the country's tourism industry.

Similarly, Bhutan, the only carbon negative country in the world, markets itself as an eco-tourist destination. It has strict rules for outsiders to visit the country, along with a "Minimum Daily Package Fee" which covers traveler's stay and tour and a fee for helping fund education and healthcare in the country. 60% of the country is mandated to be covered in forests and hosts several wildlife sanctuaries (National Geographic, 2017; UNDP, 2021).

Costa Rica is a viable candidate for eco-tourism, because of its renewable resources and its commitment to carbon neutrality. It would be insincere if highly polluting countries market themselves as eco-tourist destinations, because of the polluting nature of fossil fuels Thus, eco-tourism exists as an opportunity only available to countries willing to reduce emissions, and in turn, invest in renewables.

4.3 Summary

Renewables are an important part of reducing the greenhouse gas emissions from the energy sector. The story of these two countries should provide an instructive example into how, what, and why countries should expand their renewable energy sources. Accelerating the ambitions of the NDCs should not only rely on the political commitments of countries to climate action, but also in providing a socially and economically attractive case for why these measures should be supported. From this discussion it is evident that renewable energy sources have distinct advantages from fossil fuels, apart from their contribution to emissions reductions.

Most countries have some form of renewable energy, and harnessing these resources can help support domestic industries and skills. Investment in renewable energy sources means taking part in a larger share of the supply chain of the energy sector, for most countries. More than simply an economic case, renewables also offer a social case for the equitable access to electricity, at a local and international level. Accelerating the uptake of renewable energy should therefore not be perceived as imperative because of climate action, but also with its own ensuing benefits.

Summarizing this section, all four dimensions of socio-economic externalities mentioned are fundamentally linked to investment in domestic energy capacity. Harnessing of renewable energy sources means diversifying energy supply, the liberalization of energy access, greater independence in energy policy, and the potential to encourage tourism. These four dimensions of positive externalities were drawn from study of Costa Rica and Iceland's stories of the development of their domestic renewable sources.

5 Conclusions

The present level of ambition in the NDCs is insufficient to meet the goals of the Paris Agreement. The objective of this paper was to investigate whether there are externalities to investing in renewable energy (and thus in reducing emissions), which can make for a more compelling case in their development.

Investment in renewable energy should be seen more than just spending in climate action. Leveraging domestic renewable energy sources can help countries diversify their economy and boost tourism, on top of working towards climate goals. The examples of Iceland and Costa Rica highlight these benefits but are by no means the only examples of the co-benefits of renewable energy investment. In addition to the economic benefits, renewable energy investment has further social and geopolitical benefits that have only been touched on by this research.

The case studies show that in both cases, Iceland and Costa Rica invested in renewables, because these were the best available domestic energy resources. This decision to invest in domestic capacity paved the way for the co-benefits such as diversifying their economies, boosting skilled labor, and promoting tourism. All countries have some form of renewable capacity, and thus a potential to invest in domestic energy production.

It is important to recognize that the externalities mentioned here fundamentally arise from investment in domestic capacity. While renewable energy has the distinct advantage of reducing emissions, investment in domestic fossil fuel energy can also, to some extent, yield some of the aforementioned benefits. However, the case for renewables should still be apparent, especially in the increasing cost-competitiveness of renewables illustrated in the literature review.

Further research into the co-benefits of renewable energy investment can focus on getting deeper quantitative and analytical analysis of the benefits. Limited quantitative analysis was possible due to restrictions in data availability, and future research can benefit by proving a more direct causal relationship between the co-benefits. Iceland and Costa Rica are two examples of countries with a high mix of renewables, but other countries and their development journey can also be highlighted.

Future work into developing a deeper analysis into the mentioned co-benefits would allow for a more thorough comparison when comparing renewable and fossil energy investments. Although this paper argues that domestic renewable energy investment has significant benefits, it also recognizes that some of these benefits align with an investment in domestic fossil fuels as well. Further investigating the differences between the benefits of these two domestic investment methods would make an invaluable contribution to extending the conclusions provided by this work. Regardless, because of the widespread accessibility of renewables and its increasing cost-competitiveness, the externalities mentioned in this discussion should only grow wider in its scope and coverage.

Ultimately, the economics of renewables is the main determinant in their development, but these examples should stress the additional positive externalities of renewable energy investment. Further, investment in renewables should also be seen as an opportunity to transition to a more equitable energy future. Democratizing access to energy, whether through distributed means of generation or expanding rural electricity access, should be seen as key social benefits exclusively possible through the use of renewable energy.

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