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International Tourism in the Arctic under COVID-19: A Telecoupling Analysis of Iceland

Michele Remer and Jianguo Liu *

Center for Systems Integration and Sustainability, Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI 48823, USA
* Correspondence: liuji@msu.edu

Abstract: During the COVID-19 pandemic, tourism slowed down as the world went into lockdown. This pause in tourism provides a unique opportunity to analyze the environmental and socioeconomic effects of tourism by comparing tourism participation levels before, during, and after the pandemic restrictions. We examined tourism in Iceland, an island nation in the Arctic where international tourists vastly outnumber residents. Specifically, we systematically analyzed the materials, energy, tourist, and information flows, as well as the causes, effects, and agents of tourism in Iceland using the framework of telecoupling (human-nature interactions over distances). Results show that the U.S., U.K., and Nordic countries sent the highest numbers of tourists to Iceland. Flows of tourists to Iceland were tracked based on international flights and cruise ships, with Iceland's tourism industry returning close to pre-pandemic levels in 2022 for air arrivals, while cruise ship tourism was slower in returning to pre-pandemic levels. Agents in the Icelandic tourism industry include government entities, local businesses, tour operators, and many others. There are diverse causes for tourism in Iceland, such as the demand for nature-based tourism and a cooler climate. International tourism in Iceland had both substantial environmental effects (CO_2 emissions, damage to sensitive areas, etc.) and socioeconomic effects (e.g., increases in GDP and jobs). Many effects also spillover to the rest of the world as increases in CO_2 emissions contribute to global climate change. Tourism is also expected to continue increasing after Iceland's 2022 marketing launch of "Iceland Together in Progress." Since Iceland has had such a strong tourism rebound, other countries around the world (especially other Arctic countries) that are looking to increase their tourism can gain insights from Iceland. However, it is important to make tourism more sustainable (e.g., reduction in CO_2 emissions).

Keywords: coupled human and natural systems; tourism; coronavirus pandemic; telecoupling; sustainability

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1. Introduction

In today's globalized world, different areas of the world are more connected to each other than ever [1]. One of the major interconnections is tourism. International tourism is expected to send 1.8 billion people to other countries by 2030 and is responsible for 10% of the global GDP [2]. However, even though tourism provides travelers the chance to experience new cultures and see new places, while employing 10% of the workforce worldwide, it is susceptible to climate change and needs to meet the United Nations' Sustainable Development Goals for 2030 [2]. Other than the threat to tourism itself from climate change due to extreme weather events, insurance costs, and biodiversity losses [2], among others, tourism can exacerbate the problem of climate change through the use of fossil fuels to reach a destination, as well as damaging the sensitive ecological areas that are visited [2–4].

Tourism is very complex because it has many different variables, such as transportation, accommodation, tour operators, and different business types [5], and those variables become more numerous the farther away tourists travel from their home countries. Some

of these variables were taken out of the equation during the COVID-19 pandemic. Since the pandemic caused most of the world to be on lockdown and remain in their homes, the tourism industry was impacted due to the increased risk of infection for all modes of transport. In particular, cruise shipping and international flights were virtually nonexistent during the first part of 2020. Aviation for commercial flights decreased by 60% in 2020 [6]. During the first seven months of 2020, flight emissions decreased by 46.7% [7]. Cruise ships returned home because of the high rate of infection found on cruise ships. This virtually shut down international tourism and depending on the restrictions within each country and within regions, there was also less domestic tourism. In this paper, we chose Arctic tourism, and more specifically, Icelandic tourism, to illustrate the complexity of tourism in the context of the global pandemic.

1.1. Background of Arctic Tourism and Icelandic Tourism

Arctic tourism has existed since the 1800s, when the first guidebooks were published, with John Murray's "Handbook for Travellers" guidebook in 1836 promoting cruise tourism [8,9]. By the late 1800s, Arctic tourism was underway, and tour operators started to advertise more. The first pleasure cruise appeared in 1869 [9]. However, tourism in the Arctic has been limited historically due to sea ice cover and safety. Before the 1990s, most ships were not built to withstand the ice and harsh conditions that occurred in the Arctic, and "expedition cruising" only came about in the 1950s [9]. Once the Soviet Union collapsed, however, many more ice-breaking ships that were used for military expansion could be used for tourism [8]. Since then, the global cruise market has had an annual growth rate of approximately 7% [10]. This includes 13.45 million passengers who cruised in 2009, even after the economic crisis of 2008 [11]. In addition to access to the Arctic through boats, the commercialization of air travel opened remote areas of the Arctic to more tourists.

Most Arctic tourism is currently centered on what is called Last Chance Tourism (LCT) [12]. Due to climate change and Arctic amplification, many places in the Arctic are available for more visitors to sail through due to a reduction in sea ice cover. This has led to ecological concerns not only for cruise ship tourism but also for trade and shipping routes [13,14]. The current composition of oceanic life is also likely to change as sea ice melts because North Pacific lineages of mollusks will likely migrate once the ocean warms, causing a chain reaction in Arctic oceanic ecosystems [15]. Current climate models are predicting that the thinning of sea ice could occur in the Arctic Ocean by 2050 or earlier. These changes in the ocean's smallest creatures will trickle up to the largest wildlife that most tourists are seeking out in the Arctic, which include 11 Arctic mammals (seals, walruses, polar bears, etc.) as well as sea birds [12]. This means that many tourists in the future will have to go further into the Arctic to observe the desired wildlife, which will lead them further away from safety infrastructure in the case of an emergency [12].

Iceland was chosen out of all other Arctic countries for this study because it has only recently started to increase the number of visitors [16], so it can serve as an example of how tourism impacts a less populated area, as well as how the pandemic impacted the total number of visitors. Since Iceland is an island located on the Mid-Atlantic ridge, there are large amounts of volcanic and geothermal activity, which attracts both tourists and energy investors to travel to the country [17]. Today, Iceland has a total population of approximately 366,000 people, as of 2020, meaning that the number of tourists that visit each year greatly outnumbers the population of Iceland [18]. Tourists in Iceland are also concentrated along the coasts of the island, as that is where most residents have settled [17].

International tourists to Iceland need to travel either by air or boat. In a 2012 Oxford Economics study, Iceland's aviation activities were found to be of greater importance than anywhere else in the world [19]. Indeed, aviation by itself contributed 6.6% to the GDP and accounted for 5.5% of the workforce. Tourism in Iceland causes this to rise to 12.9% of the GDP and 12.3% of the workforce [19]. Domestic flights for native Icelanders have also been the preferred method of travel since World War II [19]. By 2000, many more civilians lived

in urban centers in Iceland (90%) compared to the past century, which had been dominated by agriculture and rural areas, leading to more domestic flights [19]. International flights first began in 1945, with transatlantic flights following in 1955 [5]. Other than tourism, Iceland has identified its most important sectors to be algae culture, data centers, and life sciences [20].

1.2. Motivations

While there have been papers on international tourism in Iceland, they have focused on tourism impacts, such as overtourism [5,12]. There have also been many papers analyzing telecouplings involving tourism [21–24], but this paper will be one of the first to focus on the impacts of the COVID-19 pandemic, with data available after the end of most countries' lockdowns. In addition, the impacts of COVID-19 on tourism are constantly shifting, as certain countries have re-opened their borders for international travel at different times or have continued tightening restrictions when cases spike. In the case of Iceland, COVID-19 restrictions have all been lifted as of February 2022, including for visitors who are unvaccinated [25]. This allows for the unique opportunity to study how the pandemic affected tourism levels before, during, and after lockdown using the telecoupling framework.

1.3. Application of Telecoupling Framework

The framework of telecoupling (human-nature interactions over distances) was first introduced in the literature in 2013 [1]. The telecoupling framework reflects the complex interactions that are seen in a globalized world and helps to quantify and define them. To do so, the telecoupling framework consists of five major components (systems, flows, agents, causes, and effects) to document how these telecoupled interactions occur. Systems include sending, receiving, and spillover systems. Sending systems are places that send people or things (e.g., goods, information) out, while receiving systems are places that receive those people or things from the sending systems. Spillover systems are those that result from interactions between sending and receiving systems, are often ignored, and are the most difficult to quantify [23]. Flows include the movement of material, energy, people, goods, and information. Agents are any entities that cause movements of flows to occur and are the orchestrators behind telecouplings, meaning that they can control if a telecoupling forms or if it ends. Causes of telecouplings are any factors that bring about the establishment of a telecoupling and induce feedback mechanisms. The causes are also fluid and will typically change which telecoupling framework is taken into consideration, and causes can be political, ecological, cultural, and more in nature. Effects are the outcomes of each telecoupling and can either be environmental or socioeconomic. However, even though these two types of effects are separated into distinct categories, it should be noted that they are strongly connected to each other [1]. Using the telecoupling framework, the pandemic's impact on tourism can be systematically and comprehensively studied. The telecoupling framework can also be used to compare to other models in different fields, such as the five forces in competitive markets first introduced by Michael Porter in 1979 [26].

1.4. Objectives

Tourism can be treated as a telecoupling process as it involves human-nature interactions over distances. Many studies on tourism telecouplings have been completed, but scientific understanding of this topic is still very limited because of the array of factors that are related to tourism. For instance, if we trace the start of a tourist's journey from beginning to end, we can see that a tourist's impact is not only on the visited country (the receiving system), but also on the rest of the world because of the emissions generated from traveling to or within the country, as well as where the food in-country is sourced and the amount of support that tourists provide to the local economy.

For the purposes of this paper, we will only be looking at one country (Iceland) for visiting tourists, to simplify the process and go deeper into the telecoupling components.

Iceland was also chosen for the high amount of data collected by its Tourist Board. Therefore, Iceland is the receiving system with other countries whose citizens visited Iceland as the sending system. The pandemic timeframe for this study will center around when the majority of the world was on lockdown and when Iceland reopened its borders to international tourism. This means that, before the COVID-19 pandemic will be considered prior to February 2020, during, from February 2020 to 2022, and after, is February 2022. The objectives of this study are (1) to identify the flows, agents, causes, and effects of the receiving system (Iceland) and sending systems (other countries sending tourists to Iceland), (2) to analyze how the COVID-19 pandemic affected these systems, and (3) to identify potential spillover systems from this telecoupling.

2. Materials and Methods

For the sending systems, countries were chosen based on the number of tourists they sent to Iceland and were considered target markets by the Icelandic Tourist Board in their visitor surveys in 2018. Spillover systems include countries affected by travel via sea or air. All references were selected based on their relevance to tourism in Iceland and were screened based on their applicability to the research objectives. This research was designed based on a previous study considering overtourism in Iceland [5], but our study expands on this study under the telecoupling framework and compares tourism before, during, and after the COVID-19 pandemic.

To simulate a tourist's search for information on Iceland, popular tourist websites were scanned by selecting the first two from each Google search ("best Iceland cruises", "best car rental website", "Icelandic cuisine", "places to visit in Iceland", "what to see on the Golden Circle", and "Ring Road"). These phrases were generated based on the most popular destinations and reasons to visit Iceland, and websites were chosen since 59.6% of tourists used these as their main source of information [27]. Since tourism in Iceland relies on travel by either air or boat, transportation data was selected to be analyzed and the spillover effects for transportation were considered. For the agent component, organizations were chosen based on their interactions or control over the movement of tourists; only those related to the Icelandic government branches or businesses involved in tourism, the transport of tourists, and the stopping of tourism during the pandemic were included for the sake of space. For all numbers and other data, only national or international organization data collections were used. Data was sourced from the Icelandic Tourist Board, the International Civilian Aviation Organization (ICAO), and the Lexus Nexus Database. The data was compiled using Excel analytics based on the datasets mentioned above.

3. Results

3.1. Telecoupled systems

The sending systems for this telecoupling were the countries with the most visitors, which included the United States, Canada, Nordic countries, the United Kingdom, Germany, France, Poland, and China (Table 1). The Nordic countries include Denmark, Sweden, Norway, and Finland. These countries were also target markets for Iceland's tourist surveys in 2018 [27]. The number of visitors from the United States increased steadily from 2015 onward and was the fastest country to rebound after the initial isolation period in 2020 due to the pandemic (Figure 1). China still has not rebounded due to ongoing COVID-19 travel restrictions. The receiving system is Iceland itself. Therefore, Iceland's respective tourist spots, including the infrastructure to receive tourists (public transportation, hotels, alternate housing, roads, gas stations, etc.), are part of the receiving system. In addition, the search and rescue (SAR) team for Iceland is part of both the receiving and spillover systems for remote areas on land (receiving) and in the water surrounding Iceland where cruise ships sail (spillover).

Table 1. Summary of the five telecoupling components of tourism in Iceland [1].

Components	Sub-Components	Examples
Systems	Sending	United States, Canada, Nordic countries, United Kingdom, Germany, France, China
	Receiving	Iceland
	Spillover	Layover flight locations Cruise ship departure ports after flights Search and rescue (SAR) teams for cruise ships
Flows	Material/Energy	Tourists Money Fuel imports for transportation and industry Greenhouse gas emissions
	Information	Cruise ship websites Magazines and other advertisements Governmental marketing campaigns
Agents		Tourists Governments Tour companies
Causes	Economic Political Technological Cultural Environmental	Tourist demand for nature-based tourism Improve economy through foreign investment Model clean energy for other countries Icelandic cuisine Cooler climate
Effects	Environmental	CO_2 and hydrogen sulfide emissions Damage to sensitive areas Conversion of habitat/wilderness to industry Unknown spillover effects
	Socioeconomic	Reduced housing for local people Increased need for safe cruising infrastructure Higher GDP Increased infrastructure demand Increase in jobs

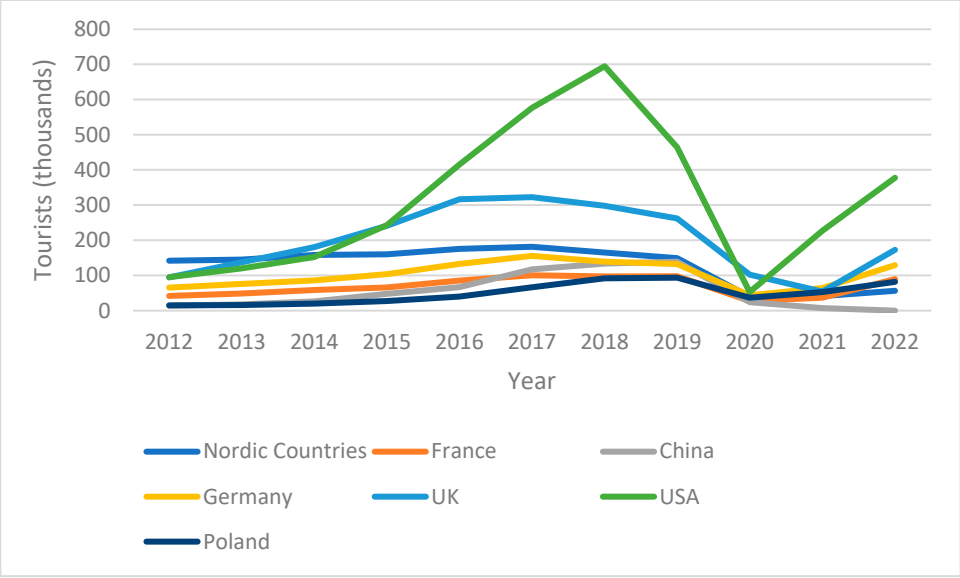

Figure 1. Countries with the most visitors to Iceland from 2012 to 2022 went to Keflavik airport. Data from 2022 is only available through September, and no data is available for China. Nordic countries data for 2022 is only available from Denmark.

Spillover Systems

One thing to note is that even though Iceland has its own SAR teams, the Icelandic Coast Guard is responsible for 1.9 million km^2 around the island [28]. However, since many cruise ships do not originate in Iceland but instead start in Argentina, as in the case of the most popular cruise ship, spillover systems can be generated from the SAR teams that are ready to serve cruise ships in the case of an emergency. This means that the spillover systems depend on the route of the cruise ship as well as the amount of funding that a given country has for its SAR teams located near a cruise ship traveling to/from Iceland.

Other spillover systems include layovers in other countries for flights. Since determining the total number of layover flights is outside the scope of this paper due to data constraints, a few examples are given here. One example from before the pandemic is that in 2018, there were 695,000 U.S. visitors to Iceland [27]. Nine percent of these visitors were from California [29], which does not provide any direct flights to Iceland, so these tourists had at least one layover flight.

Another spillover system includes flights to the country where the cruise is departing from. The most popular cruise ship to Iceland is the Ocean Diamond, which has had 499 total arrivals since 2015, the first year it started sailing to Iceland [30]. The Ocean Diamond typically departs from Ushuaia, Argentina [31], which means that most people will need to fly from their home country to the cruise ship port [31,32]. Since the highest volume of cruise passengers in 2019 came from North American (15.4 million) and Western European (7.2 million) areas [33], the midpoint [34,35] of each of these continental areas was found and averaged to be 12,400 km (France to Ushuaia, Argentina [36]; North Dakota to Ushuaia, Argentina [37]). In this case, flying out of New York (JFK) would be approximately 10,500 km on a direct flight to Ushuaia and has an extra 482 km added with a layover in Buenos Aires, as there are no direct flights [38].

3.2. Flows

There are several major types of flows: movement of tourists, material and energy, and information. Material and energy flows that occur within this telecoupled system include cars and greenhouse gas emissions involved in transportation. Information flows include the movement of money from tourists to Iceland and information on cruise ship websites, other tourist websites, blogs, and social media posts, along with advertisements from Iceland itself and other magazines.

3.2.1. Flows of Tourists

Tourists from the United States made up the majority (30%) of visitors to Iceland in 2018, with 695,000 visitors in total (Figure 2) [27]. This was followed by 298,000 visitors from the United Kingdom in 2018, which equaled approximately 13% of all foreign visitors. Nordic visitors were third in total foreign visitors with 7% and included Sweden, Denmark, Norway, and Finland. The rest of the countries with visitors to Iceland in 2018 were all under 7%. In the latest International Visitors Survey in 2016, 90.9% of respondents were there for vacation or holiday and the next 5.9% were there for a leisure-related event [27].

In Iceland, tracing the flow of tourists via air is easier than in other countries, as almost all international travelers fly into Keflavik Airport [39]. For example, in 2021, there were over 680,000 passengers that went to Keflavik, and only 109 went to other airports. In 2018, the peak tourism year, there were 2.3 million visitors that flew to Keflavik Airport, while only 7000 flew into other airports [39]. Keflavik is approximately 50 km away from Reykjavík, the capital city of Iceland, which is the most popular tourist spot to visit in Iceland. In 2009, before the peak of tourism in Iceland, there were only eleven airlines at the airport [19], and this number increased to thirty by 2018 [5].

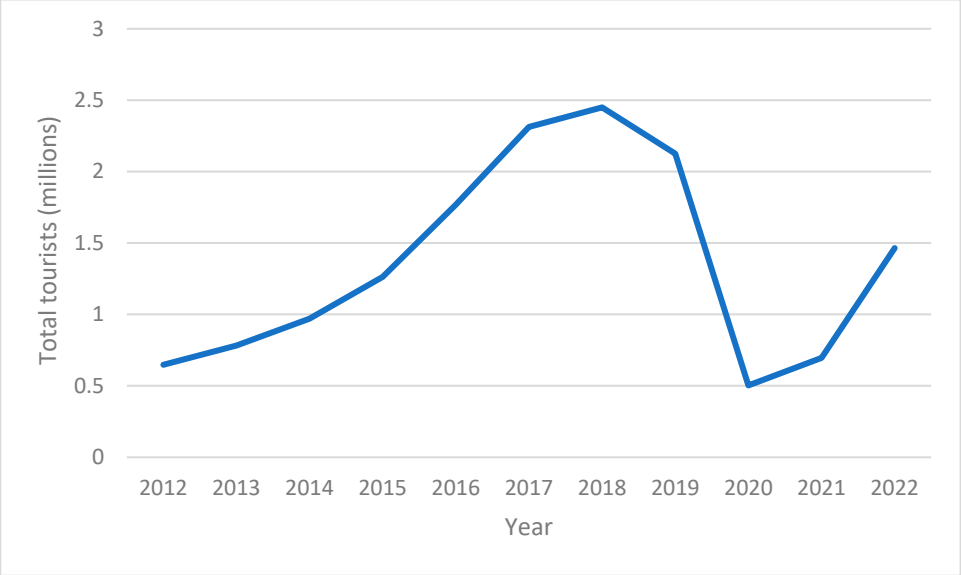

Figure 2. Changes in total number of tourists to Iceland over time. Data for 2022 is from September 2021 to August 2022.

The peak year for cruises in Iceland was 2019, the year before the pandemic started (Figure 3). During that cruise season, there were 516,200 passengers and 239,700 crew members, so a total of 755,900 people were moving through Iceland's ports in 2019. The Ocean Diamond was the cruise ship that docked the most in Iceland, with 125 total stops, followed by Le Champlain with 79 stops. It is important to note that this data was dependent on ships having their AIS (Automatic Identification System) turned on [30]. Iceland cruise ship tours are also available now for 2022. Most of the cruise shipping websites for Iceland cruises advertise based on the picturesque views in Iceland [27].

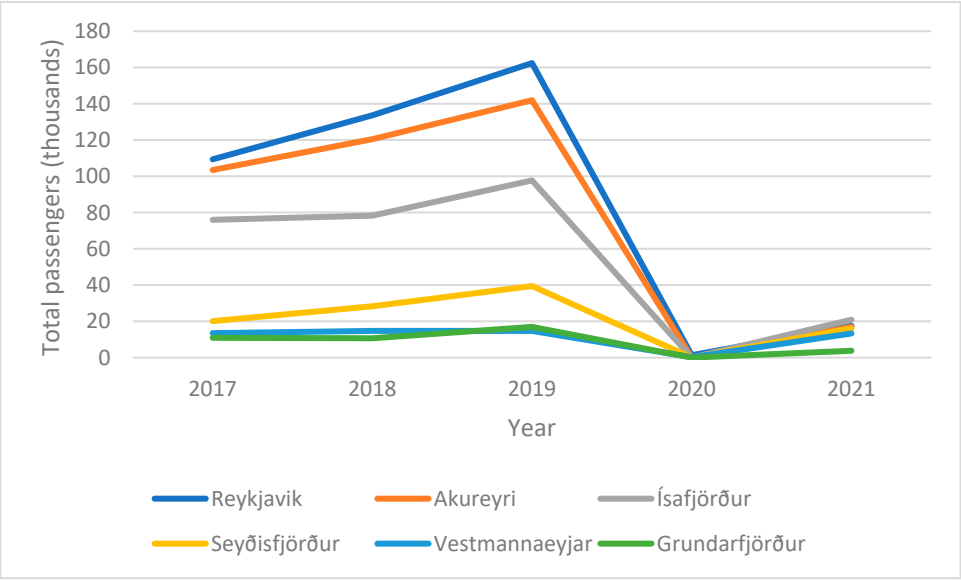

Figure 3. Distribution of cruise ship passengers arriving at the top six Icelandic harbors from 2017 to 2021 (no data available for 2022 yet). Data sourced from EMSA's SafeSeaNet is dependent on the AIS equipment being on and working.

Another important flow for this telecoupling was the transportation of tourists while they were in the country. Almost all tourists visited Reykjavík (95%), and 88.7% stayed overnight in Reykjavík. These high numbers were due to the fact that Reykjavík is the

capital, is near the only international airport in Iceland, and is a strong representation of the culture of the country [27]. Fifty-five percent of respondents also stayed overnight in the southern part of Iceland, which is closest to Reykjavík, and 47.6% stayed in the north. To travel to these different points around Iceland, most visitors to the country rented a car to navigate around the country, except for the United Kingdom. For the U.K., only 38% of visitors rented a car, with 59% of visitors going on an organized tour [27].

Depending on the length of stay, there are a few different routes that have been the most popular for tourists with rental cars [27]. For a shorter route, visitors can drive the Golden Circle, which includes Þingvellir (Thingvellir) National Park, Geysir (a geothermal area), and the Gulfoss waterfall (Figure 4). In 2018, 56.8% of tourists visited Þingvellir and 62.6% visited Geysir and Gulfoss, which were the two most popular destinations outside Reykjavík [27]. In total, the Golden Circle is approximately 230 km long [40].

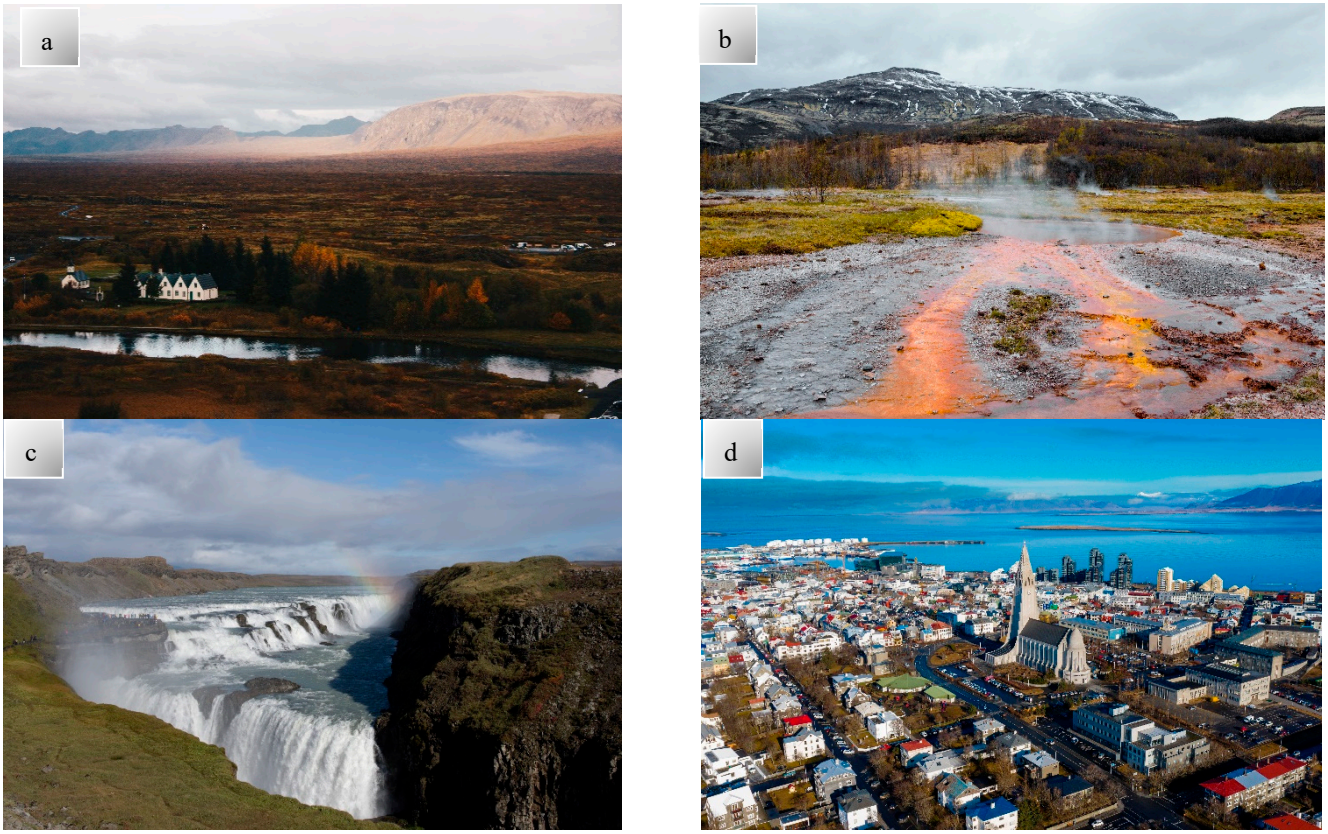

Figure 4. Popular tourist sites along the Golden Circle road: (**a**) Þingvellir National Park, (**b**) Geysir, and (**c**) Gulfoss, which are all located outside the capital city of Reykjavík (**d**). Photos by Ruslan Valeev, Gulfside Mike, Job Savelsberg, and Einar Reynis, respectively, on Unsplash.

In addition to the popular tourist sites along the Golden Circle, Iceland has another popular road called the Ring Road, or Route 1. This route spans almost the entire country and is 1330 km long, which does not include the Golden Circle [40]. Visitors can go off to the Golden Circle and then return to the Ring Road before going to Reykjavík [41]. Some of the most popular sites are on the Ring Road, indicating that the majority of tourists drove at least part of the way to visit these areas. For example, 46.2% of visitors in 2016 went to Akureyri in West Fjords, 45.3% visited Mývatn, and 40.1% visited Ásbyrgi/Dettifoss, with the latter two being located in the north [27]. In the eastern part of the country, 50.2% visited Jökulsárlón, 46.4% visited Skaftafell, 56.6% visited Vik, and 48.6% visited Skógar to see the Skogafoss waterfall [27]. These tourist sites were impacted by the COVID-19 pandemic, and the regulations surrounding the sites before, during, and after the pandemic are shown in Table 2.

Table 2. COVID-19 rules for tourist spots open before, during, and after the pandemic restrictions. The first Yes/No responses answer the following question: was the tourist spot open and the second answers the following question: are masks required?

Tourist Spots	Before	During	After
Reykjavík	Yes, No	No, Yes	Yes, Recommended
Þingvellir (Thingvellir) National Park	Yes, No	No, Yes	Yes, No
Geysir	Yes, No	No, Yes	Yes, No
Gulfoss	Yes, No	No, Yes	Yes, No
Akureyri	Yes, No	No, Yes	Yes, No
Mývatn	Yes, No	No, Yes	Yes, No
Ásbyrgi/Dettifoss	Yes, No	No, Yes	Yes, No
Jökulsárlón	Yes, No	No, Yes	Yes, No
Skaftafell	Yes, No	No, Yes	Yes, No
Vik	Yes, No	No, Yes	Yes, No
Skógar	Yes, No	No, Yes	Yes, No

3.2.2. Flows of Material and Energy

The COVID-19 pandemic impacted the worldwide rental car market, causing Iceland to have a shortage because Iceland imports its rental cars from other countries [42]. In 2019, 24,000 rental cars were being leased due to higher demand, but in 2020, car rental companies were forced to sell many cars, reducing the number to 16,000 cars [43]. Shortages of semiconductors have led to fewer cars on the market, which means that there are fewer cars available to rent [44]. Semiconductor shortages are also anticipated to continue until 2023 because of pandemic shutdown effects, with the market expected to increase by 14% in 2022 and 5% in 2023 [45]. Due to the pandemic, many travelers stopped using public transportation and had to rely on private cars to reduce the spread of COVID-19 [46]. Unfortunately, data on how many travelers are using rental cars was last updated in 2018, so the number of tourists renting cars in 2022 is not known. The number of tourists has increased by 398% in 2022 from 2021, after decreasing by 42% and 78% in the previous two years [39].

Another aspect of the transport sector in Iceland is that the country does not produce any of its own fossil fuels, as it transitioned to geothermal, hydroelectric, and renewable sources in the 1970s [47]. Due to this, tourists generate fewer carbon emissions in their accommodations in Iceland than they do in their home country, as 85–90% of Iceland's houses are heated with geothermal energy and the remaining are heated with renewable electricity [47,48]. Even though geothermal energy and hydroelectric energy are much cleaner than conventional oil-based fuels, ecological consequences can still emerge from their production as more dams need to be built and wilderness areas are turned into geothermal plants [17]. However, because Iceland does not produce any fossil fuels, it has to import all of the fossil fuels that it needs, which are mainly for transportation (fishing boats, tractors, public transport, gas-powered cars, and aviation) [49]. The top five countries that Iceland imports fuel from are Norway, the United States, Denmark, the United Kingdom, and the Netherlands (Table 3) [50]. Due to the increase in vehicles per person and their size, road transport emissions have increased by 39% since 1990, despite low GHG emissions from the energy supply system [17,51].

3.2.3. Information Flows

In 2016, most visitors (59.6%) saw or heard about Iceland as a travel destination from the internet, which includes websites, blogs, and social media. This was followed by 23.9% from magazines and 21.1% from television [27]. Since 95% of tourists visit Reykjavík, there have been over 100,000 mentions of it in web-based publications, newspapers, and blogs from 2000 to 2022. The majority of these (69,000) took place from 2016 to 2021. For Geysir/Gulfoss, the second most popular attraction with 62.6% of tourists visiting, there

was a spike in publications from 2016 to 2019 (1750) out of a total of 4600 from 2000 to 2022 [52].

Table 3. Iceland Fuel Imports for 2019. Source: United Nations Commodity Trade Statistics.

Iceland Partner Name	Import (USD Thousand)	Import Product Share
Norway	$349,633.13	46.95
United States	$212,275.13	37.81
Denmark	$67,421.87	15.52
United Kingdom	$22,147.83	5.34
Netherlands	$21,145.64	4.64
Germany	$18,003.04	3.3
Spain	$15,901.68	12.39
Sweden	$15,714.76	5.58
Canada	$15,608.04	25.57
India	$15,150.34	22.93
France	$7471.05	4.74
Poland	$5204.85	2.65
Belgium	$5012.96	5.55
Faeroe Islands	$4139.48	16.28
Finland	$3434.90	4.78

The government, along with tourism and industry organizations, banded together in 2010 after the eruption of a volcano, Eyjafjallajökull, in April of 2010 [5,53]. This led to ash spreading across the Atlantic and over Europe, causing a week-long shutdown of commercial flights and triggering large economic losses [53]. Due to this, the promotional campaign "Inspired by Iceland" was born to increase tourism and revive Iceland's economy [5]. As a result, more information was flowing to the rest of the world about the natural sites to visit in Iceland, causing an increase from 11 airlines in 2009 to 30 in 2018 [5]. From 2010 to 2015, there were over 18,000 news articles (newspapers, press releases, web-based publications, magazines and journals, and blogs) with Eyjafjallajökull in them, but this number dropped to 5583 from 2015 to 2022 [54]. Prior to the eruption, there were only 25 mentions of the volcano in the news [55]. This change is captured in the high number of magazines, journals, and blog posts mentioning Eyjafjallajökull in both 2010 and 2014 (Figure 5a,b).

After this promotional campaign, Iceland first hit over a million visitors in 2014 and peaked at 2.48 million visitors in 2018. Even though this seems to be a small number of visitors compared to other countries, there are fewer than 400,000 people who call Iceland their home [18]. Numbers dropped slightly in 2019 to approximately 2 million visitors [27].

This drop in visitors in 2019 occurred before the pandemic shutdowns. According to a 2022 report by the U.S. State Department, the decrease in tourists in 2019 was due to the closing of the Icelandic budget airline WOW Air [20]. The Organization for Economic Cooperation and Development (OECD) also credits the Icelandic krona for being worth more as a reason for the decrease in tourists; in other words, it became more expensive to travel to Iceland in 2019 [56]. In 2018, the airline flew 3.5 million passengers but was shut down due to financial concerns, with losses of 33.7 million USD. At the time, the Icelandair Group was considering purchasing it in November 2018, but plans fell through [57]. By the time US Aerospace Partners bought the brand in June 2019, the summer tourist season had already started [58]. The WOW brand has still not recovered, as it was not in the top eleven airlines with a market share in Iceland [59]. Now, the largest airline in the country is Icelandair, with 11.7% of the market share in 2021, followed by United Airlines with 6% of the market share [59].

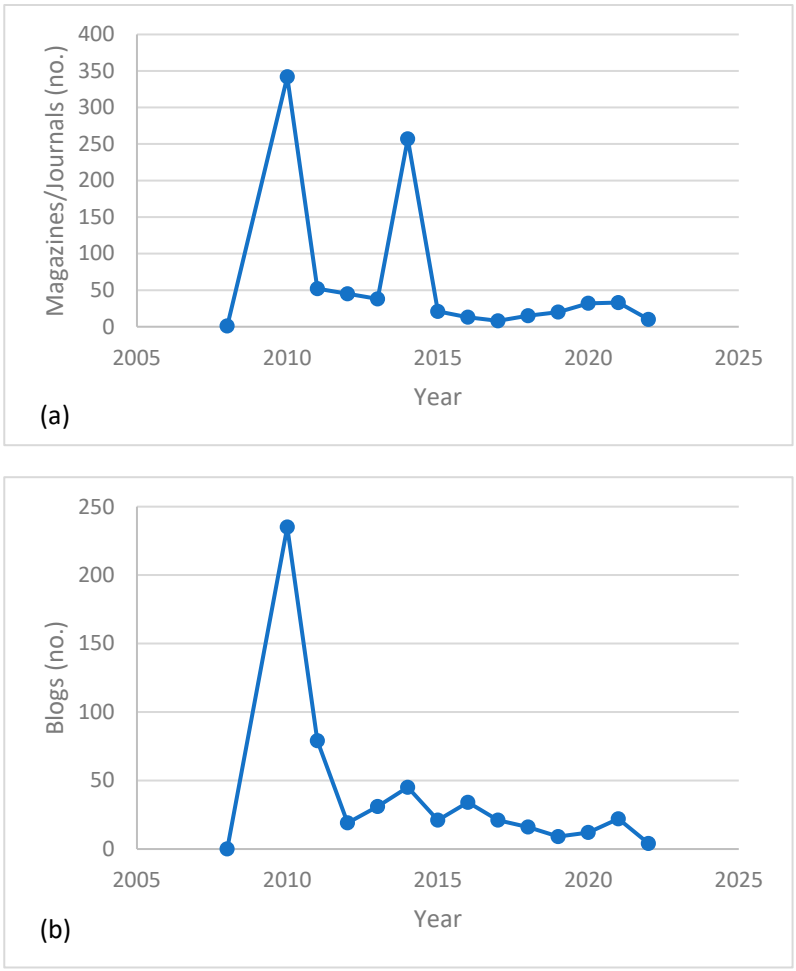

Figure 5. Number of (**a**) magazine and journal articles and (**b**) blog posts containing "Eyjafjallajökull" from 1999 to 2022, using the LexisNexis® Academic search engine (Lansing, MI, USA).

In 2017, the airline industry was estimated to support 3.5 billion USD of Iceland's GDP, with tourist spending totaling 4.4 billion USD [60]. This means that 38.3% of Iceland's GDP came from the airline industry, including tourist spending for those who traveled by air [60]. In 2019, the year before the pandemic, travel and tourism contributed approximately 4.9 billion USD to the GDP, dropped to 2.2 billion USD in 2020, and then rebounded to 3.5 billion USD in 2021 [61]. It is important to note that the 2017 data is from IATA Economics and the 2019–2021 data is from the World Travel and Tourism Council, each with its own data collection methods.

3.3. Agents

Agents for the tourism industry in Iceland include not only the tourists, but also the organizations that facilitate tourism. These include government entities, local businesses, tour operators on cruise ships, and many others (Table 4). Considering the COVID-19 pandemic, governments played an important role in whether or not tourists were able to travel by shutting down international travel and imposing other restrictions based on vaccination status. For Iceland, the decision to re-open their borders for international tourism was made by the Directorate of Health and the Department of Civil Protection and Emergency Management. Within Iceland, the government's Icelandic Tourist Board, under the Ministry of Industries and Innovation, is in charge of distributing information, registering licenses for travel agencies and booking services, and running Vakinn, which is the official quality and environmental system for Icelandic tourism [29]. Guide to Iceland is also an organization that has over 1000 Icelandic travel operators in its online database,

which includes tours, accommodations, and rental cars [40]. In addition, Icelandic workers in the tourism sector, who can be considered agents, took a large hit during the pandemic. In 2016, 10.8 jobs/1000 residents were at Icelandic airports, with the majority of them being at Keflavik Airport [19].

Table 4. List of example agents involved in Iceland's tourism.

Organization Name	Country, System Type	Type	Role
Directorate of Health	Iceland, receiving	Government	Provide information about healthcare for the people of Iceland and effective disease prevention measures [62]
Department of Civil Protection and Emergency Management	Iceland, receiving	Government	Protect public safety, protect property, and give assistance for any losses [63]
Vakinn	Iceland, receiving	Government	Iceland's quality assurance organization for tourism
Icelandic Tourist Board	Iceland, receiving	Government	Tourism data gathering, administers Vakinn, and registering operation licenses
Icelandic Travel Industry Association	Iceland, receiving	Nonprofit organization	Association of Icelandic travel and tourism companies [64]
Icelandic Tourism Research Centre	Iceland, receiving	Research project with the University of Iceland, University of Akureyri, and Hólar University	Improve and promote Iceland's tourism research [65]
Business Iceland	Iceland, receiving	Public-private partnership	Advance Iceland's business interests [66]
Iceland Tourism Cluster	Iceland, receiving	European Commission initiative	Promote competitiveness in the Icelandic tourism industry; includes 45 members from tourist value chains [67]
Tourism Skills Center	Iceland, receiving	Project funded by Ministry of Industries and Innovation	To increase staff skills in the tourism industry [68]
Center for Disease Control	United States, sending	National health agency	Actions impact international travel during the COVID-19 pandemic
U.K. Health Security Agency	United Kingdom, sending	National health agency	Actions impact international travel during the COVID-19 pandemic
Robert Koch Institute	Germany, sending	National public health agency	Actions and research impact international travel during the COVID-19 pandemic
Icelandic and other international airlines	Iceland, receiving and sending	Includes Icelandair, United Airlines, etc.	Airlines used by tourists to fly to and from Iceland
Guidebooks	Iceland, receiving	Depends on funding source for guidebook (government, independent, etc.)	Provide information to tourists on places to visit
Local businesses	Iceland, receiving	Restaurants, hotels, museums, etc.	Provide services to tourists
Argentinian and other international airlines	Argentina, spillover	Includes United, Aerolineas Airlines	Airlines used to fly to cruise originating in Argentina

As agents, tour companies, both in the country and on cruise ships, play a large role in facilitating tourism in Iceland. Cruise ships, for example, are appealing to a demographic that can afford to pay 10,000 USD or more for an Arctic cruise, which in turn is inherently riskier than a tropical cruise and requires more SAR infrastructure [69].

3.4. Causes

The causes behind tourism in Iceland vary and include economic, political, technological, cultural, and environmental factors. Environmentally, there is a large demand for nature-based tourism, especially for people who live in large cities and cannot experience it at home. Since Iceland is so sparsely inhabited, it has led to many areas of untouched wilderness for tourists to explore [70]. Many experiences that would be considered once in a lifetime for visitors from other countries can all be found in Iceland, such as volcanoes, the summer midnight sun, the Northern lights, geothermal baths, and glaciers [70]. This is es-

pecially appealing to tourists who live in densely urban areas and have extra money saved. However, because these visitors are from urban areas, their perceptions, as well as those of urbanites in Iceland itself, can lead to different definitions of untouched wilderness [71]. For example, the Icelandic Tourist Board found that the highest number of foreign visitors are from the United States, with the majority of Americans coming from New York and California, which are known for their large cities and a wealthier population [27]. These visitors, who would be considered non-purists, felt that they were visiting wilderness in the southern highlands, while wilderness "purists" who wanted to interact with untouched natural areas and wanted no services, perceived less than half of the southern highlands as wilderness [71].

Political and economic causes for international tourism in Iceland include its government's desire to improve its economy and promote foreign investment. Since Iceland's tourism decreased substantially during the pandemic, the government is looking to strengthen their tourism sector again, which is seen in the lifted COVID-19 safety restrictions and the many marketing campaigns [72]. In 2022, the Minister of Tourism signed that the "Iceland Together in Progress" marketing project would continue with an additional 550 million ISK (3.9 million USD) for funding [73]. Business Iceland, a public-private partnership, also has a marketing initiative to encourage post-pandemic tourism called Destination Iceland, which focuses mostly on exploring nature. Projects in Destination Iceland include turning pandemic sweatpants into hiking boots to explore the area and to "Let It Out" in hopes that tourists will come to Iceland and partake in scream therapy after a stressful time in isolation [66]. One other project through Destination Iceland is called "Joyscrolling," as opposed to "doomscrolling" through depressing social media headlines, which is sponsored by Inspired by Iceland, an initiative started after the volcano eruption in 2010 [66]. During the pandemic lockdown year (2020), the number of tourists visiting Iceland dropped to 488,000 and increased to 689,000 in 2021 [39]. Additionally, the number of tourists from August 2021 to 2022 reached 1.37 million [74], which was aligned with expectations since the Icelandic Ministry of Health lifted all COVID-19 safety measures on 25 February 2022 [25]. This is indicative of the success of the Destination Iceland campaign. Iceland also opened its borders to tourists regardless of vaccination status, so this could have also contributed to the increase in tourists [75].

Technologically, tourism gives Iceland a chance to showcase its advancements in clean energy and work with larger countries with deeper pockets. Investment in Iceland, also backed by Inspired by Iceland, has incentives for diversifying energy streams if the company invests in Iceland and advertises land that is prepared for development [76]. In addition, the internet and social media are the main catalysts for potential tourists to learn more about the country, with approximately 60% of visitors using these two as their main sources of information [27].

Cultural causes of tourism include tasting Icelandic cuisine, which is an enticing draw for visitors from Nordic countries [27]. Harsh weather in the past, lack of sunlight, and distance from trade sites caused traditional Icelandic foods to revolve around meats and keeping them fresh for longer [77,78]. New technology has allowed them to grow more vegetables, but fish and other meats remain dietary staples [77].

3.5. Effects

International tourism in Iceland has various environmental and socioeconomic outcomes. Environmental outcomes include increased CO_2 emissions from both traveling internationally and renting a car while in the country. These emissions partially contribute to climate change, which is causing the melting of sea ice that is allowing cruise ship tourists to see more of the Arctic in the first place [12]. However, new technology is helping to minimize some of the carbon emissions created by transportation with a new "Orca" facility using direct air carbon capture that can convert 13,000 metric tons of CO_2 and turn it into stone when mixed with water, using the power of Iceland's geothermal plants [79]. Concerns abound about carbon capture, as many criticize it for allowing the burning of

fossil fuels to continue while consuming high amounts of energy [79]. While Iceland has approximately 14% of its workforce in the tourism industry [75], providing livelihoods for native Icelanders, environmental consequences have occurred due to damaging sensitive areas and developing wilderness for tourist resorts [17]. Other unknown spillover effects also arise as new industries and areas are constantly developing in Iceland.

CO_2 emissions from international flights are substantial. For international travel, the majority (30%) of visitors to Iceland arrive from the United States. Therefore, we calculated emissions for American travelers to Iceland to show how the emissions changed before, during, and after the COVID-19 pandemic lockdown. New York was selected as the designated airport linking the U.S. to Iceland because it tied for the highest number of visitors (9%) and was the nearest major airport to Iceland. The other highest number was California with 9% of U.S. visitors, so we picked LAX (Los Angeles) as the airport for Californians to depart from because it is one of the highest trafficked airports in the state. To account for the other 91% of Americans that did not fly out of California, we chose JFK (New York) due to it also being a highly trafficked airport. In addition, JFK is closer to Iceland than many other major airports. This means that emissions were most likely underestimated due to American tourists driving or flying from other parts of the country to reach JFK, or flying out of a different airport that was farther away from Iceland. According to the International Civilian Aviation Organization (ICAO), a flight from LAX to JFK is just under 4000 km. This means that the total passengers' CO_2 emissions during a round-trip flight between LAX and JFK is 565.8 kg of CO_2 [38]. For the second leg of the trip, JFK to KEF (Reykjavik), there are 506.4 kg of CO_2 emitted. Since JFK is the closest international American airport to Iceland, a conservative estimate of total airline emissions for the remaining 91% of visitors not traveling from California is roughly 320 million kg of CO_2. For the 9% of visitors from California, there is 67 million kg of CO_2, for a total of approximately 387 million kg of CO_2 released by Americans traveling to Iceland in 2018. Using the same process for the 52,000 passengers from the U.S. in 2020, or during the height of the COVID-19 pandemic, there was approximately 23.9 million kg of CO_2 generated from New York and other American passengers and 5 million kg of CO_2 for California passengers, bringing the total airline emissions for U.S. passengers to 28.9 million kg of CO_2 for 2020. For after the COVID-19 pandemic (2022), with data through September in 2022, there have been 377,315 American passengers flying to Iceland. For New York and other American passengers, there have been 173 million kg of CO_2 generated and 36.4 million kg of CO_2 for California passengers, for a total of 209.4 million kg of CO_2 in 2022. Data for these calculations comes from the ICAO Carbon Emission Calculator, which was created to track the carbon footprint of individual passengers. To collect this data, the calculator uses the input of the starting and ending locations of a direct flight, and then uses passenger load factors and passenger-to-cargo ratios to determine the total fuel attributed to passengers based on 312 different aircraft types [38]. Once this number is determined, it is divided by the total number of passengers to calculate the average fuel burn, which is then multiplied by 3.16 to obtain the CO_2 footprint of each passenger [38]. One thing to note is that these numbers are conservative estimates of total kg CO_2, as 13% of respondents in a 2016 survey said that a stopover opportunity in Iceland was a major reason for their decision to visit Iceland, indicating that the tourist did not have a direct flight back to their destination [27]. For flights to the country where a cruise ship is departing from, emissions amount to approximately 1269 kg of CO_2 per passenger [38]. Since this is also a conservative estimate of the distance each passenger has to travel because New York is closer to Argentina than the midpoint of North America, actual emissions may be even higher. Due to a lack of data availability for where private cruise ship passengers are arriving from, estimations of total emissions from this spillover system cannot be calculated.

CO_2 emissions from rental car usage in Iceland are also high. Popular guides recommend visitors have a four-wheel drive jeep or SUV when driving in the winter [40,80]. The most highly recommended rental car company in Iceland on Google, Lotus Car Rental, has one electric car option, with their other smaller cars using gasoline, and larger rentals

car using diesel [81]. For example, the most popular economy car, the Toyota Aygo, is gasoline powered and has CO_2 emissions of 197 mg/km [82]. However, this option only has front wheel drive, so tourists who need a car for more remote roads and for the winter can rent the most popular medium sized car, which is the Dacia Duster with four-wheel drive. This car generates approximately 804 mg/km of CO_2 [82]. Lastly, for those who are looking for large or luxury cars, the most popular options are the Kia Sorento 4x4 and the Mercedes-Benz Vito Tourer 4x4. The Kia is diesel powered and has CO_2 emissions of 90 mg/km, NO_x emissions of 33 mg/km, and emission particles of 0.28 mg/km [82]. The Mercedes-Benz releases 47 mg/km CO_2 and 31 mg/km NO_x, with 0.46 mg/km of emissions particles. Carbon dioxide was analyzed for emissions because it has the largest rate of greenhouse gas emissions and stays in the atmosphere for longer than other common pollutants, such as methane [83]. Even though diesel does not have large amounts of CO_2 emissions, it still releases high amounts of other pollutants, such as particulate matter in the form of soot and NO_x [83]. For this reason, diesel vehicles have NO_x and particulate matter included for comparison to each other. If these numbers are used to catalog emissions from driving the Golden Circle (230 km), the Toyota generates 45.31 g CO_2, the Dacia 184.92 g CO_2, the Kia 20.7 g CO_2, and the Mercedes-Benz 10.81 g CO_2. For the Ring Road, which is 1330 km in length, the Toyota generates 262 g of CO_2, the Dacia 1069.32 g of CO_2, the Kia 119.7 g of CO_2, and the Mercedes-Benz 62.51 g of CO_2. This distance also is only for the road itself and does not account for any stops at sites off the road. Data on the percentage of tourists who rented cars was only available for 2018 and for countries with the highest number of tourists [27]. For example, the U.S. is made up of 30% of all visitors to Iceland in 2018 and 59% of them rented cars. For simplicity in this scenario, the smallest car from the previous car rental example, the Toyota Aygo, will be used. If every U.S. visitor to Iceland who rented a car in 2018 drove one passenger around the Golden Circle, this would have generated approximately 9287 kg of CO_2A life cycle assessment completed in 2016 of the per capita carbon footprint found that local transport caused emissions of 330 kg of CO_2-eq per tourist, with 30% of these emissions coming from rental cars, 60% from sightseeing tour buses and public transport, and 10% from sightseeing boat trips [84]. Rental car usage in Iceland also has increased from 5000 rental cars in 2006 to 21,000 in 2016 [85,86].

Socioeconomic effects include a higher GDP for the country, as more than 10% of Iceland's GDP comes from the tourist industry. In regard to the COVID-19 pandemic and the subsequent drop in international tourism, the comeback of tourism in Iceland will be vital for Iceland's economy. Profits for accommodations rose by 380% from 2010 to 2018, with the average annual investment at $600,000 USD from 2015 to 2017 for all investments [5]. Before the pandemic, a report carried out by the Icelandic Ministry of Industries and Innovation in 2017 found that many sites had reached carrying capacity for sewage treatment, and waste, with the transport system, healthcare, and law enforcement coming close to carrying capacity [5,87]. During the pandemic, pressures eased on these overtaxed infrastructures, but Iceland's economy struggled with many people out of work, dropping to only 12,600 after peaking at approximately 23,000–31,800 in 2017 (Statistics Iceland had a lower number than the Icelandic Tourist Board) [88,89]. Percentage-wise, Iceland's tourism accounts for the highest amount of the Scandinavian countries' GDP (Finland, Norway, and Sweden) at 8.4% in 2016 [75]. Since so much of Iceland's GDP is dependent on tourism, it is important for the country to return to pre-pandemic levels, but the issue lies with the lack of infrastructure to keep up with the high number of tourists. A balancing act is needed to ensure that Icelanders have the jobs and money they need to live, while also addressing the need for infrastructure investment due to the high number of tourists. Right now, the GDP is anticipated to return to 2019 levels in 2022 [90]. In addition, there is a reduced amount of housing available for local people due to apartment rentals, but in 2019, more tourists were in hotels and guesthouses instead of Airbnbs [5]. Another socioeconomic effect, particularly concerning luxury cruise ships, is an increased need for safety infrastructure for cruise ships that are trying to navigate in inhospitable waters.

Since climate change is causing a decline in Arctic sea ice extent, the area will become more unpredictable and dangerous to navigate [12].

4. Discussion

This is the first study to analyze Iceland's tourism surrounding the COVID-19 pandemic and integrate all major components using the telecoupling framework. Since Iceland's international tourists outnumber the population by such a large number and have such a high amount of airline emissions, international tourism in Iceland has far-reaching implications for the rest of the world, including areas of the Arctic that are expecting increases in tourism from the melting of sea ice and as a result of LCT [91–93]. As Arctic tourist destinations work to predict and accommodate future tourists for both infrastructure and community needs, it is important to consider the effect of visiting remote locations that can only be reached by air or sea. It is also important for the rest of the world, as tourism numbers are expected to surge after the 74% reduction in international tourism in 2020 during the COVID-19 pandemic [6], so a sustainable return to international tourism is crucial. To promote a sustainable return of tourism in Iceland, there needs to be a stronger emphasis on taking public transport while in the country instead of relying on imported rental cars that can only transport a maximum of five people in economy vehicles. Due to the potential for increased COVID-19 transmission on public transport, it would be beneficial to require vaccines, or masking and more social distancing for those who are unable to receive a vaccine. Since the best way to reduce airplane emissions is to fly more passengers on each plane and reduce the number of total flights, it would also be beneficial if the most heavily trafficked airports (in the U.S. and the U.K.) could consolidate more of their flights.

To promote a sustainable return to tourism after pandemic restrictions have been lifted, the telecoupling framework can be used by government agencies and other institutions to ensure a safe return to tourism and can provide new examples of connections that are part of the tourist industry. Table 5 presents the five themes of this framework: systems, flows, agents, causes, and effects, with examples to demonstrate the differences before, during, and after the pandemic restrictions. It is important to note that these numbers are only updated through October 2022.

Table 5. Examples of telecoupling components before (Jan. 2018–Feb. 2020), during (Feb. 2020–22), and after (Feb. 2022–Present) the COVID-19 pandemic restrictions.

Components	Sub-Components	Examples	Before	During	After
Systems	Sending	Countries	Canada, Denmark, France, Germany, Italy, Netherlands, Poland, Spain, USA, UK	No countries	Denmark, France, Germany, Italy, Netherlands, Poland, Spain, USA *
	Receiving	Country	Iceland	Iceland	Iceland
	Spillover	Cruise ship passengers	41,882 **	5433	Data not available
Flows	People	Tourists	2.29 million	598 thousand	1.4 million
Agents	Healthcare workers	Directorate of Health	Workers who provide information about healthcare for the people of Iceland	Workers who provide information about healthcare for the people of Iceland and effective disease prevention measures	Workers who provide information about healthcare for the people of Iceland and effective disease prevention measures
Causes	Economic	GDP	25.50 billion USD	23.59 billion USD	Data not available
Effects	Environmental	Emissions by American passengers	2018: 387 million kg CO_2	2020: 28.9 million kg CO_2	2022: 209.4 million kg CO_2

* Countries included are those that exceeded the average number of tourists across all years measured (2012–2022).
** Data averaged for 10 top ports from 2017 to 2021.

If we look more closely at the telecoupling framework, we can view Porter's five forces [26] as parts of the "causes" of the telecoupling framework that affects the flow of tourists. For example, the new entrants could be relevant new tourism companies in other countries that compete for tourists to Iceland, the bargaining power of customers could be the bargaining power of tourists, and the threat of substitute products or services might be movies, videos, and/or other products or services that keep potential tourists from traveling. The power of suppliers is also seen in this telecoupling through the shortage of semiconductors and rental cars in Iceland during the pandemic. Jockeying for position among current competitors can also refer to the many tourist operators for cruise ships, rental cars, and tours. All five of these forces are examples of economic causes in the telecoupling framework. There are many other causes influencing tourism, such as changes in lifestyles such as divorce in sending systems [94] and ecosystem services in sending and receiving systems [95,96].

Future research that could go into more detail on this broader view of telecoupling includes analyzing how cruise ships will be affected by the retreat of the Arctic Sea ice, as well as the interaction between energy needs, GDP, and tourism in Iceland. As international tourism starts up again around the world, telecoupling research will become even more important to analyze how countries will adapt to the high number of tourists after countries have been living largely in isolation for the past two years. The pause in the pandemic also gives governments, such as in Iceland, the opportunity to address infrastructure and carrying capacity needs.

Another positive of the telecoupling framework is its ability to systematically pull together information in one study. Even though a researcher may not be fluent in the languages or cultures of all the countries she or he analyzes, studying systems across long distances can serve as a basis for other organizations to investigate a problem spot in more detail. For example, the list of agents (Table 4) that are involved in Icelandic international tourism is not an exhaustive list, but it is a good starting point for any organization that is looking for partnerships on the same topic. As telecoupling and other systems research is further refined and developed, it will continue to provide more answers in a world that grows exceedingly complex every day.

5. Conclusions

In an increasingly complex world, the telecoupling framework helps provide answers to the research objectives posed in the introduction and offers a comparison of a coupled human and natural system throughout the COVID-19 pandemic. The flows, agents, causes, and effects are identified in Table 1 of the results section, and more detail is provided throughout this paper. The COVID-19 pandemic affected these systems by causing tourist numbers to decrease for those traveling by both air and by sea. However, tourist numbers on flights are closer to returning to pre-pandemic levels than those traveling on cruise ships. Lastly, potential spillover systems from this telecoupling include the rest of the world that is affected by the increased emissions from flights and the need for more search and rescue infrastructure to meet the increased demand when cruise ships return or exceed pre-pandemic levels. Implications from this background research include a need for higher consolidation of flights to reduce the number of planes taking off, which in turn will reduce emissions, and to consider ways to mitigate cruise ship emissions, such as routes that start closer to passengers' home countries. Limitations of this analysis include the inability to account for every flow of tourists, information, and materials in one paper and the inability to identify all spillover systems.

Due to the complexity of tourism and the growing interest in socioecological interactions, there is room for further research on this topic. Future research in this area could expand the number of receiving systems to include countries that conduct trade with Iceland, instead of focusing only on tourists. Until Iceland's transport industry can shift away from fossil fuels, trade continues to be important in Iceland because of the importation of oil-based fuels. In addition, Iceland's renewable energy infrastructure has a lot to offer

other countries and makes it particularly attractive for industries that are energy intensive. The tourism in Iceland can, therefore, serve as a starting point for other countries that do not have easy access to geothermal energy and to continue minimizing the environmental effects of this technology. With the adoption of the telecoupling framework and streamlining telecoupling research into policymakers' hands, complex issues, such as tourism, can continue to be more holistically addressed and more effectively managed.

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