The Nordic Region Sets the Standard in Eco-Friendly Electricity Production

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ABSTRACT

There is a global problem with climate change, which stems from the use of fossil fuels and simultaneously represents the primary source of energy worldwide. This issue is far from trivial due to the human and material consequences observed in various regions around the world. At the same time, the Paris Agreement and the United Nations Framework Convention on Climate Change (UNFCCC) have set an ambitious goal of achieving zero emissions by 2050, while global temperatures have risen by one degree Celsius since the previous century. In this context, clean energy, including electricity, plays a crucial role. However, only a few countries have managed to produce electricity from renewable resources. Among these are the Nordic countries, which have not only achieved this but have also shown substantial progress in terms of consumption. Therefore, their indicators should be used as a reference in other regions to improve sustainability standards.

Keywords: Climate change 1; electricity 2; fossil fuels 3; renewable resources 4, Nordic region 5

I. INTRODUCTION

There is growing global concern about addressing the problem of global warming, attributed to greenhouse gases, which result from the use of fossil fuels. This concern, along with the efforts of various countries, was formalized with the Kyoto Protocol in 1998 [1], which came into effect in 2005, the Paris Agreement (2015) [2], in force since 2016, and the United Nations Conferences of the Parties [3], held annually since 1995, in addition to the actions that multiple nations have taken individually according to their own strategies and characteristics.

In this context, the Nordic region stands out for its commitment, comprising Denmark, Finland, Iceland, Norway, and Sweden. Broadly speaking, this region is characterized by its notable commitment to the use of renewable resources while seeking to meet energy needs, with significant advances in this regard. Therefore, it is worth delving into specific aspects related to electricity production in the region, which is often associated with so-called clean energy.

Globally, on average, two-thirds of electricity is generated through fossil fuels, with renewable resources a distant second, accounting for just under one-third. It is thus necessary to analyze each of the Nordic countries individually, as they can serve as a

reference point for many other nations. To provide context, an analysis of relevant combined indicators for the countries in the region is presented, followed by a review of specific aspects related to electricity production, as well as the energy sources used to meet each country's consumption needs and other elements related to the import and export of fossil fuels.

II. RESULTS

To address the subject matter, it is important to note that the Nordic countries have shown a commitment to exceeding the climate goals proposed by the Kyoto Protocol [1] and the Paris Agreement [2]. Concerning electricity production, which is the focus of this document, each of the countries in the region—Denmark, Finland, Iceland, Norway, and Sweden—generates electricity primarily from renewable resources, positioning them differently from the global average. Hence, analyzing their status, both collectively and individually, is important.

II.1 COMBINED KEY FIGURES OF THE NORDIC COUNTRIES

A key factor in considering the Nordic countries as study subjects is their rankings in the Human Development Index, as shown in Table 1, where they are listed alphabetically.

Table 1. Human Development Index. Based on data provided by the United Nations Development Programme (2023) [4].

Country name	HDI Rank	Human Development Index (HDI) 2022
Denmark	5	0.952
Finland	12	0.942
Iceland	3	0.959
Norway	2	0.966
Sweden	5	0.952

As can be seen, the Nordic countries rank between 2nd and 12th in the global Human Development Index, which is remarkable. Norway stands out, ranking second worldwide after Switzerland, while Iceland ranks third, and Sweden and Denmark share the fifth position.

Table 2. Gross domestic product (GDP) per capita. Based on data provided by World Bank [5].

Country Name	2022	2023	World ranking
Denmark	$ 67,790	$ 67,967	14
Finland	$ 50,735	$ 53,756	25
Iceland	$ 75,135	$ 78,811	12
Norway	$ 108,798	$ 87,962	5
Sweden	$ 56,300	$ 56,305	19

To further explore the issue, it is worth noting the global rankings of the Nordic countries in terms of GDP per capita, which range from 5th to 25th place. Once again, Norway stands out as the region's most prominent economy, ranking fifth globally.

Table 3. Contribution of GDP to the Global Total. Based on data provided by the World Bank [6].

GDP	2023
Denmark	0.38%
Finland	0.28%
Iceland	0.03%
Norway	0.46%
Sweden	0.56%
Nordic countries	1.72%
World	100.00%

In terms of contribution to global GDP, the Nordic region accounts for only 1.7% collectively. Sweden is the largest economy in the region, ranking 24th globally.

Tabla 4 Annual GDP Growth by Country. Based on data provided by the World Bank [6].

Countries	60.4 Years Average	10 Years Average	5 Years Average	2019	2020	2021	2022	2023
Denmark	2.40	2.35	2.50	1.49	(2.42)	6.84	2.73	1.89
Finland	2.70	0.84	0.63	1.22	(2.35)	2.84	1.34	(1.04)
Iceland	3.75	3.91	3.58	1.86	(6.94)	5.15	8.88	4.06
Norway	2.99	1.67	1.62	1.12	(1.28)	3.91	3.01	0.51
Sweden	2.51	2.34	2.08	1.99	(2.17)	6.15	2.66	(0.20)
World	3.45	3.05	3.01	2.64	(2.93)	6.26	3.09	2.72

When calculating the average annual growth over 60 years, the past decade, and the last five years, the Nordic countries show positive results, except during the COVID-19 pandemic and in 2023 when Finland and Sweden experienced slight negative results due to rising prices in Europe and tensions stemming from the Russia-Ukraine conflict. However, all countries have significantly recovered from the pandemic's economic setback.

Table 5 Population by Country. Based on data provided by the World Bank [7].

Country	2023	Contribution
Denmark	5,946,952	0.074%

Finland	5,584,264	0.070%
Iceland	393,600	0.005%
Norway	5,519,594	0.069%
Sweden	10,536,632	0.131%
Nordic countries	27,981,042	0.349%
World	8,024,997,028	100.000%

When examining the population size of the region, it represents just 0.3% of the global total.

Table 6. World proven crude oil reserves (2023). Based on data provided by OPEC. (2023) [8].

Country	Millions barrels
Denmark	346
Norway	7,642

From an energy perspective, only Norway and Denmark show significant levels of proven oil reserves.

Inflation rates in the Nordic countries have generally remained below double digits. Like many other nations during the COVID-19 pandemic, inflation levels rose, although they remained below the global average. The Russia-Ukraine conflict also influenced inflation rates in 2023.

Table 7. Inflation rate, average consumer prices. Based on data provided by IMF [9].

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	April 2024
World	3.2	2.7	2.7	3.3	3.6	3.5	3.2	4.7	8.7	6.8	5.9
Denmark	0.4	0.2	0.0	1.1	0.7	0.7	0.3	1.9	8.5	3.4	1.5
Finland	1.2	-0.2	0.4	0.8	1.2	1.1	0.4	2.1	7.2	4.3	1.2
Iceland	2.0	1.6	1.7	1.8	2.7	3.0	2.8	4.5	8.3	8.7	5.6
Norway	2.0	2.2	3.6	1.9	2.8	2.2	1.3	3.5	5.8	5.5	3.3
Sweden	0.2	0.7	1.1	1.9	2.0	1.7	0.7	2.7	8.1	5.9	2.6

Iceland has experienced inflationary increases, partly due to growing tourism, rising wage levels, and heightened demand, resulting from its strong GDP growth [10].

II.2 KEY FIGURES OF DENMARK

To provide context, Denmark has committed to reducing greenhouse gas emissions by 70% by 2030, using 1990 as the baseline, and aims to achieve carbon neutrality by 2050. Additionally, Denmark is promoting electric vehicles through tax incentives and plans to phase out fossil fuel-powered vehicles by 2030 [11]. Furthermore, authorities have mandated that all public transport contracts must be free of fossil fuels.

It is estimated that around 51% of new cars in Denmark are electric [12],

demonstrating the country's ability to compete with Norway in this area. To analyze the composition of inputs used in electricity generation, refer to Figure 1.

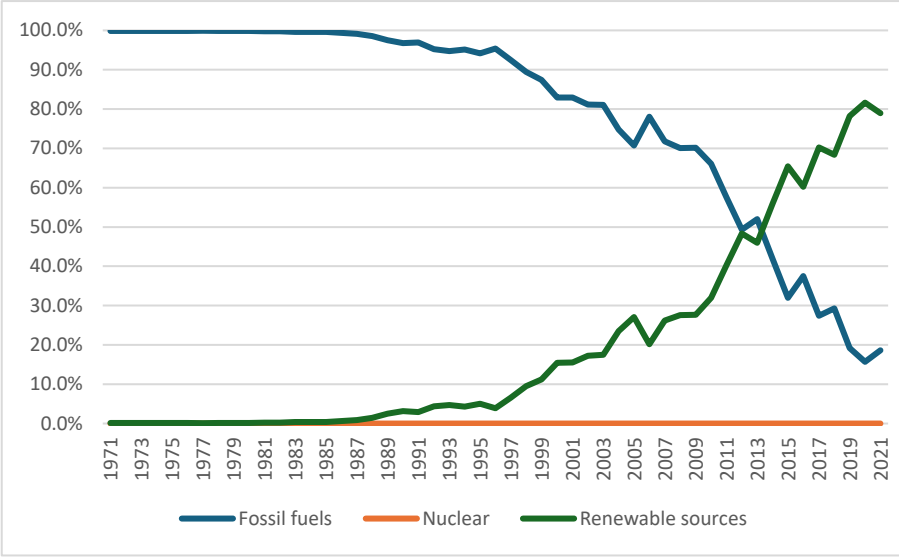

Figure 1. Denmark's Contribution to Total Electricity Output. Derived from data provided by the International Energy Agency (IEA), n.d.) [13].

Denmark reveals a significant shift in its use of fossil fuels starting in the late 1980s, with a notable transition towards renewable resources from the second decade of this century. Notably, in the most recent records, the contribution of renewable resources to electricity production is close to 80%.

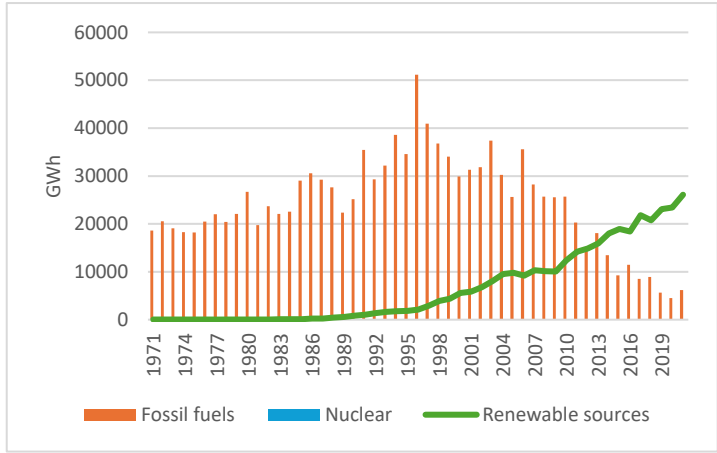

Figure 2. Trends in Key Inputs for Electricity Generation in Denmark (gigawatt-hour (GWh)). Data sourced from the International Energy Agency (IEA), n.d.) [13]

Over the long term, the rise of renewable resources in terms of GWh is remarkable,

reducing fossil fuel usage to just one-fifth.

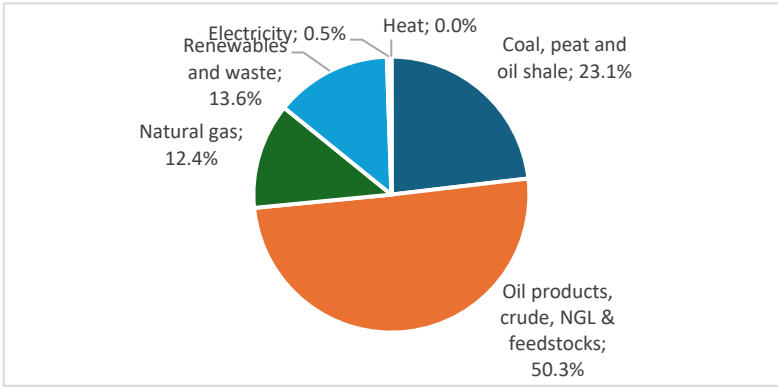

Figure 3. Denmark´s Contribution to Total Energy Consumption (Petajoules, PJ) (Average 1971-2021). Data sourced from the International Energy Agency (IEA), n.d.) [13].

In terms of energy consumption, Denmark remains dependent on fossil fuels, accounting for 62.7%, including natural gas, over a 50-year period, as shown in Figure 3.

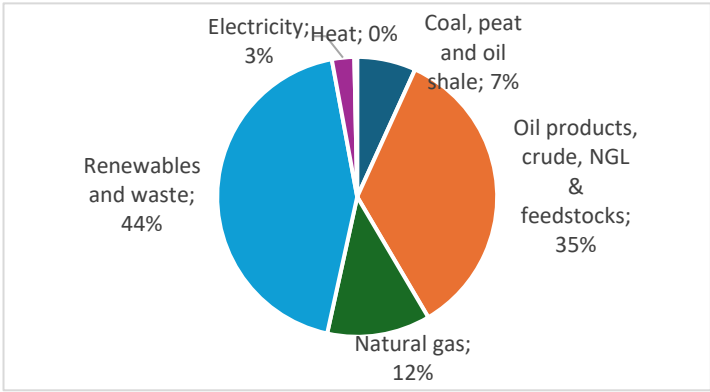

Figure 4. Denmark´s Contribution to Total Energy Consumption (Petajoules, PJ) (2021). Data sourced from the International Energy Agency (IEA), n.d.) [13].

By 2021, according to the latest available data provided by the International Energy Agency, fossil fuel use has decreased by approximately 16% compared to the 50-year average. However, fossil fuels still account for 47% of Denmark's energy consumption. Renewable resources have shown significant growth, reaching 44%, with a 30.4% increase. Electricity, while still accounting for only 3.5%, has also grown compared to the 50-year average.

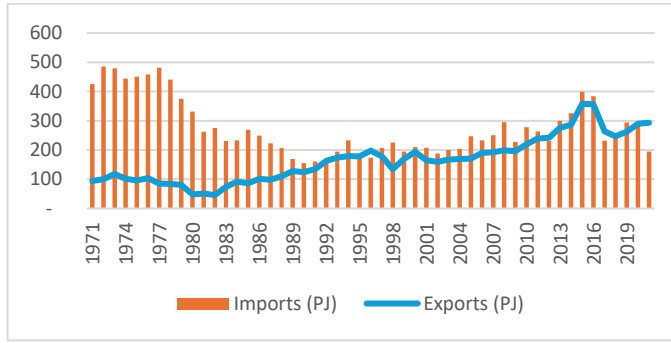

Figure 5. Trends in Oil Products Exports and Imports in Denmark. Data sourced from the International Energy Agency (IEA), n.d.) [13].

Regarding oil product exports and imports, the trend has remained stable since the 1990s.

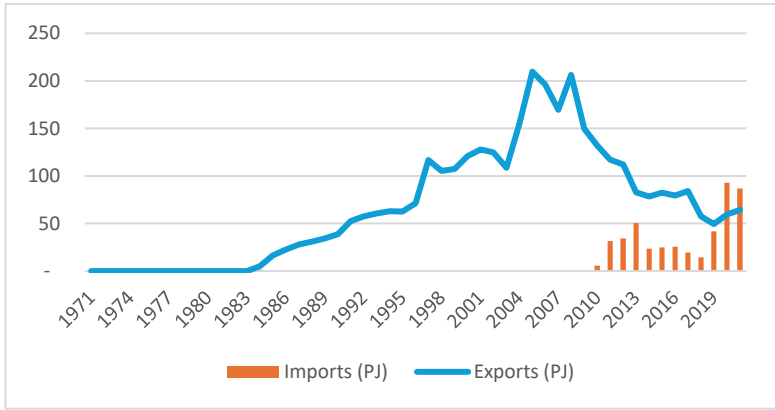

Figure 6. Trends in Natural Gas Exports and Imports in Denmark. Data sourced from the International Energy Agency (IEA), n.d.) [13].

Similarly, in the case of natural gas exports and imports, there has been a notable decline in imports since 2009. It is worth mentioning that exports have only started to gain some relevance from the second decade of this century and have remained at levels comparable to imports in recent periods.

II.3 KEY FIGURES OF FINLAND

Finland aims to achieve carbon neutrality by 2035, meaning it plans to absorb as much CO2 as it emits because of human activity [14]. To provide further context, it is expected that by 2024, electric cars will account for 43% of the total vehicle fleet [15].

In this context, it is essential to consider the composition of the inputs required to generate electricity in Finland, as shown in Figure 7.

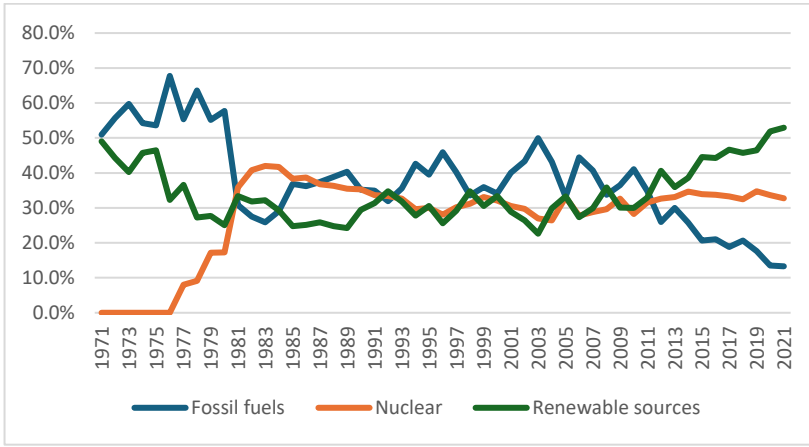

Figure 7. Finland´s Contribution to Total Electricity Output. Derived from data provided by the International Energy Agency (IEA), n.d.) [13].

The largest share of electricity generation comes from renewable resources, reaching 52% in 2021, followed by nuclear energy, with fossil fuel usage showing a downward trend since the second decade of this century.

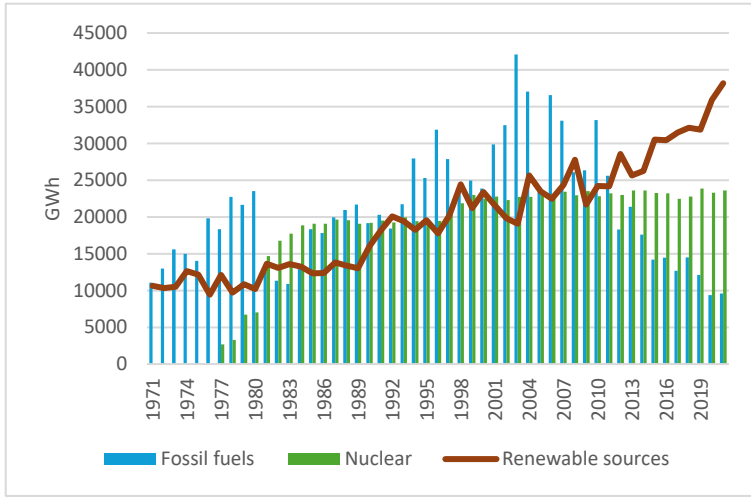

Figure 8. Trends in Key Inputs for Electricity Generation in Finland (gigawatt-hour (GWh)). Data sourced from the International Energy Agency (IEA), n.d.) [13]

When analyzing the components, it is observed that the only input showing a growing trend is that of renewable resources, considering production in GWh. Meanwhile, nuclear energy seems to have exhibited a horizontal trend since the end of the last decade of the previous century.

Figure 9. Finland´s Contribution to Total Energy Consumption (Petajoules, PJ) (Average 1971-2021). Data sourced from the International Energy Agency (IEA), n.d.) [13].

Similarly, from the perspective of energy consumption over five decades, Finland has depended on fossil fuels for 43.1%, compared to 41.5% from sustainable resources.

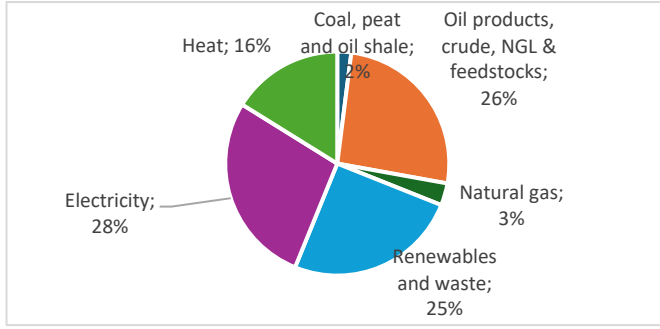

Figure 10. Finland´s Contribution to Total Energy Consumption (Petajoules, PJ) (2021). Data sourced from the International Energy Agency (IEA), n.d.) [13].

In 2021, renewable resources along with electricity met 53% of the energy demand, while fossil fuels accounted for slightly less than one-third.

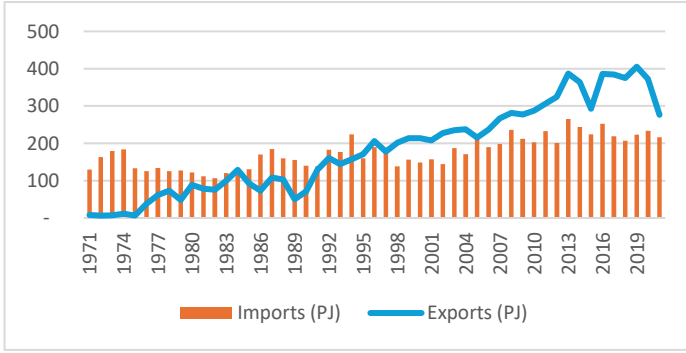

Figure 11. Trends in Oil Products Exports and Imports in Finland. Data sourced from the International Energy Agency (IEA), n.d.) [13].

In terms of oil product exports and imports, Finland has shown a positive balance since the end of the previous century, while exports have shown fluctuations within a parameter tending towards horizontal since the second decade of the current century.

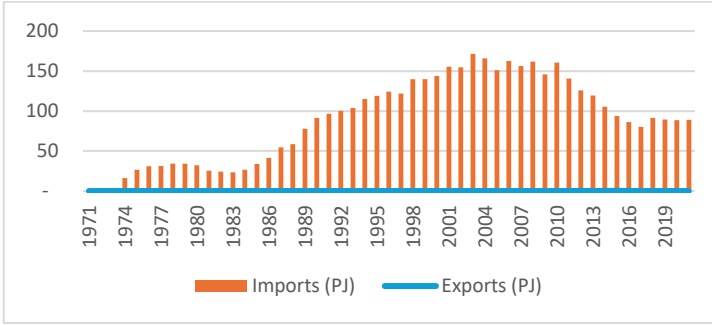

Figure 12. Trends in Natural Gas Exports and Imports in Finland. Data sourced from the International Energy Agency (IEA), n.d.) [13].

In Finland, the natural gas balance is in deficit, with no export counterbalance against imports. It is important to note that 12% of energy relies on natural gas. This partially explains the impacts on growth and price indices due to the Russia-Ukraine conflict, as prices of strategic inputs have risen.

II.4 KEY FIGURES OF ICELAND

Even though Iceland is an island, it is interesting to consider its indicators in terms of actions related to climate change. For instance, the country aims to achieve carbon neutrality before 2040 and reduce greenhouse gas emissions by 40% by 2030. Additionally, most of Iceland's heating and electricity needs are met by renewable sources, particularly hydroelectric and geothermal energy [16].

Surprisingly, 70% of Iceland's vehicles have been electric since 2022 [17].

Regarding electricity production, it is noteworthy that Iceland relies 100% on natural resources.

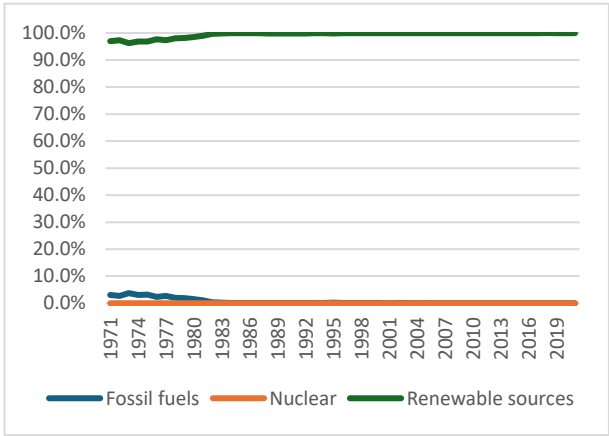

Figure 13. Iceland´s Contribution to Total Electricity Output. Derived from data provided by the International Energy Agency (IEA), n.d.) [13].

It should be noted that Iceland has maintained natural resources as the sole input for

electricity generation, even though levels have increased in the long term, as seen in Figure 14.

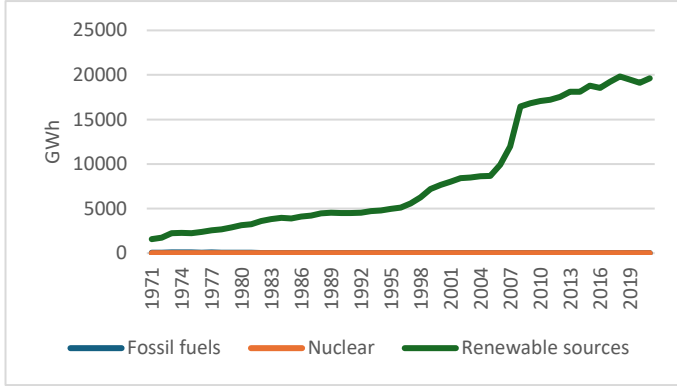

Figure 14. Trends in Key Inputs for Electricity Generation in Iceland (gigawatt-hour (GWh)). Data sourced from the International Energy Agency (IEA), n.d.) [13]

Another revealing fact is that Iceland has covered more than 70% of its energy needs with natural resources, on average, for a span of 50 years, as shown in Figure 15.

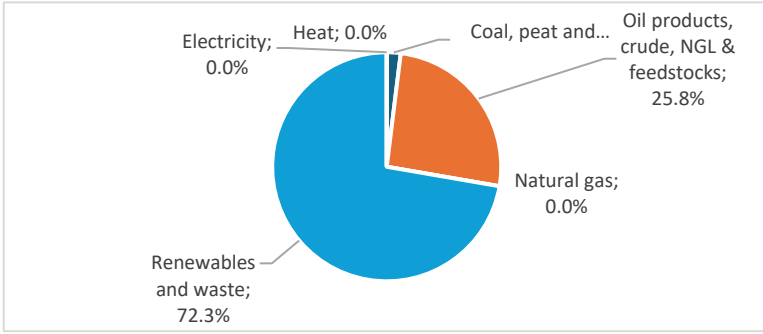

Figure 15. Iceland´s Contribution to Total Energy Consumption (Petajoules, PJ) (Average 1971-2021). Data sourced from the International Energy Agency (IEA), n.d.) [13].

Moreover, according to the latest data from the International Energy Agency, Iceland has continued to progress, meeting nearly 90% of its energy needs with sustainable resources and 9% with fossil fuels, while other sources remain insignificant.

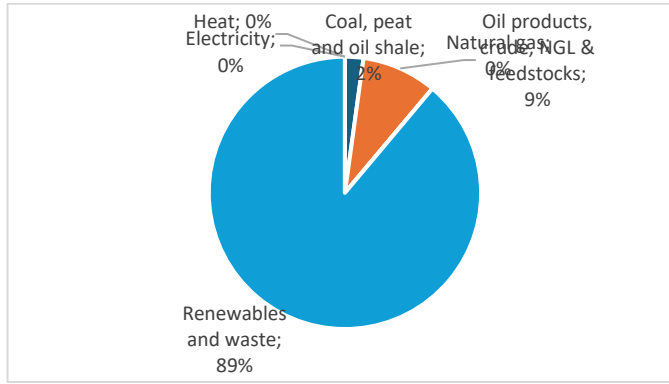

Figure 16. Iceland´s Contribution to Total Energy Consumption (Petajoules, PJ) (2021). Data sourced from the International Energy Agency (IEA), n.d.) [13].

Furthermore, Iceland imports all the oil products it uses, and no export records were identified through the International Energy Agency.

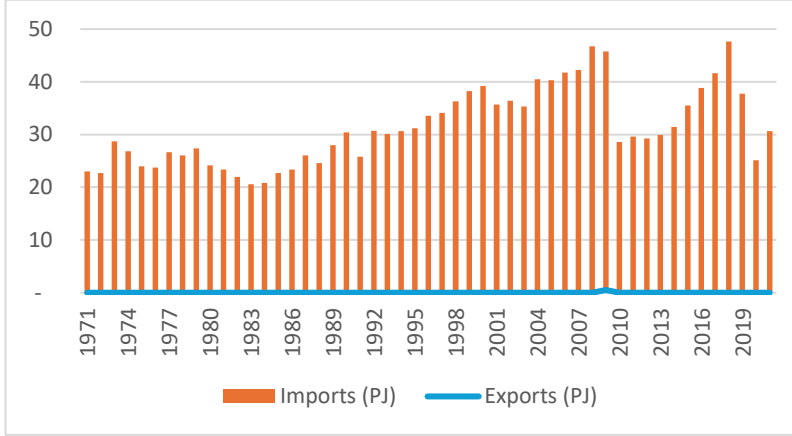

Figure 17. Trends in Oil Products Exports and Imports in Iceland. Data sourced from the International Energy Agency (IEA), n.d.) [13].

Regarding natural gas, Iceland has no records in the International Energy Agency, consistent with Figure 16, where there is no data for this fuel.

II.5 KEY FIGURES OF NORWAY

Norwegian authorities have set a goal to achieve carbon neutrality by 2030, meaning they aim to offset human-caused carbon dioxide (CO2) emissions through the country's own capacity to absorb them from the atmosphere [18].

It is also interesting to note that in Norway, the taxes on electric vehicles are related to the amount of CO2 and nitrogen oxide emissions, with vehicles weighing more than 500 kg paying additional fees for every extra kilo. This is a step forward after the

experience gained in this area. Moreover, it is crucial to consider that 90% of new cars in the country are electric [19].

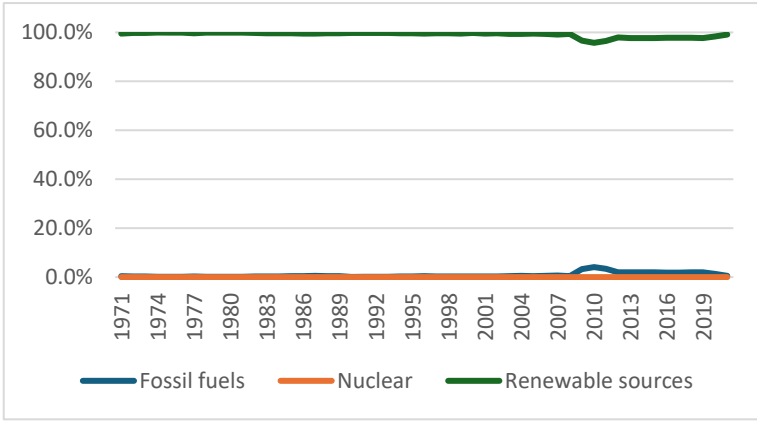

Figure 18. Iceland´s Contribution to Total Electricity Output. Derived from data provided by the International Energy Agency (IEA), n.d.) [13].

As with Iceland, Norway's electricity production is almost entirely reliant on natural resources, reaching 100% for several years, with minimal contributions from fossil fuels.

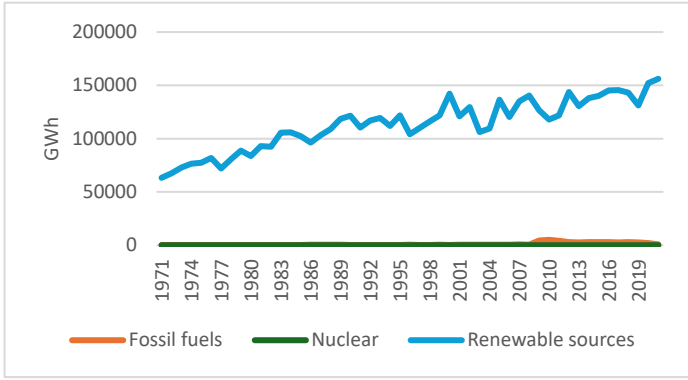

Figure 19. Trends in Key Inputs for Electricity Generation in Iceland (gigawatt-hour (GWh)). Data sourced from the International Energy Agency (IEA), n.d.) [13]

In terms of production observed in GWh, while it has been increasing over time, Norway sustains electricity production with renewable resources, placing the country in a distinct position compared to the global average.

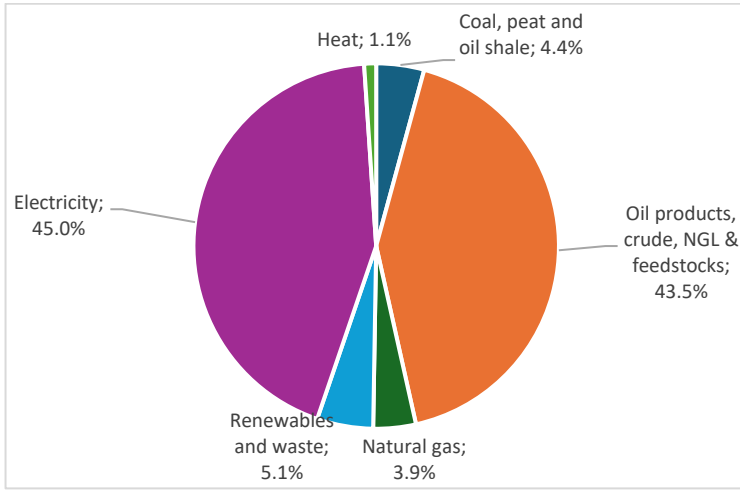

Figure 20. Iceland´s Contribution to Total Energy Consumption (Petajoules, PJ) (Average 1971-2021). Data sourced from the International Energy Agency (IEA), n.d.) [13].

It is also notable that over five decades, from the perspective of the country's energy consumption, fossil fuels met 47.4% of the demand, while electricity, combined with sustainable resources, accounted for 50.1%, which is significant given that electricity is also produced from renewable resources.

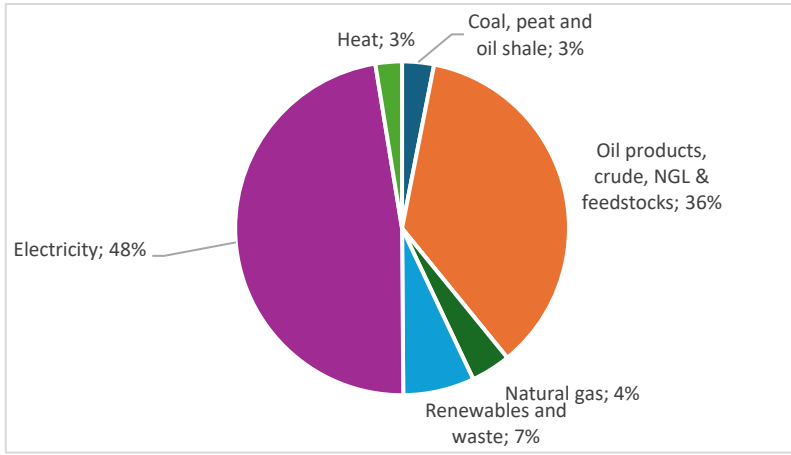

Figure 21. Iceland´s Contribution to Total Energy Consumption (Petajoules, PJ) (2021). Data sourced from the International Energy Agency (IEA), n.d.) [13].

Furthermore, according to the latest data from the International Energy Agency, fossil fuels account for 40%, while electricity and renewable resources already meet 55% of energy requirements, once again placing Norway in a very different position compared to most countries in the world.

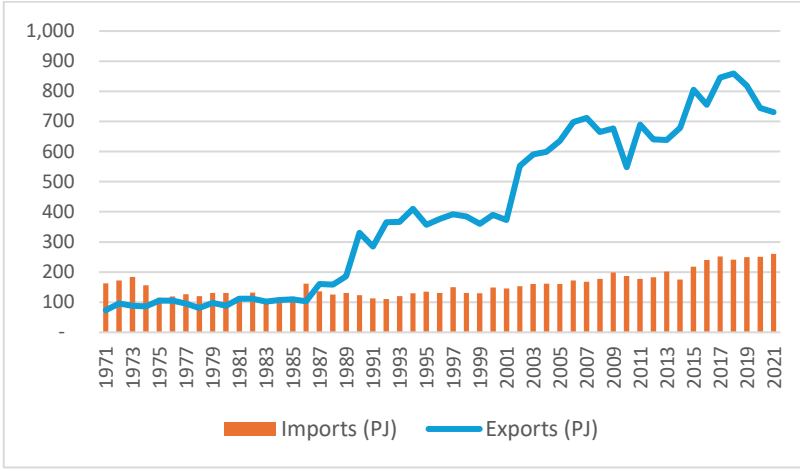

Figure 22. Trends in Oil Products Exports and Imports in Iceland. Data sourced from the International Energy Agency (IEA), n.d.) [13].

It is noteworthy that oil product exports exceed imports by 2.8 times, leveraging Norway's petroleum reserves.

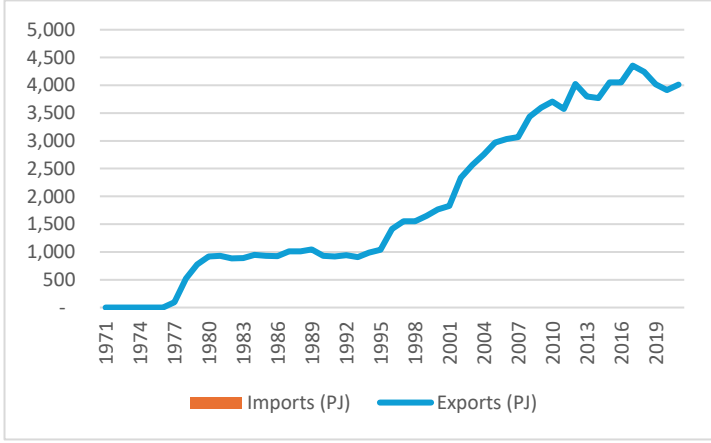

Figure 23. Trends in Natural Gas Exports and Imports in Iceland. Data sourced from the International Energy Agency (IEA), n.d.) [13].

Regarding natural gas, Norway is 100% surplus, with only exports.

II.6 KEY FIGURES OF SWEDEN

As for Sweden, the country plans to achieve zero net greenhouse gas emissions by 2045 [20].

Additionally, new electric vehicles in Sweden reached 42.7% in September 2023 (True Energy 2023) [15].

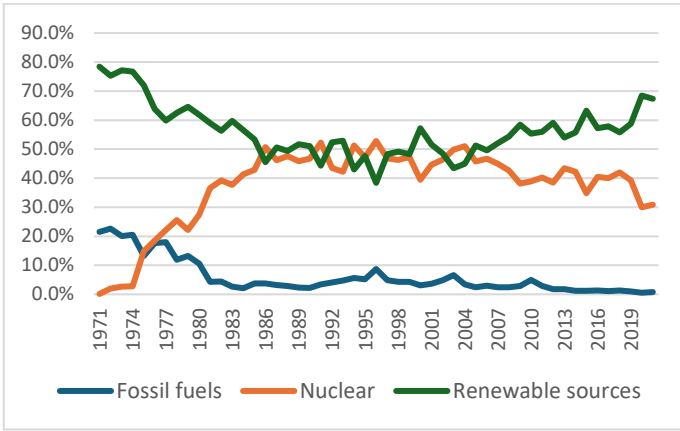

Figure 24. Sweden´s Contribution to Total Electricity Output. Derived from data provided by the International Energy Agency (IEA), n.d.) [13].

To produce electricity, Sweden uses renewable resources, nuclear energy, and fossil fuels, in that order of importance. However, the former meets 67.4% of the demand, while fossil fuels account for less than 1%.

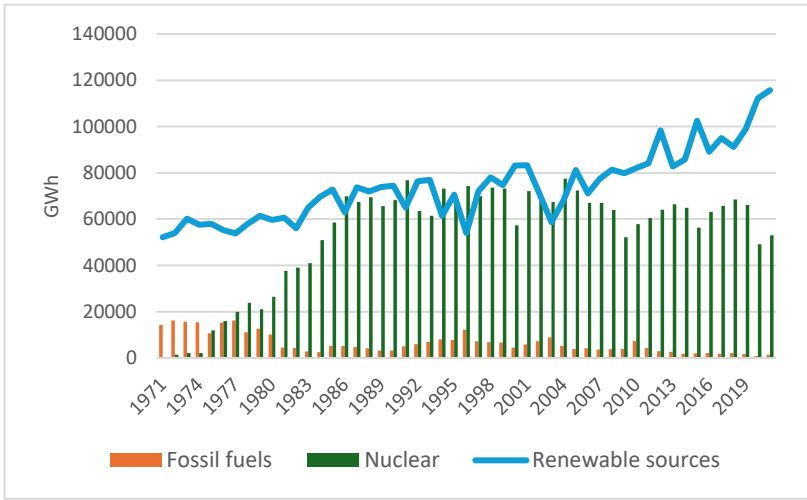

Figure 25. Trends in Key Inputs for Electricity Generation in Sweden (gigawatt-hour (GWh)). Data sourced from the International Energy Agency (IEA), n.d.) [13]

According to the time series analyzed from 1986 to 2007, sustainable resources showed levels like nuclear energy, although the former reflected an upward slope at the end.

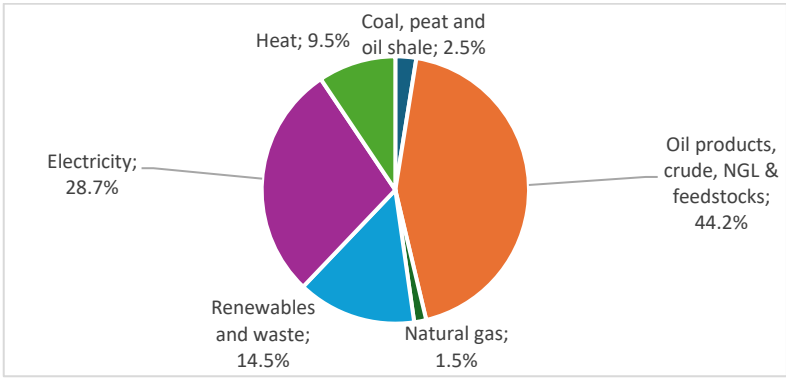

Figure 26. Sweden´s Contribution to Total Energy Consumption (Petajoules, PJ) (Average 1971-2021). Data sourced from the International Energy Agency (IEA), n.d.) [13].

Over the span of 50 years, 45.7% of consumption needs have been met with fossil fuels, while electricity and renewable resources contribute 43.2%.

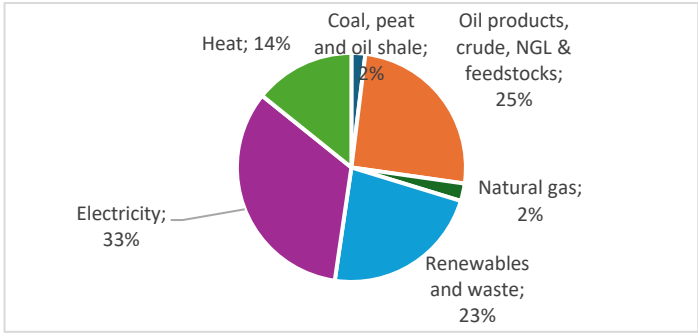

Figure 27. Sweden´s Contribution to Total Energy Consumption (Petajoules, PJ) (2021). Data sourced from the International Energy Agency (IEA), n.d.) [13].

In the most recent observation provided by the International Energy Agency, fossil fuels account for 27%, which is 16 percentage points lower than the 50-year average. Likewise, electricity and renewable resources now meet 56% of Sweden's energy needs.

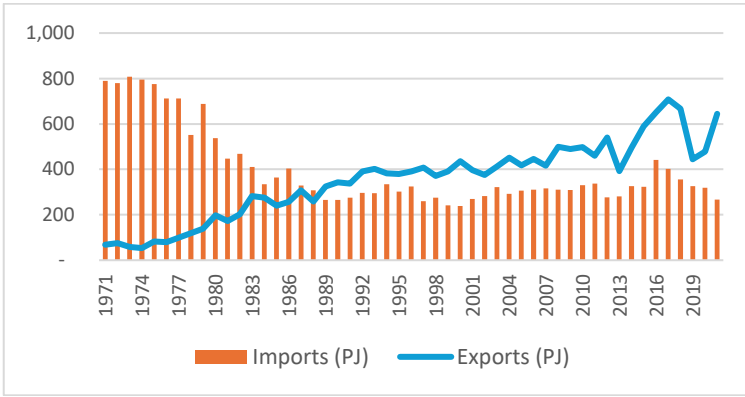

Figure 28. Trends in Oil Products Exports and Imports in Sweden. Data sourced from the International Energy Agency (IEA), n.d.) [13].

Since the late 1980s, Sweden has maintained a positive balance in oil products.

Figure 29. Trends in Natural Gas Exports and Imports in Sweden. Data sourced from the International Energy Agency (IEA), n.d.) [13].

On the other hand, Sweden relies on imports for 99% of its natural gas, which also explains the impact of the conflict between Russia and Ukraine.

III. DISCUSSION

The Nordic countries have notably prioritized environmental preservation. It is also important to consider that their combined economy accounts for only 1.7% of the global economy, and their population is less than 1% of the world's total. This raises the question: can the advancements in electricity production and efforts to achieve net-zero CO2 emissions in the short term be replicated in much larger countries, given the various economic incentives involved? Furthermore, why have nations of similar size not yet achieved the environmental benchmarks set by the Nordic countries?

It is also worth noting that with the increase in electric vehicle sales, the region is transitioning to new challenges. For instance, while fiscal incentives have played a crucial role in the substitution of internal combustion vehicles, they must now address

other factors affecting infrastructure and adapt incentives to the new reality. Norway, for example, has begun implementing differentiated tax incentives based on vehicle weight.

IV. CONCLUSION

The Nordic countries rank among the top 12 in the world for human development index, with Norway and Iceland taking second and third place, respectively. Furthermore, Norway ranks fifth in the world for GDP per capita, while the rest of the region's countries fall between 12th and 25th place.

The regional economy accounts for less than 2% of global GDP, and the population is just 0.3% of the world total. Nordic countries have experienced positive annual economic growth for six decades, except for specific events such as the COVID-19 pandemic and in 2023 when Finland and Sweden reported negative growth due to rising European prices and supply chain disruptions caused by the Russia-Ukraine conflict. Inflation levels have generally remained below 2%, with notable increases during the pandemic period, although still below global averages.

Only Norway and Denmark have significant oil reserves, in that order of importance. The representatives of Nordic countries appear committed, not just on paper but in practice, to producing electricity from sustainable resources. As a result, they have diverged from the global average, which depends on fossil fuels for just over 60% of energy needs and on renewable resources for less than 30%.

Nordic countries are expected to achieve carbon neutrality by 2030 in Norway, 2035 in Finland, 2040 in Iceland, and 2045 in Sweden. This is significant given that, under the Paris Agreement, many other nations, including Denmark, have set 2050 as the target year for achieving this goal.

It is estimated that more than half of new cars in Denmark are electric.

By 2024, 43% of all vehicles in Finland are expected to be battery-operated as well.

Since 2022, 70% of vehicles in Iceland are electric-powered.

In Norway, 90% of vehicles are powered by electricity.

Iceland, Finland, Norway, and Sweden meet their energy demands primarily through sustainable resources, which is a revealing statistic that sets them apart from the global average, where 56% of energy needs are met with fossil fuels. It is worth mentioning that Denmark is very close to achieving a balance between sustainable resources and fossil fuels.

Denmark seems to have balanced its oil products trade in recent years while reducing natural gas exports to levels comparable to the early 21st century.

Finland has a surplus in oil products but a deficit in natural gas.

Iceland has a deficit in oil products due to high import levels and has no recorded exports or imports of natural gas.

Norway has a positive balance in oil products and is 100% surplus in natural gas.

Sweden shows a similar situation to Finland, with a surplus in oil products but a deficit in natural gas.

Producing and promoting the use of electricity when its primary inputs come from sustainable resources is consistent with the goals of promoting clean energy. Conversely, promoting the consumption of electricity when it is generated from fossil fuels runs counter to climate change mitigation strategies. In the Nordic countries, electricity can be considered clean, with over 60%—and in some cases 100%—of it produced from renewable resources.

Given these results, it is advisable to further investigate the specific fiscal incentives in each country to promote the use of environmentally friendly resources.

It is also essential to delve into Norway's experience in promoting electric vehicles, analyzing the results of the initial incentives and how they have been adjusted based on the outcomes. Norway appears to have already experienced the future many other regions will face in terms of mitigating global warming, so it is important to analyze their economic policies and related strategies more deeply.

It is also necessary to conduct comparative analyses between countries of similar size and contrast their environmental policies and incentives.

Additionally, case studies of regions that have successfully transitioned from fossil fuels to sustainable resources in electricity production should be analyzed.

Evaluating the economic incentives that hinder the transition from fossil fuels to the widespread use of sustainable resources should also be a relevant line of research.

Finally, it is crucial to explore the feasibility of replicating the strategies applied by the Nordic countries in other nations, and to analyze why other nations of similar size have not yet reached the environmental benchmarks set by these countries.

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