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Spatial analysis of the BEV market and the corresponding charging infrastructure in Hungary

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Abstract

The adoption of fuel-efficient vehicles, especially battery electric vehicles (BEVs), is becoming an emerging priority on the global level. At first, it may seem that the major issue from the consumer side is the high price of BEVs that are not competitive with internal combustion (IC) vehicles. However, aspects like technological developments, battery safety measures, implemented safety features, design, range anxiety, charging infrastructure, environmental consciousness and sustainability also play a significant role in the decision-making process of BEV purchasing. This paper examines the connection between BEV registrations and Hungary's available public charging infrastructure. Data on the number of new BEV registrations, public charging stations and energy consumption from public charging are gathered for each county and region in Hungary. Until 2020, a division between the Eastern and Western parts of the country can be detected considering BEV adoption, but in 2021 this difference will diminish. Even though it can be seen from the raw data that the number of BEV registrations is growing faster than the number of available charging stations, existing stations prove to be properly located, covering regions that either have high BEV registrations or are part of transit paths with high traffic. Also, it is shown that BEV registrations grow proportionately higher in regions where more charging stations are available.

Keywords

battery electric vehicles, adoption, charging infrastructure, charging station location, Hungary

1. Introduction

Cognitive sustainability has become increasingly important in various fields, including transportation and technology. Considering the Hungarian battery electric automotive market, this paper aims to analyse the importance of cognitive mobility, specifically regarding the development of charging infrastructure and the degree of its utilisation in the country. Decision-making processes regarding transportation are highly dependent on several cognitive aspects that affect key areas of mobility, such as cognitive sustainability, vehicles and infrastructures (*Zöldy and Baranyi, 2023*). Elements of these areas related to e-mobility, such as charging infrastructure, safety features, new technology adoption, and environmental consciousness, highly influence purchasing decisions and adoption of battery electric vehicles (BEVs) (*Li et al., 2017*). More than that, one of the most important factors in BEV adoption is the development level of the charging infrastructure (*Eberle and von Helmolt, 2010*), which is related to cognitive mobility in several ways. Examples include optimal route planning decision-making, reducing range anxiety and providing a more comfortable driving experience. For instance, range anxiety is one key driver in EV adoption (*Noel et al., 2019, 2020*), which can be solved with better battery capacity providing higher range, but yet this comes with a large expense for consumers that lowers EV adoption (*Adepetu and Keshav, 2017*).

Also, recent research shows new engineering solutions for increasing battery lifetime and efficiency by altering the design parameters of IPM (permanent interior magnet) motors (*Horváth and Nyerges, 2023*); however, these techniques are still in the phase of development. Therefore, building a complex EV charging infrastructure equipped with fast chargers placed in the appropriate locations (*Pevec et al., 2019*) may be the solution to reduce range anxiety and benefit the adoption of BEVs in the present. For example, *Illman and Kluge (2020)* examine Germany's new EV registrations and public charging infrastructure. They conclude that the charging speed influences EV adoption even more than the number of charging stations. Besides the charging speed, the location of public chargers is of great importance too. *Lucas et al. (2018)* also analyse the EV market in Germany and observe that 50% of the energy supplied comes from less than 20% of the available charging stations, which suggests an inadequate allocation of the existing charging stations.

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The paper is structured as follows. Section 2 presents the data and methods used, and section 3 briefly presents the evolution of the electric automotive market and compares it with the evolution of the charging infrastructure in the country. Section 4 shows spatial correlations between counties and regions considering three variables: number of BEV registrations, the number of publicly available charging stations, and kWh of energy used from public charging in 2020 and 2021. Section 5 is dedicated to discussion, and concludes the article.

2. Data and Methods

This paper uses a combination of privately owned and publicly available data and focuses on the connections between BEV adoption and the complexity of the charging infrastructure in Hungary. One part of the data comes from the data collector company, DATAHOUSE, which gave private information on the number of new BEV registrations in Hungary from 2017 to 2021 and new BEV sales from 2014 to 2016. The second database used for quantifying the evolution of the charging infrastructure in Hungary is a public database provided by the Hungarian Energy and Public Utility Regulatory Authority (MEKH: http://www.mekh.hu/beszamolo-az-engedelykoteles-elektromos-toltoberendezesekrol-2022-ii-negyedev). This database provides data on the number of publicly available electric charging stations and the energy used from public charging (kWh) from 2016 to 2022. Lastly, data on the number of total passenger automotive vehicle stocks are collected from the Hungarian Central Statistical Office (KSH: https://www.ksh.hu/stadat_files/sza/en/sza0040.html).

After examining the data using Descriptive statistics tools, a spatial representation of the analysed variables is performed in the GeoDa statistical software. Data is divided into counties and regions to find significant spatial correlations among them using tests like local neighbor match connectivity and Moorans' I performed on the new BEV registration data in 2020. Further, I searched for connections between the number of charging stations, the amount of energy (kWh) consumed at these stations, and the number of new BEV registrations in the different regions by analysing the years 2020 and 2021 and comparing the maps resulting from the representation of the mentioned variables.

3. The evolution of the number of BEV registrations and the public charging stations in Hungary

The electric automotive market is globally emerging, and Hungary is not an exception. Based on the new registration and sales data provided by the DATAHOUSE private data collector company, *Figure 1* represents the number of new BEV registrations yearly in Hungary from 2014 to 2021.

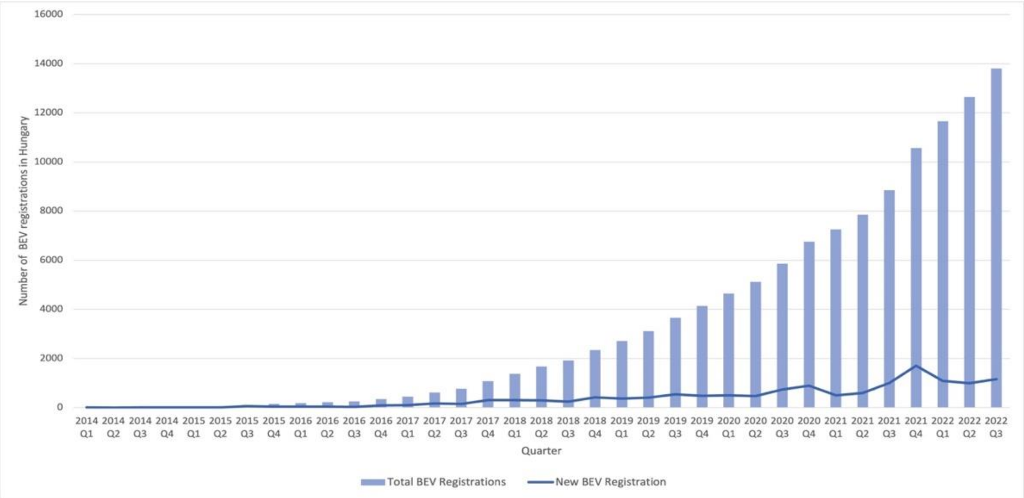

Figure 1. Number of registered BEVs in Hungary from 2014 to 2021.
(Source: Own data and compilation.)

The trend is increasing as the number of BEV registrations in the third quarter of 2022 is more than 30 times higher than in the first quarter of 2017. The minimum increase in BEV registrations is 7%, while the maximum is 120% from the second to the third quarter of 2015. Regarding the new quarterly BEV registration, there are periods of decrease, but the overall trend is increasing.

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One main factor influencing the purchase of BEVs is the availability of complex charging infrastructure. For instance, in Hungary in 2020, a total of 7.1 GWh of power was used from publicly available charging stations, an increase of 25% compared to the previous year (*MEKH, 2021*). We know from the data provided by the Hungarian Energy and Public Utility Regulatory Authority (MEKH) that the number of charging times in the country dropped significantly in the second and third quarters compared to the first quarter of 2020, both for the AC and DC charges. Similarly, the energy used for EV charging decreased in the mentioned quarters compared to the beginning of 2020. However, in 2020 the Covid-19 pandemic held back overall mobility, especially during severe lockdowns in the second quarter. However, the decrease in the next quarter's charging time is reasonable due to an increased share of home office work. Thus, it is probable that the increase of 25% in the energy used for EV charging would have been even higher without the pandemic. *Figure 2* shows the number of available charging stations in Hungary from 2016 to 2021. It is to be seen that both the number and type of charging stations grew remarkably, the number of charging stations being more than 100 times as high in 2021 compared to 2016 and 38 times higher compared to the end of the year 2017.

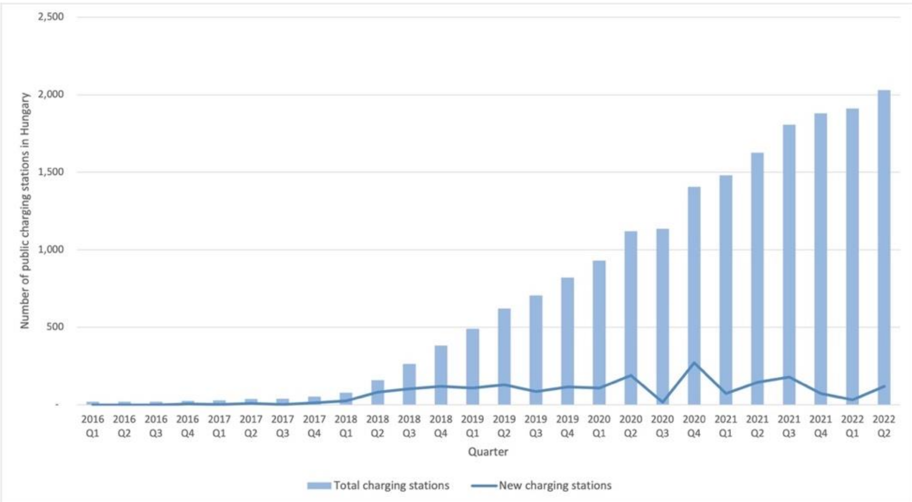

Figure 2. A number of electric vehicle charging stations in Hungary from 2013 to 2021 by type.
(Source: MEKH: http://www.mekh.hu/beszamolo-az-engedelykoteles-elektromos-toltoberendezesekrol-2022-ii-negyedev and own compilation.)

Comparing the quarterly average growth rates, data shows that the average growth rate of BEVs, which is 25%, is three percentage points higher than the average growth rate of charging stations in the analysed period. Further, we can observe that the quarterly growth rate of public charging stations follows the growth rate of new BEV registrations with a time lag (*Figure 3*)[1]:

[1] Unfortunately, we do not have data on the number of charging stations between 2014 and 2016. However, the total number of charging stations in the first three quarters of 2016 was constantly equal to 20, and thus the growth rate in the previous period can be considered negligible.

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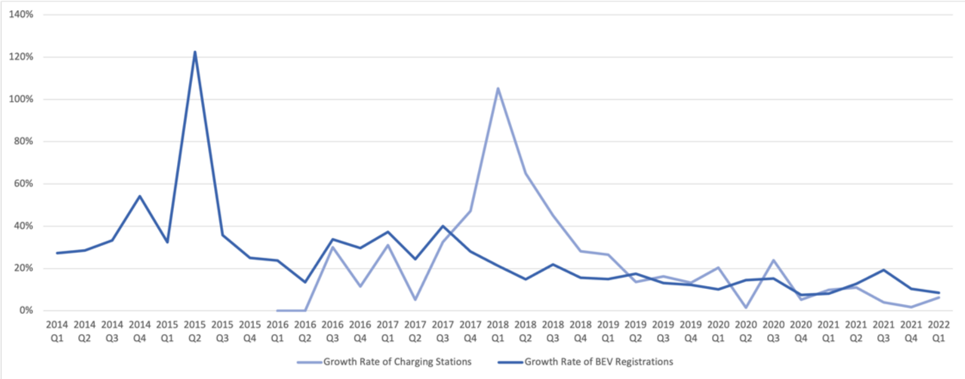

Figure 3. Quarterly growth rate of total BEV registrations and public charging stations in Hungary from 2014 to 2022.
(Source: own compilation.)

The highest growth rate of BEVs was witnessed in the third quarter of 2015 and was followed by a boom in the number of charging stations only three years later. That is an expected effect, as the government probably did not invest in public charging stations before the appearance of electric vehicles. After the boom periods, the variance of both rates decreases and keeps moving in the range of 0–22% quarterly growth. We can also observe that the growth rate of BEV registrations is followed by an increase in the public charging stations in the following quarters, which suggests that the number of stations adapts to the number of BEV registrations.

4. Spatial repartition of new BEV registration and the charging infrastructure

In this section, the number of BEV registrations, public charging stations and the consumed energy from charging (kWh) are analysed by dividing the country into regions and observing spatial connections between them according to the mentioned variables. Thus, besides the quantitative aspect of the charging infrastructure measured by the number of public charging stations, I implement a qualitative measure to show whether these stations are well-located in the country.

4.1 Spatial analysis of the total BEV registrations from 2014 to 2022

The BEV market in Hungary is a dynamically evolving sector. Here the territorial evolution of this market is analysed with a county-level resolution. Firstly, we can observe the number of total registered BEVs from January 2014 to June 2022 in each county (*Figure 4*). Note that the capital (Budapest) and the surrounding county (Pest) are outliers. This was expected, as Hungary is a relatively small country with a very high economic concentration around the capital.

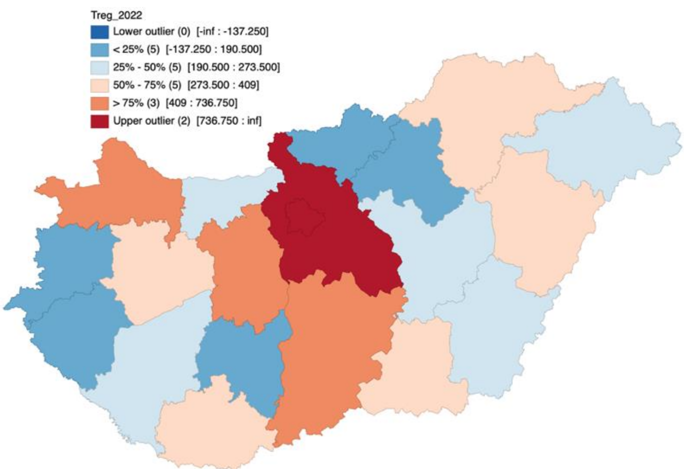

Figure 4. Total BEV registrations from January 2014 to June 2022 in Hungary by county.
(Source: Own data and compilation in GeoDa.)

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Further, note that the number of BEV registrations in the eastern part of the country is relatively low. This is also sustained by the result of Moran I's test (Moran's I = 0.324), where the contiguity weight is set to "Queen" of order 1, which defines neighbours by the existence of a common edge or vertex. We can observe on the LISA cluster map (*Figure 5*) that there is one county (Borsod-Abaúj-Zemplén) that has a significant positive (low-low) spatial association, showing that a low value of BEV registrations in this county is positively associated with the low values of the neighbouring counties.

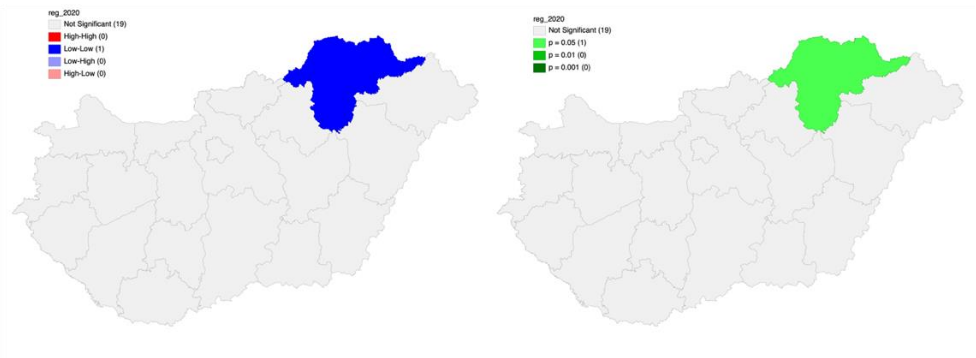

Figure 5. LISA Cluster Map and Significance Map for total BEV registrations from January 2014 to June 2022 in Hungary.
(Source: Own data and compilation in GeoDa.)

4.2 Spatial comparison of BEV registrations and the charging infrastructure in 2020

Due to the Covid-19 pandemic, 2020 was difficult, especially in the transportation sector. Still, the provided raw data shows that, except for the third quarter, new BEV registrations grew compared to the previous year (*Figure 1*). The repartition of new registrations by region this year is represented by the map on the left-hand side of *Figure 6*. As regions differ by size, population and density, the absolute values of BEV registrations are not the best when comparing EV adoption willingness across regions. Therefore, the map on the right side of *Figure 6* represents the number of new BEV registrations in 2020, divided by each region's total personal automotive vehicle stock. Thus, we get a value that expresses the per cent of new BEV registrations in 2020 compared to the total personal automotive vehicle stock in the specific region. When arranging the regions in four quantiles, we can observe that the lower values are in the Eastern, while the higher values are in the Western part of the country.

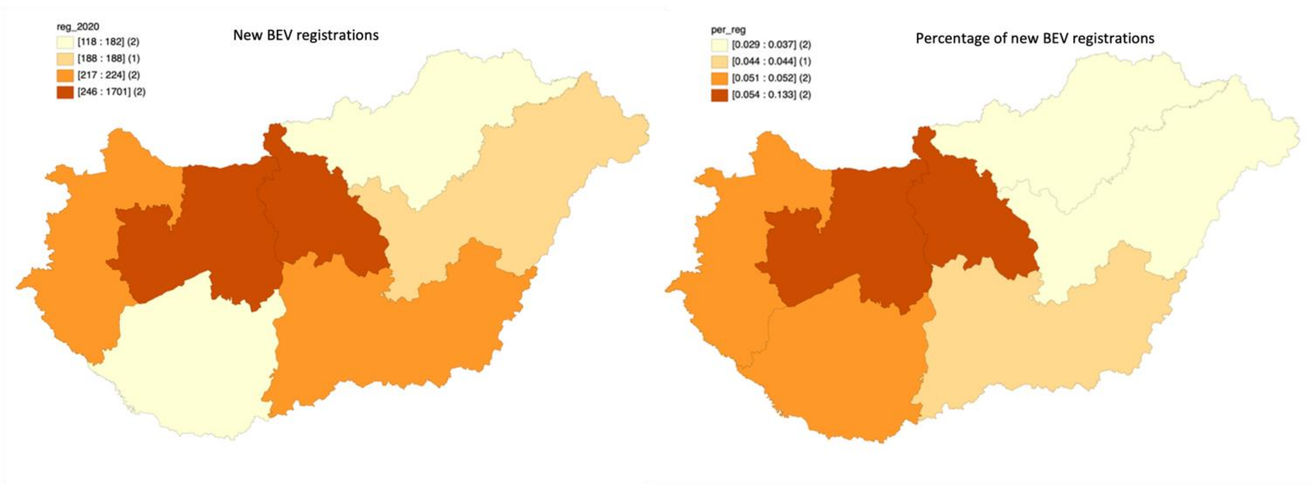

Figure 6. New BEV registrations and their ratio to the total personal automotive vehicle stock in Hungary in 2020 by region.
(Source: KSH: https://www.ksh.hu/stadat_files/sza/en/sza0040.html, own data and compilation in GeoDa.)

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This means that relative to the overall usage of automotive vehicles, the ratio of newly registered BEVs is higher in the Western part of the country. I performed a local neighbour match test, suggested by *Anselin and Li (2020)*, with two neighbours and Euclidean distances. The local neighbour match cardinality map shows that 6 out of 7 regions have at least one common neighbour with a connectivity link. However, not every connection is significant (Table 1):

Table 1 Local neighbour match cardinality and p-value

Region:	Card	CpVal
Southern Transdanubia	2	0.000
Western Transdanubia	2	0.000
Central Transdanubia	1	0.533
Central Hungary	1	0.533
Southern Great Plain	0	-
Northern Great Plain	2	0.000
Northern Hungary	1	0.5333

The map on the left side of *Figure 7* shows all matches, while the one on the right shows only significant connections. We can observe again that the Eastern part of the country is interconnected, with all regions having low values (*Figure 7*), while the western regions again have significant connections, all regions having high values (*Figure 7*). Central Hungary is the East-West divide region with extremely high values of new BEV registrations compared to the whole stock of personal automotive vehicles. This area has an insignificant connection to its western neighbour and no connection to other surrounding regions. This links back to the low-low spatial correlation found between the North-Eastern counties (*Figure 5*) that held for all BEV registrations in the country measured in absolute values.

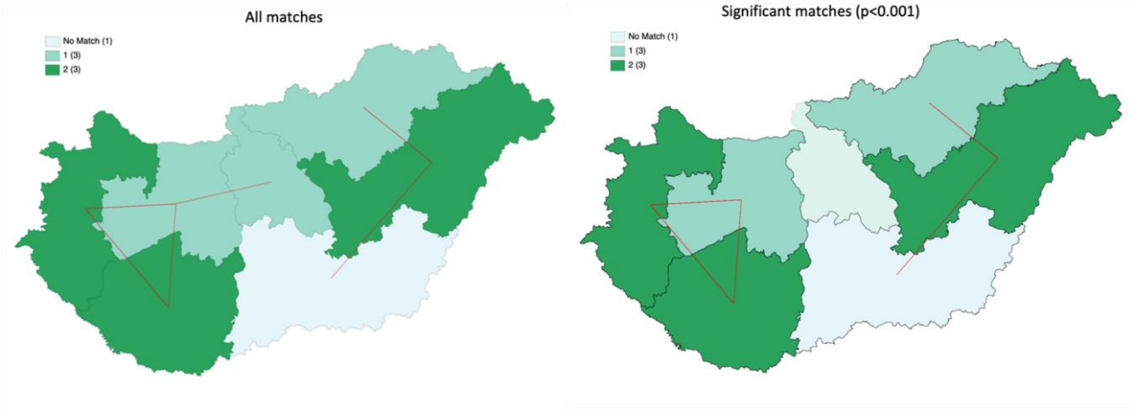

Figure 7. Local neighbour match connectivity and significant locations (p = 0.05).
(Source: KSH: https://www.ksh.hu/stadat_files/sza/en/sza0040.html, own data and compilation in GeoDa.)

Figure 8 shows the number of public charging stations at the end of 2020. As expected, most public charging stations are located in Central Hungary. The most significant difference compared to the map representing the new BEV registrations (left side of *Figure 6*) is that even though in the Southern Great Plain the number of newly registered BEVs in 2020 was higher than in the Northern Great Plain, the number of charging stations is reversed.

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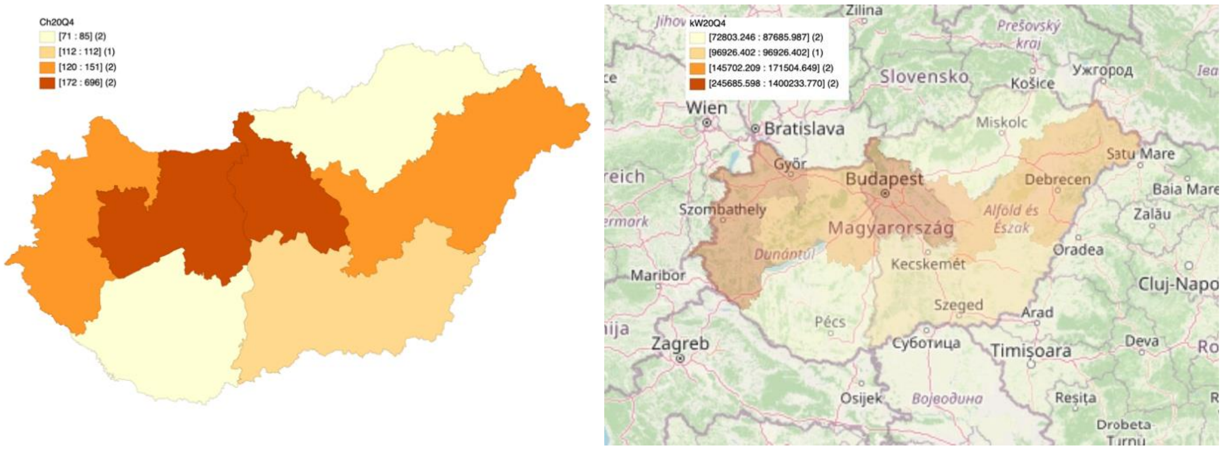

Figure 8. The total number of public charging stations located in Hungary in 2020.
(Source: MEKH: http://www.mekh.hu/beszamolo-az-engedelykoteles-elektromos-toltoberendezesekrol-2022-ii-negyedev and own compilation in GeoDa.)

One possible explanation is that the location of the charging stations was built near the highways for transiting vehicles that generated high traffic in the region. However, there are two major transit routes from Romania, one that crosses the border at the Northern Great Plain region and the other at the Southern Great Plain region (right side of *Figure 8*). Still, the number of charging stations is higher in the first one, probably due to the usual higher traffic of fuel-efficient vehicles. This assumption is sustained by the energy consumption value represented by *Figure 9*, in which we can also observe that the kWh consumption is higher in the Northern region. Of course, it is rational that EV owners charge their vehicles in places where chargers are available. However, if they were really badly located, the consumption would also be lower.

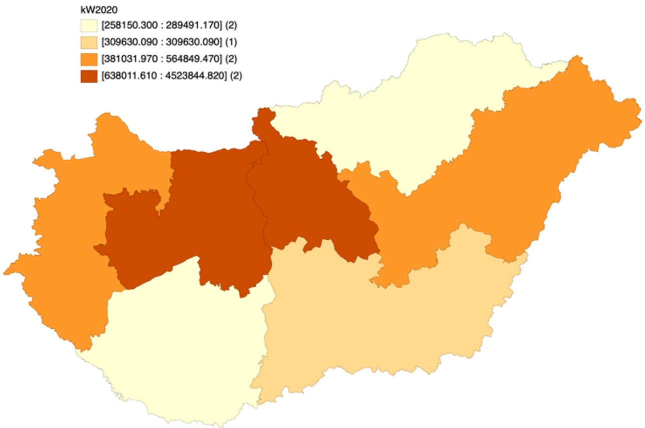

Figure 9. Total energy consumption at the public charging stations in Hungary in 2020 (kWh).
(Source: MEKH: http://www.mekh.hu/beszamolo-az-engedelykoteles-elektromos-toltoberendezesekrol-2022-ii-negyedev and own compilation in GeoDa.)

4.3. Spatial comparison of BEV registrations and charging infrastructure in 2021

Compared to 2020, in 2021, the difference between the Eastern and Western sides of the country is not that obvious. Analysing *Figure 10*, one can observe that in terms of absolute values, most BEV registrations were made in Northern Great Plain region after Central Hungary. More than that, even to the whole stock of personal automotive vehicles in the country, the ratio of new BEV registrations in this region is in the third quartile (*Figure 10*):

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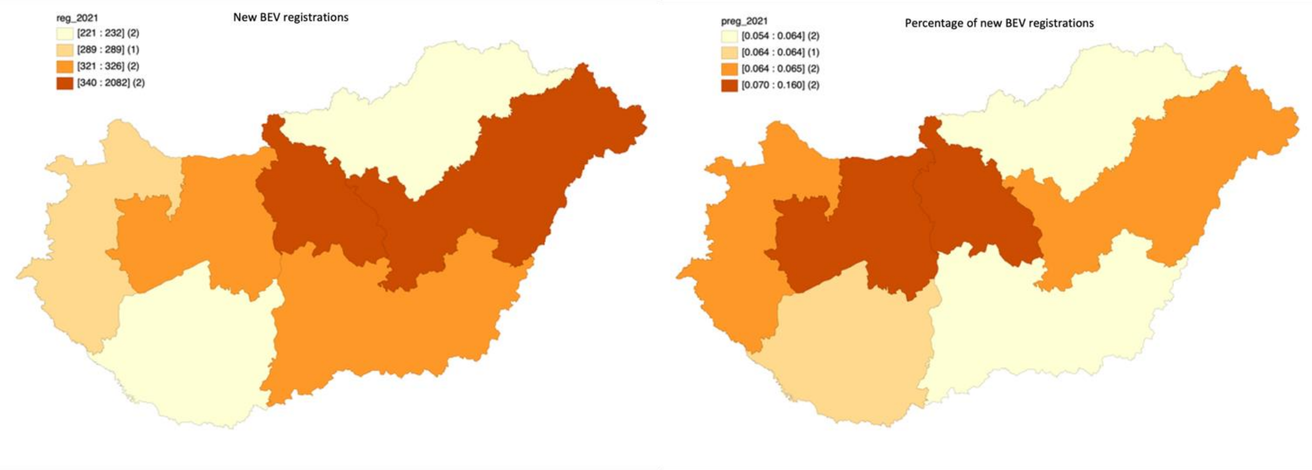

Figure 10. New BEV registrations and their ratio to the total personal automotive vehicle stock in Hungary in 2021 by region.
(Source: KSH: https://www.ksh.hu/stadat_files/sza/en/sza0040.html, own data and compilation in GeoDa.)

Note that the mentioned region is where the number of charging stations in the previous year was relatively high compared to the number of new BEV registrations. Thus, registering the second highest number of BEVs within the regions can be due to the reduced range anxiety or positive marketing effects due to the visualisation of the high number of EV chargers on roads. More than that, the response to the lack of charging stations in the Southern Great Plain region came quickly, as by the end of 2021, it moved up from the second to the third quartile (*Figure 11*):

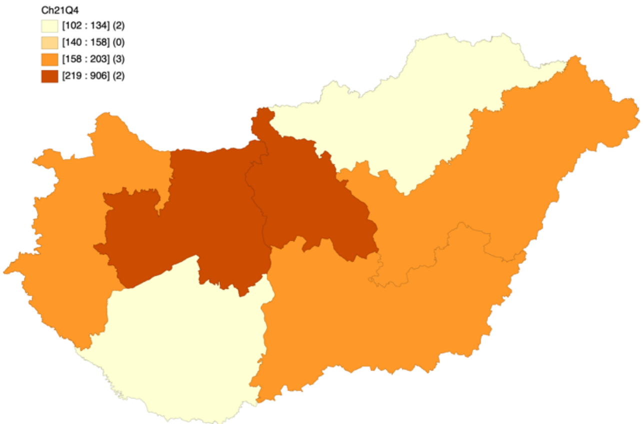

Figure 11. A total number of public charging stations located in Hungary in 2021.
(Source: MEKH: http://www.mekh.hu/beszamolo-az-engedelykoteles-elektromos-toltoberendezesekrol-2022-ii-negyedev and own compilation in GeoDa.)

With the growth in the number of public charging stations in the Southern region, the mentioned transit path connecting Hungary and Romania in the Southern Great Plain region became more frequented by EV drivers. This can be seen very well in Figure 12, as the energy consumption at the charging stations grew remarkably in the Southern region, probably because of the available high number of BEVs in the region and the growing number of charging stations on the transit lane.

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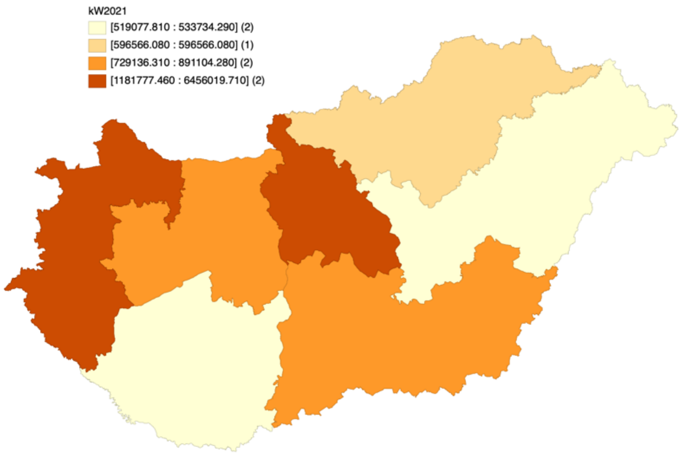

Figure 12. Total energy consumption at the public charging stations in Hungary in 2020 (kWh).
(Source: MEKH: http://www.mekh.hu/beszamolo-az-engedelykoteles-elektromos-toltoberendezesekrol-2022-ii-negyedev and own compilation in GeoDa.)

This result suggests that the location of the public charging stations influences the decision-making in optimal route planning and BEV purchasing.

5. Conclusion

It can be concluded that the Hungarian BEV market is fast-evolving in terms of new BEV registrations and the development of the charging infrastructure. Considering the absolute number of new BEV registrations in 2020, there was a significant low-low spatial correlation within counties in the North-Eastern part of the country. This suggests that in this region, the BEV adoption is slow-growing compared to other counties, which was expected as the overall development of the region is also lower. When considering the new BEV registration to the whole stock of personal automotive vehicles, a division of the country can be observed in the West and East. Significant connections can be found between Eastern and Western regions; however, the Central Hungarian region is not significantly connected to any sides, acting as a watershed between the East and the West. In 2021 this difference started to vanish as the new BEV registration on the Eastern side grew remarkably, probably due to the increase in public charging stations in this region.

Overall, the number of registered public charging stations follows the growth of BEV registrations. On the other hand, the average growth rate of BEVs is higher than that of public charging stations, with the quarterly average growth rate of BEVs being 25%, while this value for charging stations is 22%, showing the need for a faster developing charging infrastructure. Although the number of charging stations could grow faster, the location of the chargers is crucial: well-located stations provide optimal route planning for BEV owners. For instance, in the Southern Great Plain region, the energy consumption from public charging grew remarkably when the number of stations increased. Also, the number of public charging stations probably positively affected BEV adoption, as in the Northern Great Plain region, the high number of charging stations was followed in the next year with the increase in the number of BEV registrations in the second quartile. Future research providing a quantitative measure of the effect of the number of charging stations in 2020 on the number of BEV registrations in 2021 in the Southern Great Plain region could be useful in affirming this conclusion.

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Marginal Abatement Cost, A Literature Review

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Abstract
Since the 1990s, articles have widely used MAC curves to analyse the best alternatives in terms of cost-effectiveness when deciding to abate a negative externality. Most of the articles are related to CO_2 abatement as the main externality to be reduced, and the main advantages and disadvantages of the MACC tool are presented in the literature review presented here. Finally, it is determined whether the curve is a definitive method for analysing and elaborating policy and business decisions or whether the tool needs to correct the methodology to increase the scientific consensus.
Keywords: abatement, externality, marginal cost, policy-making, MACC

1. Introduction

The European Union has set ambitious targets for tackling the externalities of road transport that require significant changes in the sector. This article analyses the situation of externalities related to CO_2 emissions and accidents.

In terms of greenhouse gas (GHG) emissions, the European strategy for road transport establishes a very ambitious plan because this type of transport is responsible for more than 70 % of the total emissions of the transport sector in the EU (*Figure 1*). This is why it sets two important objectives: for 2030, the sector's emissions should be reduced by 55 %; and zero emissions should be achieved by 2050.

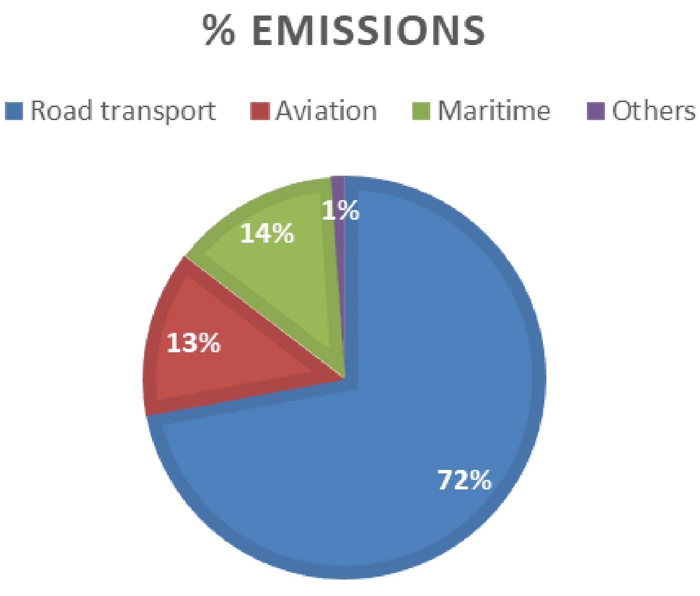

Figure 1. Transport-related emissions in the EU in 2020
Source: Eurostat

Regarding accidents, the European Commission's objectives focus on ending road traffic fatalities, with the objective of zero fatalities by 2050 as the long-term goal, while in the short-medium term, the aim is to reduce the number of casualties fatalities by 50% by 2030 compared to 2019 (*Figure 2*):

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Figure 2. Changes in the number of road fatalities
Source: Eurostat

These ambitious targets set by legislators require aggressive measures in the transport sector to address negative externalities and achieve the agreed commitments. The sector's transformation towards emission neutrality is a major challenge when defining the alternative that achieves the greatest reduction of externalities at the lowest possible economic cost. To answer this question, since the early 1990s, the "marginal abatement cost" curves began to be known as an effective tool for policies aimed at combating environmental and other externalities. This article reviews the literature on this subject to determine whether the marginal abatement cost curve (MAC curve or MCC) is a definitive tool for policy-making in externality reduction. This curve relates the cost of reducing an additional unit of externality (measured in tons of CO_2 if we are talking about pollution) to the reduction achieved in this externality. The diagram below shows how in recent years, the debate on the marginal abatement cost is closely linked to the transition towards more sustainable mobility (*Figure 3*):

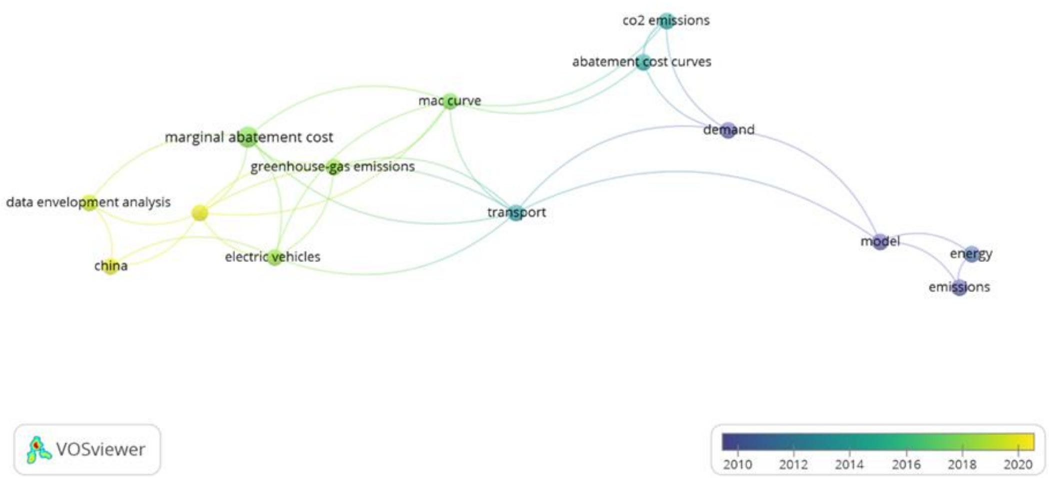

Figure 3. MAC curves
Source: Own edition with VoSviewer

2. MAC curves in environmental protection

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There are two general ways to construct marginal abatement cost curves: a bottom-up approach using technical mitigation options; and the other approach to derive MACCs from computable general equilibrium (CGE) models (Wächter, 2013). In this article, I will focus on the most common bottom-up model in the literature. The MACC curve consists of three elements. The "y" axis is the marginal abatement cost measured in euros per unit of externality reduced. On the "x" axis, the volume of externality reduction achieved by each of the alternatives studied to deal with the analysed externality is represented. These technological alternatives, the bars on the graph, are the third element that allows us to analyse which technology achieves the most cost-effective externality reduction in a given period once the table has been constructed. An example of a MAC curve is given in Figure 4.

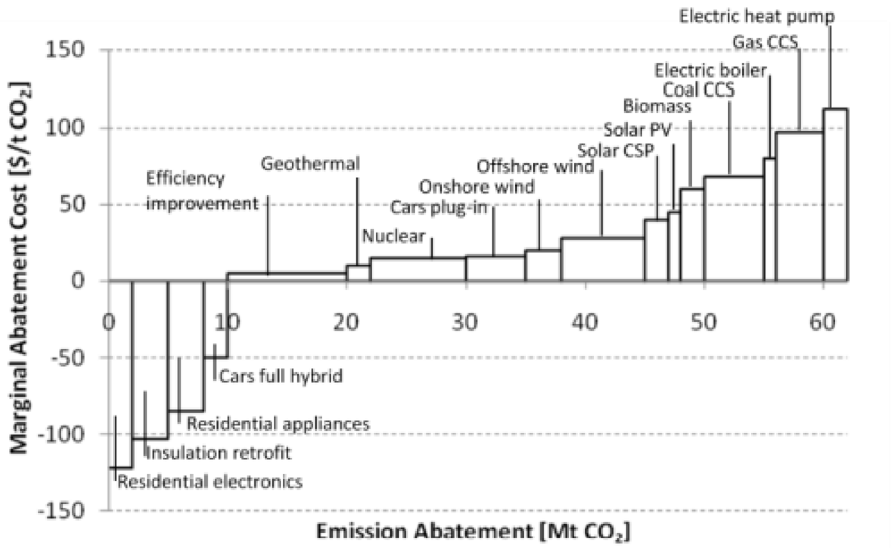

Figure 4 MAC curve example
Source: Kesicki, 2013

The three elements that make up the curve can be observed in this example of the most common MACC, the one used to analyse the most efficient technology for reducing pollutant emissions. If interpreted from left to right, the measures with the lowest marginal abatement cost are observed. Some even have a negative abatement cost, meaning they represent a saving and should therefore be the priority for solving the analysed externality. While on the other hand, the technologies that are further to the right will be the most costly to implement.

One of the most well-known methodologies for obtaining a MACC is regarding the analysis of each technology's Net Present Value (NPV), expressed by the following formula (Eq. 1). At first, the net present value of each technological alternative is calculated. It is divided by the amount of abatement achieved, multiplied by -1 to convert a negative cost into a positive one and vice versa.

(Eq. 1) $$€/_{tCo2} = \frac{NPV}{tCo2\ reduced}\ x\ (-1)$$

Where:
NPV: Net Present Value
T: ton
CO_2: Carbon Dioxide

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3. MAC curves in road safety

With the signing of the Kyoto Protocol in 1997, countries were confronted with a target for reducing greenhouse gas emissions on the world political stage for the first time. It was in the 1990s that the literature related to MAC curves as a possible decision method for reducing atmospheric pollution began to be published. Previously, only a few studies related to oil prices could be found at the end of the 1970s. Using the WoS search engine, the 40 most relevant articles were analysed. The first relevant fact is that the same journal, Energy Policy, has published eleven.

Regarding the position of these articles on the MACC curve, the vast majority are limited to using the methodology to analyse the abatement potential in a specific industry or country, which can be considered an acceptance of the MACC methodology as an alternative with broad scientific acceptance, although most of the articles mention the limitations of the MAC curve (Fabian Kesicki, 2011), (Kesicki, 2011), there are only two articles among the 40 most cited articles that openly oppose the MACC methodology as a valid decision method. Kesicki and Ekins (2012) focus their criticism, especially on McKinsey's work with the following words, "it does not take into account interactions and the dynamic character of decarbonising the economy; it summaries average costs across a technology, though we know the variation in project costs within a technology can be much greater than variations between the average costs of competing technologies; it presents information about a single year's emissions, though they depend crucially on earlier abatement actions". Moreover, secondly, the article (Ward, 2014), criticises the methodology in its entirety. It claims that there is an error of interpretation since, according to its hypothesis, the alternative with the lowest marginal abatement cost is not always the preferable one to carry out. For this, Ward shows an example where the technological alternative with the lowest MAC value is the one that achieves the least amount of abatement. Thus, the conclusion is "Whilst MAC curves are just one tool used in assessing strategy, there remains a large risk of prioritising energy efficiency measures using an incorrect interpretation, which is likely to be wasting resources in the sub-optimal implementation of efficiency measures".

Within the literature on MAC curves, it is inevitable to mention the consultancy firm McKinsey, which since 2013 has carried out multiple studies on the MAC curve for many countries and sectors, primarily focused on pollution abatement. In addition to their work on environmental externalities, in 2013, they carried out a pioneering study on applying the curve to develop policies to improve road safety. This approach was a novelty, as this method was used for the first time to deal with a transport externality other than the environmental one. Following the curve methodology, the first step is to analyse the history of road accidents in a specific area to determine the reasons and design the alternatives that will be placed on the curve. This involves a preliminary fundamental analysis of the cost of each of these possible policies, which, together with an estimate of the reduction in accidents for each of them, makes it possible to analyse the cost of each measure in terms of the number of deaths it prevents and its cost to society.

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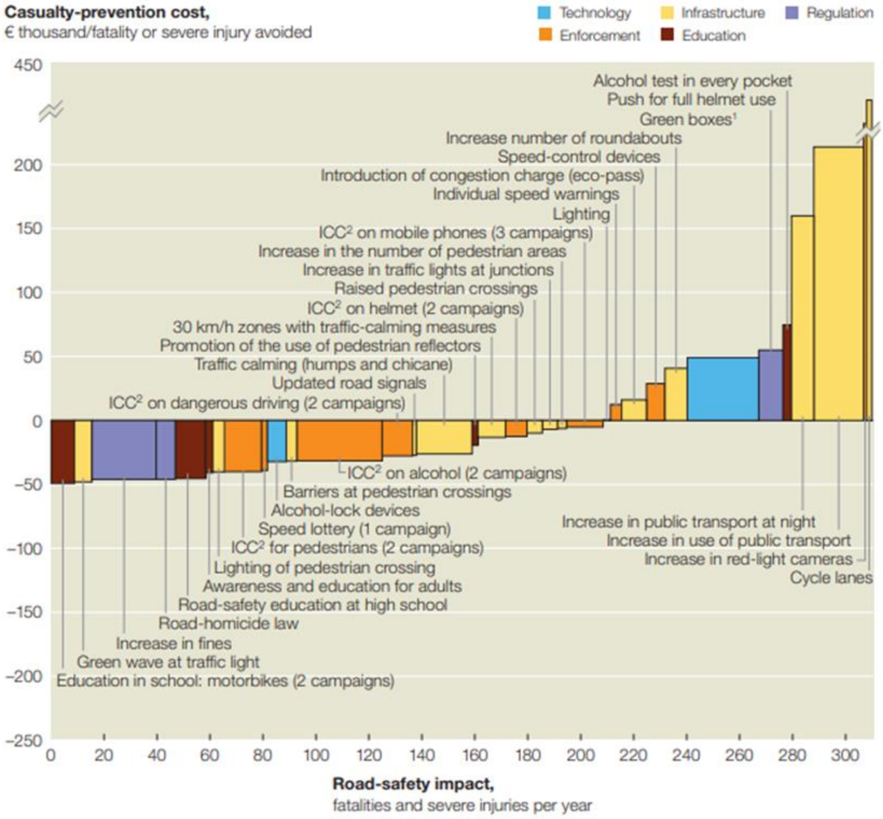

Figure 5 MAC curve example on road safety
Source: Ghislanzoni, Myerson, Ragani, 2013

Since McKinsey's work, an increase in articles on OMC has been observed in the literature analysis. With China being the most polluting country in the world, it is understandable that five of the six most cited articles since 2014 deal with its situation. The literature includes abatement curves on coal-fired power plants on which China remains dependent (Limin Du, 2015), articles presenting the situation of emissions caused by industry in large cities such as Shanghai using a curve (X. Zhou, 2015), and others that address the issue of energy efficiency in the country's buildings and its potential for the future as a tool for emission reduction targets (He Xiao, 2014) which concludes with an optimistic forecast " the annual CO_2 reduction potential of newly constructed buildings will be 214 million tCO_2, 42% of total potential by 2030". These articles highlight the importance of MAC curves as a widely accepted method of policy decision-making in China. In recent years, the most cited works have focused mainly on coal abatement and the energy sector in various countries. However, a major difference is the absence of the classic MAC curve in all of them, transforming it into a more complex but analytical curve with greater mathematical support that responds to the evolution of the debate on the possible weaknesses of the McKinsey methodology. Articles that are focused on advice on decision-making on abatement reflect the new developments in its methodology to combat the static nature of the classic MAC curve; "this study involved a comprehensive analysis of possible developments and potential alternative pathways for GHG reduction for the transport sector and the first application of a cost-optimising energy system model for Gauteng. The presented method can also be applied to other socio-economic sectors or the whole energy system" (Tomaschek, 2015).

4. Conclusion

This article's analysis of the existing literature on marginal abatement cost presents two main conclusions. On the one hand, most of the literature agrees on the tool's usefulness as a practical policy decision method, but almost all of them also recognise its limitations and, therefore, the room for improvement. As strengths, the literature highlights the visual and easy-to-analyse approach provided by the curve to compare different technologies or policies. As a weakness, the most repeated one is the static character of the curve that does not consider the possible variation in energy prices. Therefore, in the conclusions of most of the articles, although the recent ones are starting to present interesting new methodologies for overcoming these weaknesses, the need

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is expressed to continue developing the curve until a higher level of uncertainty is reached, which allows the MAC curve to be positioned as a method of broad scientific consensus in the development of policies to combat an externality is highlighted.

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Sustainability and Climate Risk Data: A New Era for Investment Decision-Making in the Age of Climate Change

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Abstract
As economic actors face increasing pressure to be socially responsible and environmentally conscious, investors look beyond traditional financial metrics and seek data to support their decision-making. Measuring and reporting sustainability and climate risks is a relatively new discipline with several interrelations to economic, financial, risk management, and other cognitive study areas such as climate sciences, and have come a long way in the last couple of years. We are in the middle of the evolutionary process, as data availability and coverage are much better than a decade ago. However, there is still a lot to do until the new metrics and indicators are fully embedded in risk management frameworks and decision-making processes, similar to traditional risk measures. In our essay, we will explore the role of third-party data vendors for sustainability, ESG, and climate risk-related information, their importance in the modern investing world, and review the major challenges. We give an insight into the evolution of the market of data vendors and also the regulatory landscape. Finally, we explore the unique roles of central banks and their challenges in implementing actions in sustainability.
Keywords
climate risk data, ESG data vendors, carbon emissions, sustainability

1. Introduction

It is no doubt anymore that climate change is one of the most significant challenges of our times. Even to an ordinary person not working in the field of climate sciences, it is now getting clearer and clearer that extreme weather events are growing, with increasingly severe consequences on the economy, value chains, and the entire society. In addition, it is enough to think about air pollution in big cities, plastic pollution, oil spills, biodegradation, and deforestation to understand that the environment around us is seriously deteriorating, which makes our economic systems unsustainable.

Due to the increased pressure from the public to mitigate the consequences of climate change, politics and regulations are also changing. For example, 196 countries signed the Paris Agreement in 2015, intending to limit the warming of the global average temperature to 1.5 °C above pre-industrial levels. Later, the European Green Deal was announced in 2019 to achieve carbon neutrality by 2050, with an interim goal of reducing greenhouse gas (GHG) emissions by 40% by 2030 compared to 1990.

The targets are ambitious, and tremendous financial investment must be channelled into the green transformation to achieve them. That is why the financial system and its regulators will play an essential role. Consequently, the world of investing is also changing, and today, ESG (Environmental, Social, Governance) factors – among which environment, more specifically climate-related risks – are coming to the forefront of investors' minds (*Bokor, 2022*). One exciting piece of evidence, for example, is that the interest in web searches on ESG has been consistently growing (*Figure 1*).

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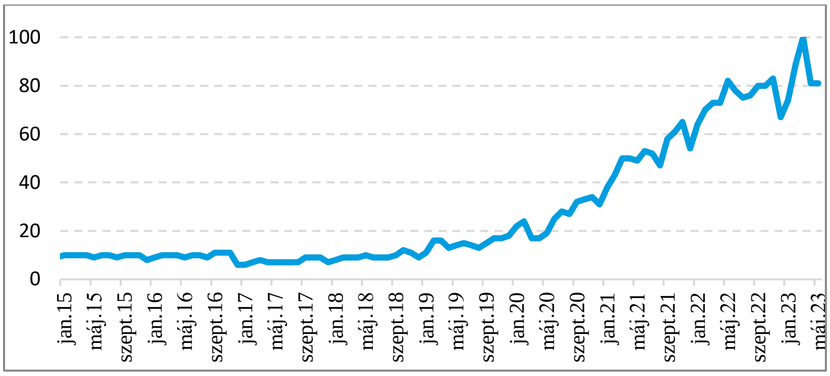

Figure 1: Google search trends for ESG
(source: Google Trends - https://trends.google.com/home)

It is also a good indication of the importance of the topic that more and more investors declare some dedication to sustainability goals. For example, the signatories to the United Nations' Principles of Responsible Investment (UN PRI) reached the level of 4000, representing more than $120 trillion in Assets under Management (*Figure 2*):

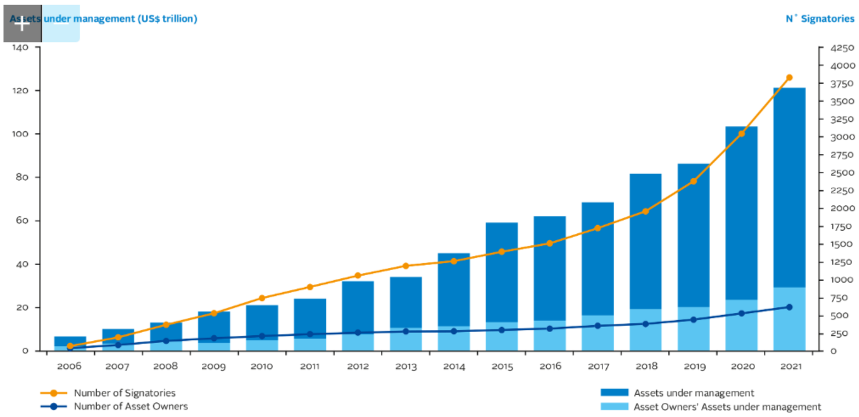

Figure 2: Number of signatories and Assets under Management to United Nations Principles for Responsible Investment
(source: https://www.unpri.org/annual-report-2021/how-we-work/building-our-effectiveness/enhance-our-global-footprint)

However, although sustainability topics are popular and driven higher up on the agenda, serious obstacles exist when implementing practical investment strategies dedicated to supporting the green transition. This article is about sustainable climate risk management. We hypothesise that a new era is yet to come for investment decision-making. Considerable change will appear due to climate change, where the bank sector has an important role.

2. Importance of Robust and Reliable Data

In market-based economies, businesses need to be transparent to allocate resources effectively. In the past, transparency mostly meant that investors demanded companies to be open about risk and rewards and to present how investments can be turned into cash (*Kolozsi et al., 2022*). Climate change's impact varies in degree and manner affecting every economic player. As the issue of sustainability gains more prominence, economic actors are increasingly expected to demonstrate their commitment to sustainable practices. Investors want to evaluate business sustainability and seek ways to incorporate such factors into risk models, return expectations, and prices of financial products.

"*There may be unique recipes and different solutions for a green transition, but it is beyond dispute that green transformation will not happen without measurement*" (*MNB, 2022a*). To accurately identify and assess climate-related risks, it is essential to have access to reliable, well-organised input data, among others, the following:

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- **Emissions data**: greenhouse gas (GHG) emissions, carbon footprint, and other pollutant emissions from the company's operations and supply chain.
- **Energy usage data:** energy consumption across the company's operations, including electricity, heat, and transportation fuels.
- **Water usage data:** the amount of water the company uses in its operations and the quality and availability of water resources at its locations.
- **Social impact data:** the company's labour practices, human rights violations, stakeholder engagement, and community impact
- **Financial data**: the company's revenues and expenditures, e.g., the share of "green" CAPEX or revenues from "brown" activities.
- **Climate-related financial risk data**: potential financial impacts of climate-related risks such as extreme weather events, changes in government regulations, and physical risks to assets.
- **Supply chain data**: the environmental and social impacts of the company's suppliers, including their emissions, energy usage, and labour practices.
- **Environmental impact data:** the company's impact on ecosystems and biodiversity, such as deforestation, pollution, and waste generation.
- **Climate scenario analysis** involves modelling the potential impacts of different climate scenarios on the company's operations and financial performance.

Overall, a thorough analysis of corporate sustainability and climate risk exposure requires inputs from multiple sources, including the company's operations, supply chain partners, and the broader environmental and social context in which it operates. It is essential to see that investors are interested not just in backwards-looking data (e.g., historical data on emissions), as it does not give a complete picture of entities' sustainable practices. Therefore, forward-looking analysis techniques are also necessary.

In most cases, investors usually do not have the resources (time, expertise, etc.) to collect and synthesise data and develop models and methodologies for all the companies and financial variables around the globe. That is why they usually "outsource" the related processes and tasks, i.e., they rely on the services of third-party data vendors and rating agencies. The market of service providers in the "classic" economic areas is well established, with vendors covering a broad set of services, data (e.g., Bloomberg, Reuters), and some specialists. Data and modelling also have a long history. For example, traditional credit rating agencies already have approximately a hundred years of history.

3. The Emergence and Evolution of the Vendors' Market

Measuring and reporting climate and sustainability risks constitute a relatively new discipline that has come a long way in recent years. About ten years ago, such topics were not the focus of the investor community. However, in the middle of the last decade, with the ramp-up of green bonds (bonds that aim to support climate-specific, sustainability-related special environmental projects), a new market emerged, as the increasing demand for information by investors and policymakers is driving growth in the market of sustainability/ESG/climate risk data vendors.

In many instances, dozens of players in the market operate in a complex ecosystem *(Figure 3)*, with interrelated services and relations to each other. Different vendors provide diverse products and services, from raw data and reports covering multiple ESG aspects to highly advanced analytical platforms. Their focal points include stock screening, competitive benchmarking, portfolio construction and analysis, risk management, evaluating green bond frameworks, drafting second-party opinions, conducting scenario and controversy analysis, and offering ratings and rankings.

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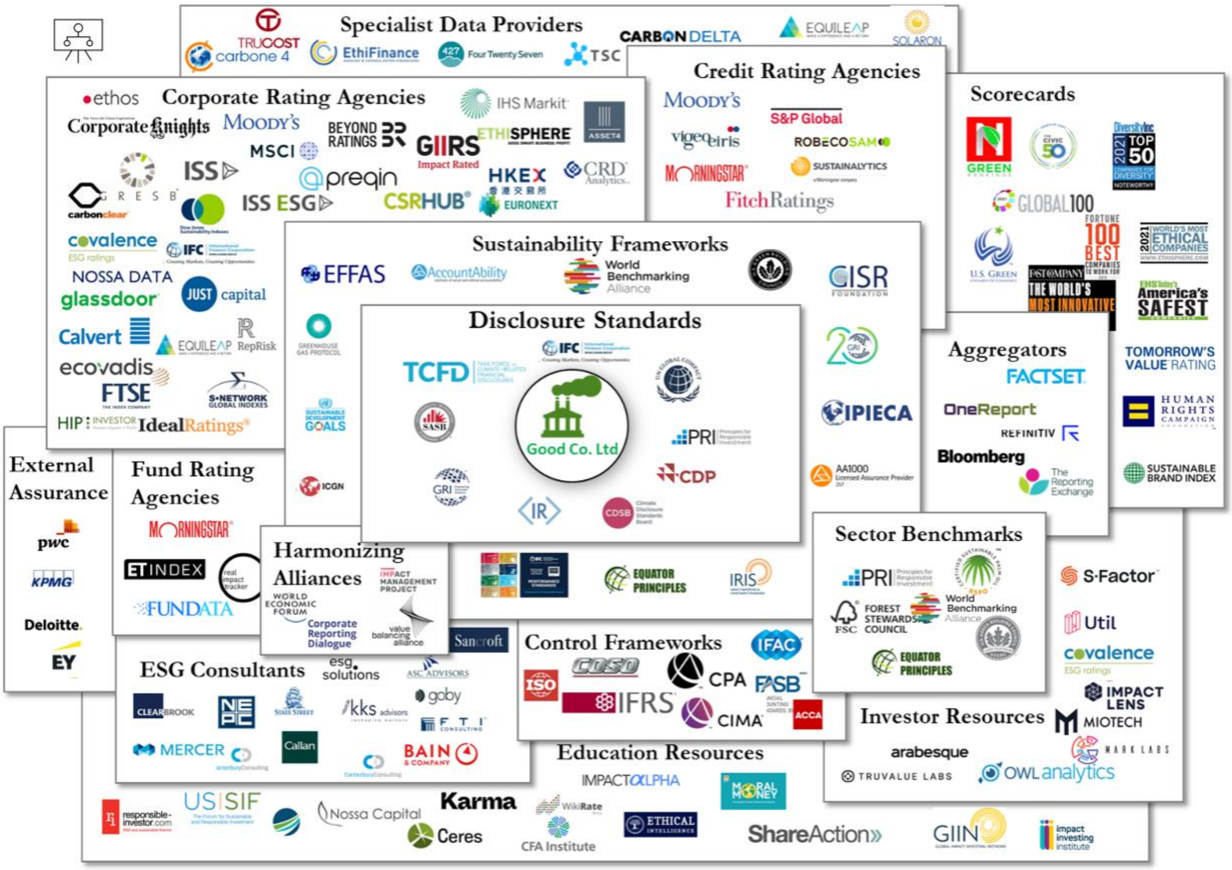

Figure 3: Most important players in the ESG ecosystem
(source: https://www.tsc.ai/the-esg-playbook)

Despite the difficulty in overviewing the ecosystem's structure, the players can be classified into four main, simpler categories. (*Mittal et al., 2022*).

1) **Data providers with a global focus:** wide coverage in terms of geography, asset classes, and metrics (e.g., MSCI, SnP, Fitch, ISS).
2) **Classic market data vendors:** providers of financial market data, enhanced with ESG/climate risk as one of the offerings (e.g., Bloomberg, Refinitiv).
3) **Specialists**: vendors focusing on a specific topic (e.g., on climate risk only: Carbon 4 Finance, green bonds: FGM).
4) **Platform providers**: data and tech companies offering platforms, often using third-party input data (e.g., State Street).

3.1 Forces affecting the vendors' market

To understand the current events and put the trends into context, first, we assess the market state using Porter's Five Forces framework (*Mähner, 2021*). Investors can differentiate between data and analytics vendors by considering various factors such as their market coverage, quantity and quality of indicators and metrics, and methodology. However, due to the diversity of solutions and general uncertainties around the data and methodologies, trust and credibility play the most crucial role when selecting a third-party vendor. Building a reputation in this market requires specialised expertise, access to comprehensive data sources, and a track record of reliable and accurate assessments. That is why it is not by chance that the market is dominated by giant institutions like Moody's, MSCI, Fitch, Bloomberg, and S&P. Although

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there are several start-ups and newcomers, entering into the "Class A" league is cumbersome due to the above-mentioned reasons. Hence, we consider the threat of new entrants relatively low (*Avetisyan and Hockerts, 2017*).

The bargaining power of buyers is mixed. Large global corporations, and multilateral institutions, have more bargaining power due to their ability to demand customised services or negotiate pricing. Large institutional investors can even develop in-house capabilities. However, smaller companies may have limited leverage, mainly if they heavily rely on ESG ratings to do their business.

The bargaining power of suppliers is relatively low. As mentioned above, the most significant providers are usually quite huge companies which can negotiate on their terms. Also, those which renowned rating agencies own can utilise the data collected or generated by the group. On the other hand, smaller ESG rating agencies have a weaker position when negotiating with their suppliers.

The threat of substitute services is relatively low. ESG ratings are highly specialised and distinct from other financial or non-financial assessments. While alternative approaches, such as self-assessment frameworks or industry-specific certifications, exist, they do not offer the same level of comprehensive evaluation as the big agencies.

As opposed to the views of *Avetisyan and Hockerts (2017)*, we believe that, despite the market being dominated by the big players, the competitive rivalry among them is fierce. They try to differentiate themselves from each other by using different methodologies and approaches and try to enhance credibility by increasing transparency in their methodologies. However, they face the challenge of protecting their intellectual property (*UNEP FI, 2022*). More prominent players have a clear advantage here because of their better efficiency of scale, better brand recognition, and longer-standing relationships with clients.

3.2 Consolidation as a major trend

A significant and reputable traditional rating agency often owns sustainability data vendors. However, this was not always the case. The present landscape results from mergers and acquisitions over the past few years (*Avetisyan and Hockerts, 2017*).

Many traditional rating agencies have decided to enter the market by acquisition. For example, S&P Global bought Trucost, a provider of environmental data and ESG analytics, in 2016 and acquired The Climate Service (TCS) and its integrated climate risk platform in 2022. Moody's acquired Vigeo Eiris in 2019 and purchased RMS and Four Twenty-Seven, a data research firm focusing on physical risk analyses. Morningstar bought Sustainalytics in 2020, while Inter-continental Exchange acquired Urgentem in 2022. In addition, several partnerships were made. For example, BlackRock established cooperation with Rhodium Group, Quantis joined BCG, and recently, Moody's and McKinsey announced cooperation in sustainability topics (*UNEP FI, 2022*).

Based on recent experiences, the industry consolidation may continue. Most smaller players will likely either be bought or merged with other big players. As the industry matures, cost efficiency will play a more significant and prominent role. If a smaller actor wants to stay independent, he must specialise.

3.3 Challenges

Investors are increasingly interested in sustainable investing; therefore, ESG has become an essential tool for evaluating businesses' performance. To support investors in making sound decisions, input data must satisfy at least the following criteria:

1. **Accuracy** - Data should be precise and error-free.
2. **Relevance** - Data should be related to the specific needs of the user.
3. **Comprehensive** - The data collected must be complete and include all relevant information.
4. **Consistency** - Data should be consistent and comparable across different sources.
5. **Cost-effectiveness** - The cost of data collection and maintenance should be reasonable.

Despite the evolution in the market, climate risk and ESG data vendors face several challenges; there are critics associated with almost all of the above criteria.

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A survey by *Blackrock (2021)* arrived at a similar finding. When looking at challenges integrating ESG risks, most of the interviewed banks marked data-related considerations as the main obstacles and the absence of standardised approaches and varied definitions of ESG risks *(Figure 4)*. Another survey yielded a similar result: the institutional investors who responded stated that the main challenge to speeding ESG adoption for their company is the lack of reliable and consistent data (*Kumar et al., 2020*).

Figure 4: Challenges in the adaptation of ESG
(source: Blackrock, 2021)

Third-party data providers are quite divergent in their approaches, leading to high uncertainty when one is trying to figure out how to implement sustainable strategies. Given the above-mentioned challenges, it is not surprising that there is high pressure from investors for transparency on coverage, methodologies, and chosen metrics when choosing a third-party vendor *(Figure 5):*

Figure 5: The most important factors to consider when choosing vendors
(source: UNEP FI, 2022)

Investors already use a range of approaches when integrating sustainability and climate risks into their decision-making. One easy way is tilting the investment portfolio from brown companies to greens, i.e., excluding those with higher GHG emissions and replacing them with lower emitters. The effectiveness of these actions in promoting the transition to a sustainable economy depends on the reliability of the input data. While certain companies provide regular reports on their environmental data, this is not the case for all players; data vendors may provide estimated emission data with their proprietary models. The prevalent notion among investors is that estimated emissions can be a feasible alternative to reported data, indicating an underlying belief that data providers have effectively bridged the gap in data accessibility. Inaccurate data, however, represents a significant risk in various scenarios. Using GHG data that is not comprehensive or reliable can cause investors mistakenly identify brown companies as green companies and vice versa.

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Also, there are similar concerns with ESG ratings that try to compress an assessment of the impact of environmental, social, and governance factors on a company into one figure. It is important to understand that a rating – similar to traditional credit ratings - never measures the risk levels perfectly (*Cantor and Packer, 1995*).

Several critics say, for example, that ESG ratings are difficult to understand as E, S, and G factors are not measuring interrelated risk factors (*Lopez et al., 2020; Jacobs and Levy, 2022*), and there is a limited correlation between ratings on the same issuer across various agencies. All these inconsistencies can lead to incorrect information being presented to investors. It is also a threat that some companies may intentionally manipulate their ESG data to present a more positive image. For example, a company may select only its most sustainable operations to report on while ignoring less flashy practices.

Even if ESG ratings are perfect both on a micro and a macro level under any scenario, an environmental disaster can still happen if models are flawed. Missing risk factors, inaccurate data, and inadequate risk weights can lead to misjudged risk assessments and decisions. This is especially crucial for missing risk components. In this case, a company trying to improve the ESG rating in good faith can quickly increase the environmental harm related to the ignored factor.

The risks above are even greater if investors are overreliant on the ESG ratings. We argue that although these indicators are very useful in understanding some aspects of environmental harm, they are imperfect in measuring all important dimensions of sustainability. If we consider these values as a perfect measure, it is conceivable that instead of reducing the risks, we will dramatically increase the ignored risks.

Similarities to traditional credit rating agencies can be our cautionary tale (*Harper, 2011*). The systemic risk in ESG ratings is that they could be subject to the same conflicts of interest and failures of oversight that plagued credit rating agencies in the lead-up to the 2007–2008 financial crisis. ESG rating agencies could become too reliant on fees from companies they are meant to evaluate objectively, which could compromise the integrity and accuracy of their ratings. Moreover, as more investors incorporate ESG factors into their decision-making, there is a risk that companies could engage in "greenwashing" by manipulating their ESG scores to look better on paper rather than making substantive changes in their practices (*de Freitas Netto et al., 2020*). These risks highlight the need for transparency, accountability, and due diligence in the ESG ratings industry.

It is important to highlight that when we give an overview of critics, we do not suggest that data providers or rating agencies are doing a bad job or are negligent in any manner, e.g., in collecting or estimating data. Instead, these services are the most accurate they can provide due to the limited access to information and general unavailability of data.

4. Overview of the Regulatory Landscape

To address the challenges mentioned previously, the regulatory landscape surrounding sustainability and ESG reporting is also rapidly evolving and becoming increasingly important in many countries worldwide. While certain countries have been quicker to adopt and implement regulations, others are catching up.

EU has been at the forefront of ESG regulation with initiatives such as the Sustainable Finance Disclosure Regulation (SFDR) and the Taxonomy Regulation. The SFDR requires financial market participants to disclose how they incorporate ESG risks and opportunities into their investment decision-making, while the Taxonomy Regulation provides a classification framework to help identify which economic activity shall be regarded as environmentally sustainable (*Figure 6*):

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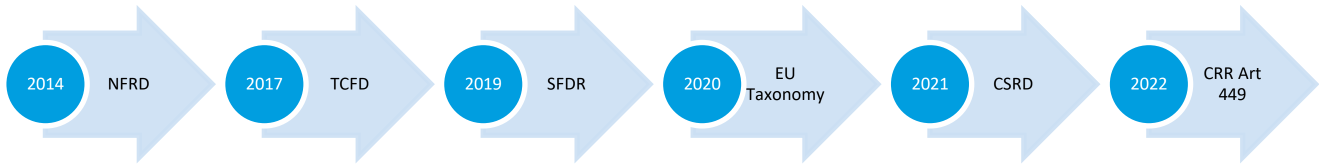

Figure 6: The most important milestones of policymaking affecting sustainability reporting

The new regulation, the Corporate Sustainability Reporting Directive (CSRD), addresses the flaws of the Non-Financial Reporting Directive (*NFRD, 2014*), which proved insufficient. CSRD introduces a more detailed reporting requirement on companies' impact on the environment, human rights, and social standards. All large corporates that are operating in the EU (both listed and non-listed) will be gradually subject to the reporting requirements. This will significantly add to the data availability and decrease greenwashing, as more than 50,000 companies are affected, as opposed to the 11,700 under the scope of the previous directive.

The European Banking Authority (EBA) released one of the most recent regulations in early 2022, reflecting on the banks' role as a credit provider to retail, SMEs (Smalla and medium sized enterprises), and corporate borrowers. It focuses on the banks' corporate and real estate lending to identify carbon-intensive sectors and borrowers. Banks and financial institutions are required starting in 2023, to disclose information to their stakeholders on how they identify, measure, manage, and monitor ESG risks and opportunities, with a special focus on climate-related risks such as physical and transition risks,

The new disclosure will provide information on ESG risk both in qualitative and quantitative terms. The first three tables give qualitative insight and transparency on how well the banks have incorporated ESG risks into their business strategies and governance structure, covering Environmental, Social, and Governance risks separately. The most important part is the ten sheets for quantitative disclosures, covering transition risks, specifically energy efficiency and carbon intensity of the loan books, physical risks, and mitigation actions. By 2024, Green Asset Ratio and total Scope 3 emissions must also be reported.

Table 1 - Qualitative information on Environmental risk
Table 2 - Qualitative information on Social risk
Table 3 - Qualitative information on Governance risk
Template 1: Banking book- Climate Change transition risk: Credit quality of exposures by sector, emissions and residual maturity
Template 2: Banking book - Climate change transition risk: Loans collateralised by immovable property - Energy efficiency of the collateral
Template 3: Banking book - Climate change transition risk: Alignment metrics
Template 4: Banking book - Climate change transition risk: Exposures to top 20 carbon-intensive firms
Template 5: Banking book - Climate change physical risk: Exposures subject to physical risk
Template 6. Summary of GAR KPIs
Template 7 - Mitigating actions: Assets for the calculation of GAR
Template 8 - GAR (%)
Template 9 - Mitigating actions: BTAR
Template 10 - Other climate change mitigating actions that are not covered in the EU Taxonomy

Figure 7: Pillar 3 prudential disclosures on ESG risk - Article 449a CRR
(source: EBA, 2022)

Article 449a CRR represents important progress in ESG disclosure and aims to improve data availability, robustness, and comparability in a standardised way. However, there are still a couple of deficiencies (*Peacock and Marino, 2022*).

(1) the disclosure provides a point-in-time assessment only
(2) some part of the data will likely rely on estimates (there are already several third-party vendors providing dedicated solutions for banks for Pillar 3 reporting), and given the general difficulties of assessing such information (e.g., Scope 3

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emissions), methodologies will likely differ between banks and as a consequence, it will be still challenging to compare the disclosed information, or at least there will be some degree of uncertainty.

(3) it is still challenging to measure how lending, climate risk, and credit risk are related.

(4) certain assets, such as the trading book, are excluded

We consider the new Pillar 3 disclosure requirement as a good starting point. We anticipate that investor attention will initially focus on the simpler indicators, e.g., exposures to the top 20 carbon-intensive firms and industry concentrations. We also expect that after a few reporting periods EBA will evaluate the received information and fine-tune the reporting requirements.

5. Practices from a Central Bank Perspective

The level of involvement of central banks in sustainability and climate risk agenda has also changed in the past couple of years. A decade ago, such topics barely appeared among the top focuses of central banks. There was a fierce debate about whether central banks had to deal with it. Many argued that the responsibility associated with climate change lies with the elected governments and raised concerns that central banks' core functions, such as monetary policy, might be compromised if they are given an additional mandate for which they have no specific tools (*Bingham et al., 2023*).

As years passed, several professional debates clarified the picture, and now the mainstream view is that central banks have an important role in promoting sustainability. This position is even derivable from their primary mandates because of the potential for disturbances to price stability, stability of the financial system, the well-being of companies, payment systems – these may be all affected by the change in climatic conditions. Central banks have special, multiple roles. On the one hand, they are investors due to their role in managing foreign exchange reserves and maintaining asset purchase programs. On the other hand, many central banks have the role of financial supervisory authority, in which function they want to understand the financial sector's resilience to climate risk and may require various data reporting. Last but not least, central banks also try to lead by example and demonstrate their dedication by disclosing information on their operations (e.g., TCFD report). Challenges associated with measurement, backtesting, and data availability exist in all the above roles.

5.1 Central banks in the role of an investor

Green bonds as a convenient investment strategy in reserve portfolios

Increasing the share of green bonds in their foreign exchange reserve portfolios has been one of the central banks' most commonly used impact strategies. Concerning such products, investors are interested mainly in two pieces of information: clear identification of the green label and measurement of the impact. All these assessments require a significant amount of data and analysis. Therefore, impact reports have been increasingly prevalent in recent years. The purpose of an impact report is to provide investors with meaningful information about the environmental benefits of the projects financed by the proceeds of green bonds. These reports are typically created by the issuer of the bond or by a third-party verification company. The report's credibility rests on consistent measurement, reliable data, frequent publication, and integration into the company's reporting framework. Impact reporting is still in its infancy, with several problems that may lead to inaccuracies or misleading information. One issue is the lack of a common definition of a green project and no standard methodology for calculating the environmental impacts. This can make it difficult for investors to compare different projects and may result in investors making decisions based on incomplete or inaccurate information (*Manasses et al., 2022*).

Another problem is the lack of transparency. Some issuers may provide limited information about the project being financed or may only report on specific aspects of the project's environmental impact. This can make it difficult for investors to understand the project's full impact and to assess whether it meets their own environmental criteria. There is also a risk of "greenwashing", where issuers may exaggerate the environmental benefits of a project in order to attract investors. This can be especially problematic for smaller issuers who may lack the resources to conduct rigorous impact assessments. Finally, there is the issue of verification. While some issuers may use third-party verification companies to assess the environmental impact of their projects, there is no guarantee that these companies are truly independent.

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Sometimes, the verification company may have a financial relationship with the issuer or be pressured to provide a positive assessment to maintain the relationship. There has been progress that was addressing the above challenges. For example, Climate Bonds Initiative (CBI) was the first to develop a taxonomy and methodology on the subject, followed by the ICMA Green Bond Principles (GBP) and the Nordic Position Paper (NPSI). As a result, the breadth of metrics and approaches has increased, but it is an important issue that standards are heterogenous and not mandatory. Transparency issues may exist, as methodologies and data sources are sometimes not public. The EU Green Bond Standard (EUGBS), which is on its way, is intended to complement the current standards, and is expected to improve the situation with increased data requirements. Challenges are still abundant as impacts are often ex-ante and based on estimates by issuers or third-party experts. Ex-post reporting is also important. The actual impact may differ from ex-ante estimates. Ex-post assessment is still not that widespread. Some relevant impacts are not even quantifiable. Notwithstanding their remaining shortcomings, impact reports are already a game changer in measuring investments' climate impact. Further improvements and standardisation, potentially accelerated by regulatory requirements, could make green bonds more attractive to impact investors and central banks.

Asset purchase portfolios are on the way to net zero.

In the period following the global economic crisis that erupted in 2008, QE – quantitative easing – became the main element of the monetary policy toolkits. Central banks purchased government securities, mortgage bonds, and corporate bonds and increased their balance sheet significantly with the objectives of conducting monetary easing and achieving inflation targets. Due to different focus and lack of methodologies, sustainability and climate risk considerations did not play a role when building these portfolios.

Things have changed significantly since the introduction of the first asset purchases. For example, several investors globally declare some dedication to sustainability goals and announce their commitment to reducing the carbon footprint of their holdings to net zero by 2050. Despite new asset purchases being stopped recently due to tightening monetary policy conditions, resulting in decisions being practically narrowed to reinvestments, central banks are also trying to investigate how they can integrate sustainability criteria into their portfolios ex-post and reach a better alignment with Paris Agreement.

One method for decarbonising a portfolio is "tilting", i.e., the adjustments of investments during rebalancing by transitioning from higher emitters towards lower emitters (*Giese et al., 2021*).

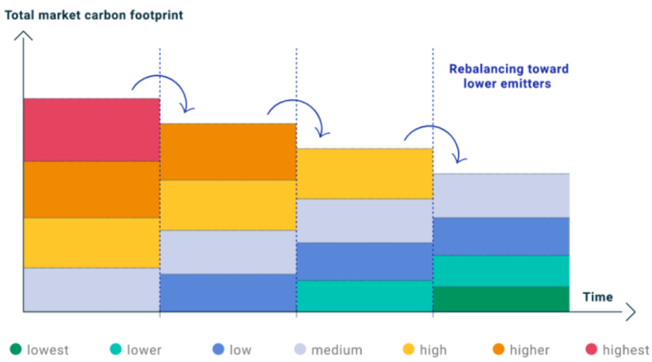

Figure 8: Stylised portfolio with a periodic rebalancing toward lower emitters
(source: MSCI ESG Research – https://www.msci.com/www/blog-posts/constructing-net-zero/02768215423)

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The approach is seemingly easy; however, some practical issues must be considered; for example, what approach do we use to determine if a company has a high carbon footprint? If they are “brown” based on high past emissions and are excluded, financing may become more expensive for them, making the green transition more difficult, contrary to the original idea. If we consider forward-looking indicators too (for example, we look at the green commitment and decarbonisation plans of the company management), it can give a more accurate picture (assuming that we truly believe those plans have explanatory power for decreasing future carbon footprints), but the analysis and implementation of these plans is quite time-consuming (*Marczis, 2022*). Despite the challenges, some pioneering central banks, e.g., Central Bank of Sweden, ECB and Bank of England, announced that their corporate bond holdings would “tilt” to reflect climate consideration.

ECB is trying to decarbonise its portfolio with issuer-specific climate scores that combine the evaluation of backwards-looking emissions and forward-looking targets and assessing the quality of the issuer’s climate disclosures (for further info please visit: *https://www.ecb.europa.eu/press/pr/date/2022/html/ecb.pr220919~fae53c59bd.en.html*). It is interesting that despite its proactive position, ECB received criticism for its tilting exercise NGOs (for further info please visit: *https://greencentralbanking.com/2022/09/27/ngos-criticise-ecb-asset-decarbonisation-plan*), and the lack of transparency behind the methodology was one of the reasons. Another demand by activist groups was the complete exclusion of the issuers with the highest carbon emissions, such as companies in the coal sector.

ESG considerations in central bank investing

Integrating ESG considerations into the investment process is even more difficult than portfolio decarbonisation due to the numerous other factors (such as S and G) influencing ESG ratings. While impact investing is relatively straightforward, the main goal of ESG integration needs to be established, as this approach is a risk management tool. It helps integrate ESG factors into the investment process, which would not be taken into account otherwise, helps avoid ESG controversies, etc., but it is not necessarily the best tool to mitigate climate change. Some central banks have already integrated ESG factors into their investment processes (e.g., Banca d’Italia, ECB pension funds). This has been more widespread in equity portfolios, where in some cases, the investments are passive and „only” the benchmark needs to be replaced using some ESG equity index. At the same time, some have started considering ESG factors in their fixed-income portfolios but mostly only for information purposes, not necessarily influencing security selection yet.

ESG integration is much less straightforward than impact investing. Some challenges include a lack of reliable and decision-useful ESG data and ESG ratings still too heterogeneous. It is also unclear which integration strategies help avoid ESG risks, which may be impactful and encourage companies to improve their sustainability performance, etc.

5.2 Central banks in the role of financial supervisors

In many instances, central banks have the role of financial supervisory authority, too and are responsible for the oversight and regulation of financial institutions and markets. They play a crucial role in safeguarding the financial system from various risks related to sustainability and climate change.

In recent years, there has been growing concern that extreme weather events and changing climatic conditions can seriously affect businesses and industries, leading to financial losses and instability. Therefore, supervisory authorities now recognise the importance of incorporating climate risk into their regulatory framework.

One way they address climate risk is by encouraging financial institutions to disclose their exposure to environmental risks, which will significantly contribute to the data challenges addressed in the previous chapters (e.g., see EBA Pillar 3 disclosure on ESG risks). Moreover, authorities promote sustainable finance by providing guidance and incentives for financial institutions to invest in sustainable projects and businesses. For instance, the Central Bank of Hungary introduced preferential capital requirements on loans with energy-efficient home purposes. Additionally, regulators are incorporating climate risk into their stress-testing methodologies to assess the resilience of financial institutions under various scenarios. Given that the applicability of methodologies based on purely historical data is limited, these stress tests, as forward-looking metrics, can help identify potential vulnerabilities and guide supervisory actions (*MNB, 2022b*).

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5.3 Central banks in the role of a reporter

The Task Force on Climate-Related Financial Disclosures (TCFD) in 2017 released recommendations to support companies and other institutions to publish structured information on climate risk to the public. Over the past five years, there has been significant growth in the number of companies and other organisations that adopted the TCFD framework (TCFD, 2022).

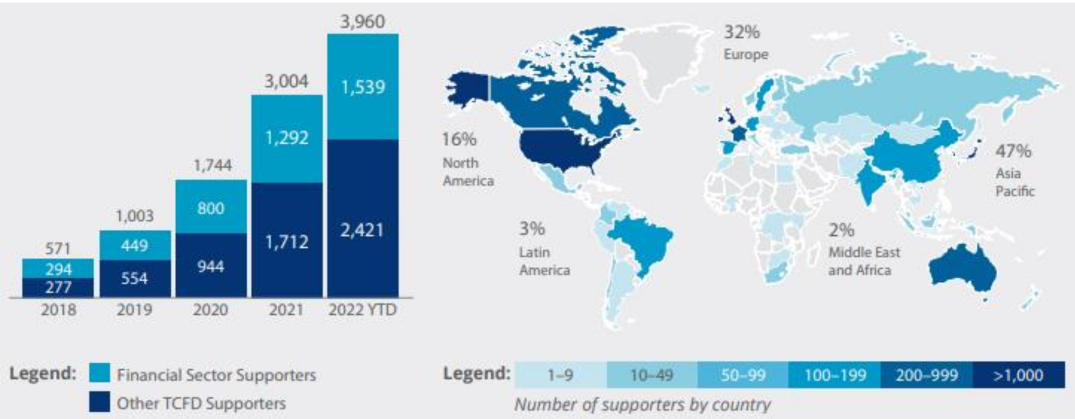

Figure 9: Number and Geographic Distribution of TCFD Supporters
(source: TCFD, 2022)

In addition to the above-mentioned activities, many central banks aim to lead by example and demonstrate their dedication to sustainability by disclosing climate risk-related information on their assets and operating activities (for further info please visit: *https://www.ecb.europa.eu/ecb/climate/climate-related-financial-disclosures/html/index.en.html*). Preparing a TCFD report is not easy, as it requires an in-depth overview of one's exposures and activities, a set of input data is also necessary, and a meaningful selection of indicators.

6. Summary

We aimed to give a broad overview of how we reached a world hungry for sustainability and climate risk-related data. Ten years ago, interest in ESG-related topics was somewhat limited. However, since the beginning of the last decade, the change in climatic conditions has become evident even for ordinary people. Due to the increased pressure from the public, policymakers, regulators, and the world of investing started to change. More and more players aim to understand their exposure to climate risk, and the pressure to disclose one's impact on nature is increasing.

Initially, data were mainly scarce and unstructured, hard to use to support any accurate decisions. Although several vendors started to collect non-financial information on companies (e.g., emissions), the data were mainly voluntarily, and coverage was available for large global companies. Service providers came up with methodologies to model unavailable data points, but the early models were rather rough estimations based on industry and revenue inputs, with a high degree of uncertainty on real emissions. Since then, decent progress has been made in both physical and transition risk assessment. Now there exist not only backwards-looking models but also forward-looking approaches; raw data, ratings, and even more sophisticated methodologies similar to value-at-risk.

Despite the progress, there is still criticism about sustainability, climate risk, and ESG data, which is not attributable to the inadvertence of vendors but rather to the regulatory background, i.e., reporting of ESG risk has been so far non-mandatory.

Due to the uncertainties around methodologies and difficulties in comparing metrics across data vendors, credibility, trust, and brand recognition have become important selection criteria. That is why the industry started to consolidate. Several mergers and acquisitions have been observable recently. We expect this trend in the industry to continue in the future. Most smaller players will be bought or merged with other ESG rating agencies. As the industry matures, cost

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efficiency will play a more significant and prominent role. If a smaller actor wants to stay independent, he must specialise.

The regulatory landscape has also come a long way. In the early years, there were only recommendations for the industry. However, realising the problems, and not incidentally the push from market players, regulators started to catch up with the trends, and now with the introduction of the EU Taxonomy, NFRD, CSRD, and most recently, EBA's Pillar 3 disclosure requirements on ESG risk will bring a new era where hopefully data availability, coverage will significantly improve.

We gave an insight into central banks' unique role in sustainability and climate risk topics. On the one hand, central banks appear on the map with a role as an investor, and they need data to integrate sustainability and climate risk considerations into their investment decisions. On the other hand, they also need data when they are in the role of the financial supervisory authority trying to understand the financial sector's resilience to climate risk. Last but not least, central banks also try to lead by example and demonstrate their dedication by disclosing information on their operations (e.g., TCFD report).

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BluBSIoT: Advancing Sustainability through Peer-to-Peer Cross-Ledgering in Social Internet of Things

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Abstract
The global emphasis on sustainability has stimulated the demand for state-of-the-art solutions that drive the green and blue economy. However, the exponentially growing data analysis remains constrained, leading to a substantial disparity between data supply and demand. This discrepancy primarily arises from data being isolated, inaccessible, and infrequently shared due to concerns regarding data governance and privacy breaches. To tackle these challenges, we propose the integration of Peer-to-Peer (P2P) cross-ledgering within the Social Internet of Things (SIoT) framework as a promising approach to advance cognitive sustainability through improved information sharing and storage. The P2P network configured at the base facilitates a decentralized and secure exchange of information among diverse stakeholders involved in promoting sustainability. By leveraging the immutability and authorized accessibility of blockchain, consortia nodes evaluate and segregate data suitable for on-chain, off-chain, or one-to-one transactions. This ensures the safeguarding of sensitive data while enabling seamless collaboration and sharing. The integration of ledger systems enables interoperability across multiple platforms, fostering smooth information exchange between entities engaged in green and blue economy initiatives.

Keywords
Green economy, Cognitive science, Social Internet of Things, Blockchain, Sustainability

1. Introduction

1.1. Blockchain Technology for secure storage and communication

A blockchain can be viewed as a distributed smart database. Rather than holding the data in a centralized architecture, this digital ledger is distributed among all the network users. A further point is its immutable back traversal of all transactions ever transpired by the network entities (*Priya et al., 2022*). It is by no means an exaggeration to state that the blockchain is vastly complex to hack, with no central authority to cause faults to bankrupt the system. The consensus process uses a pre-set verification algorithm that automatically facilitates data transmission, verification, and storing on a blockchain. This process brings out the property of immutability as the cryptographically locked block of transactions threaded together to form a chain. Bitcoin cryptocurrency has been the initial application of blockchain, but then cryptocurrencies become just one of the technology's use cases (*Upadhyay, et al., 2021*). Additional support for its usability comes from Ethereum blockchains, which use functions to facilitate automatedly triggered smart contracts. In light of these properties, blockchain collaborations can be attained viable by self-executing code eradicating the intermediaries to mediate concerning transacting parties (*Njualem, 2022*). These deductions imply that trustless environments can use this technology where the users can trust the authenticity of records of a distributed ledger. Incentivization and tokenization are not vital elements of blockchain. Regardless of the same peer-to-peer (P2P) methodology, different blockchain platforms retain the resemblance of the essentials and tend to open their framework based on the infrastructure or motive of the use case.

1.2 IoT network of smart green and blue devices

Internet of Things (IoT) sensors and devices have been used for remote monitoring. These methods generate considerable interest in resource management that reaches an optimum stature with minimal resource cost and maximal profits by monitoring diverse environmental parameters of blue and green resources (*Daoud et al., 2022*). The data acquired from IoT sensors and devices can be used for immediate notification for action and long-term observation, and analysis with generalization (*Zahoor, Mir, 2018*). A secluded IoT platform for meticulous resource management and environmental monitoring was proposed in existing literature (*Haertel et al., 2022*) with distinctive approaches of multiple views for various high-level scenarios. The deployment and evaluation of various platforms with sensors and devices were studied. Evidence of implementations in research (Qasabeh et al., 2022), (Rayes, Salam, 2022) suggests the lack of infrastructure from some

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perspectives. The absence of a standardized protocol that incorporates appropriate privacy-preserving mechanisms has impeded the secure sharing of sensitive blue and green economic data. This deficiency undermines the ability of stakeholders to effectively collaborate and develop insights that could lead to innovative and sustainable solutions for complex economic and environmental challenges. Developing a robust and privacy-preserving data-sharing protocol is essential for ensuring sensitive data's confidentiality, integrity, and availability, thereby enhancing data-driven decision-making processes.

Data analysts demand comprehensive insights into the data management processes that precede data arrival in their systems (*Gastón, 2017*). Prior data management uncertainties, such as using strict data cleaning methodologies or malicious alterations, create scepticism about the accuracy of analytical results. In addition, conventional security approaches impose significant energy consumption and processing overheads on IoT devices (*Ashir et al., 2022*). The central server-based security frameworks that underpin these approaches are costly and inefficient, as summarized in *Table 1*. As such, alternative security solutions that are lightweight, distributed, and energy-efficient are necessary to enhance the security of IoT devices and mitigate the risks associated with centralization (*Effah, Bai, Quayson, 2022*).

Table 1. Literature summary in socialization contexts

	Reputation	Socialization	Timeliness	Context Awareness	Social Trust
Fu et al. (2022)	Yes	No	No	Yes	Yes
Nitti et al. (2015)	Yes	Yes	Yes	No	No
Mabodi et al. (2020)	Yes	No	Yes	No	Yes

1.3 Social Internet of Things

The point of convergence of social networking with IoT leads to an extended IoT paradigm referred to as the Social Internet of Things (SIoT) (*Rayes, Salam, 2022*). The smart objects are socially interconnected in a network to subject the material things to a virtual dimensionality cognitive function. The deployed things can smartly interact on social networks to reach social loops for intelligent information to publish to benefit a community group of users and actuate gestures. The deployed network autonomously navigates on efficient object discovery. It is a primary concern on the level of reliability in establishing contacts to share information within the range of socially interconnected things (*Chauhan et al., 2022*). Socialized things contribute to offering scalable networking while increasing the degree of trustworthiness, as illustrated in *Fig. 1*. However, it can be observed from our present-day scenario that ever-increasing demand far and wide is for decentralized trust-enforcing strategies in various social networking contexts. SIoT can revolutionize precision agriculture by enabling the collection of data on crop conditions and environmental factors (*Polas et al., 2022*).

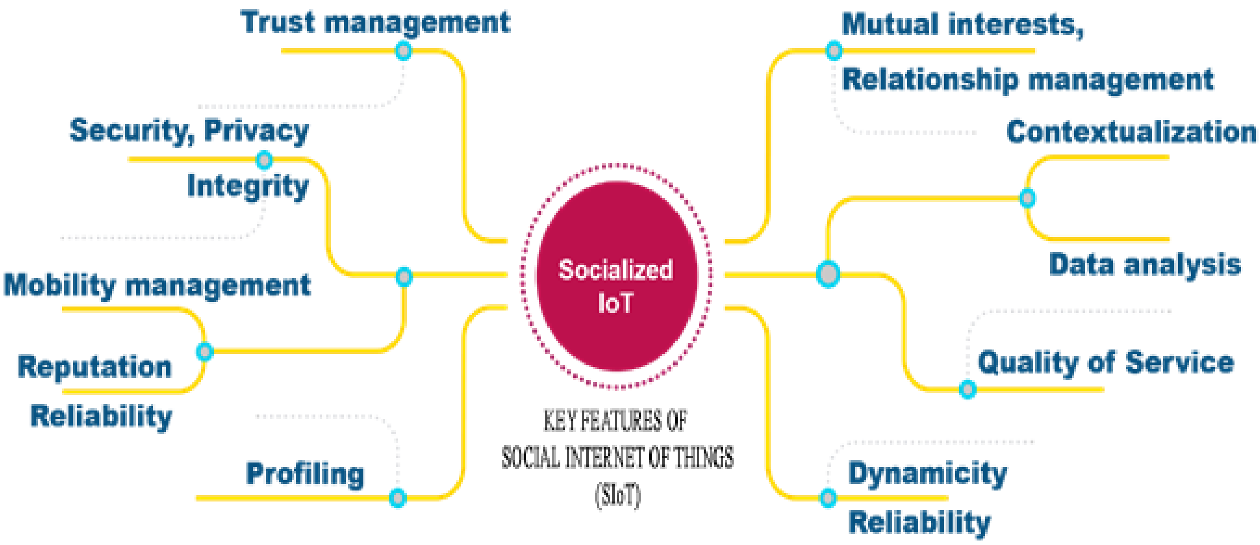

Fig. 1 Characteristics of SIoT

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With smarter green resource management, farmers can achieve scientific crop cultivation. Automation, intelligence, and remote surveillance can revolutionize modern precision farming practices to enhance productivity and efficiency. Various factors are crucial for achieving optimal green resource management in precision agriculture, including atmospheric monitoring, soil analysis, and pest control. By leveraging SIoT, we can transform agriculture and pave the way for a more sustainable future which is summarized in *Table 2*:

Table 2. Literature summary

	Reputation	Social	Timeliness	Context Awareness	Social Trust
Wang et al. (2022)	Yes	No	No	No	Yes
Bao et al. (2013)	Yes	No	No	No	Yes
Chen et al. (2015)	Yes	No	No	No	Yes
Datta et al. (2015)	Yes	No	Yes	Yes	Yes
Xu et al. (2014)	Yes	No	No	Yes	Yes
Gai et al. (2022)	Yes	Yes	No	Yes	Yes

1.4 Consortium group of nodes

A private permissioned Blockchain is a type of network that imposes restrictions on who can access, edit, and verify data on the blockchain (*Heidari et al., 2022*). In the case of a network that involves multiple organizations, it is referred to as a Blockchain consortium. The mechanism of the consortium assumes that the participants are known, registered, and verified within the consortium. The underlying algorithm is designed to validate the ledger once a considerable amount of node responses is signed, eliminating the energy costs associated with hashing protocols (*Singh et al., 2021*). Business networks usually support this consensus mechanism. We plan to utilize a blockchain incorporating the interoperable consortium consensus to minimize processing time and associated costs.

1.5 Cross-ledgering of Blockchains

Cross-ledger denotes the number of approaches that attempt to establish distributed ledgers or blockchains (*Abdelmaboud et al., 2022*). A wide spectrum of diverse blockchains is expected to continue operating in parallel. It is necessary to interconnect such diverse blockchains securely and efficiently to guarantee a universal, unified, and non-segregated realm for distributed ledgers. The primary motivation of cross-ledger is to have multiple interconnected ledgers that exploit transaction locality to achieve scalability, while different ledgers can be designed to offer different functionality (*Sekarlangit, Wardhani, 2021*). The core problem of cross-ledgering is to deploy ledgering without influencing the functionality of other correlated blockchains.

2. Green and blue resources' sustainability

Despite the tremendous volumes of data being generated, a significant challenge lies in finding a secure, privacy-preserving, and globally accessible solution that can unlock the potential of the emerging blue and green economy. Integrating SIoT and decentralized technologies presents a unique opportunity to address the sustainability issues associated with green and blue resources. By connecting and monitoring various devices and sensors, IoT enables real-time data collection and analysis, providing valuable insights into resource consumption, waste management, energy efficiency, and ecosystem preservation. P2P offers scalable storage and computational capabilities, allowing for efficient data processing and collaborative decision-making across stakeholders. The ongoing research and development efforts in this field aim to design and implement robust frameworks that ensure the collected data's security and privacy while enabling seamless sharing and collaboration among stakeholders globally. The pursuit of a safe, privacy-preserving, and borderless solution for unlocking the potential of the green and blue economy is an ongoing endeavour. By harnessing the power of IoT and blockchain, researchers and developers are actively exploring ways to achieve sustainable resource management and promote environmental conservation on a global scale. The outcome of these efforts holds excellent promise for shaping a more sustainable and resilient future for our planet.

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3. Problem analysis

Problem 1 – Energy depletion and excessive expenditure: Blockchain technology's environmental and sustainability ramifications have not been adequately analyzed, particularly concerning its energy consumption. Obtaining more precise and comprehensive information on current and future energy usage related to a blockchain is urgent and requires more exacting methodologies and alternative situations. Developing nations require careful monitoring and sustainability assessments to alleviate detrimental environmental effects. There is a considerable cost in uploading data to blockchain platforms to tackle environmental and ocean data inadequacies. The reason is that most people and fishers are not smart, technologically savvy and without smartphones. There are inadequate standards and frameworks for organizing blockchain activities toward environmental protection and blue resources management.

Problem 2 – On-transit data disclosure: Public data availability to all the entities across a network. Massive data upload onto the blockchain creates a bottleneck in scaling the storage system. Although many studies and research claim that blockchain is safe in every aspect, some studies show that it is still hard to ensure complete privacy, which may create more opportunities for hackers.

Problem 3 – Interoperability between the blockchains implemented within the same context: Currently, most blockchain networks operate independently. The biggest challenge to interoperability is the existence of many blockchain networks that differ in parameters, such as consensus models, transaction schemes, and smart contract functionality.

Problem 4: Once written into the blockchain, data cannot be changed. However, there are situations where data has to be modified by its owner, which cannot be feasible. Because blockchains are deemed immutable, correcting inaccurate or fraudulent data can be onerous. Any inaccurate data input into the blockchain record would be highly costly for the supply chain. This is directly related to human error. Despite the accuracy of data and information flow, the logistics process is still vulnerable to human error, which could cause an increase in rejection rates of process outcomes.

4. Methodology: Secured information storage

Utilizing the Deep Belief Network (DBN) as a generative model of the Deep Neural Network (DNN) technique involves structuring it as a stacked Restricted Boltzmann Machine (RBM) and Sigmoid Belief Network (SBN). The customized DBN comprises three cascaded RBMs with three hidden layers {h1, h2, h3}. An input vector {X=h0} and the hidden layer h1 are connected to a generative stochastic Artificial Neural Network (ANN) known as RBMI. During the first layer training, the DBN is treated as a single-layer RBM and is trained using the constructive divergence technique. During the second layer training, the DBN has two layers, where the upper layer is assumed to be RBM2 and the lower layer is assumed to be a Sigmoid belief network with weight W1 frozen (*Fig. 2*):

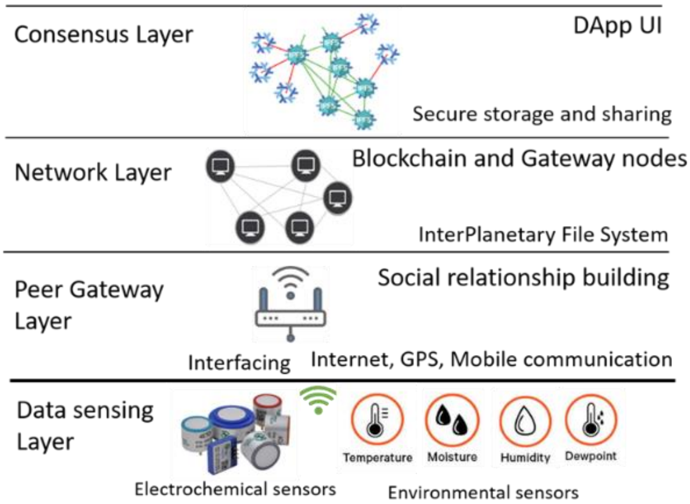

Fig. 2 BluBSIoT: Layered Architecture

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Similarly, during the third layer training, the top layer is treated as RBM3 and the other two as SBN with weights W1 and W2 frozen. The mathematical process of DBN is represented by Eq. (1):

$$P(X, h^1, h^2, \dots, h^n) = P(X|h^1)P(h^1|h^2) \dots P(h^{(n-2)}|h^{(n-1)})P(h^{(n-1)}, h^n) \qquad \text{(Eq. 1)}$$

The probability $P(h^{(n-1)}, h^n)$ of (1) is defined with RBM utilizing (Eq. 2) and (Eq. 3):

$$P(h^i|h^{i+1}) = \prod_j P\left(h_j^i|h^{(i+1)}\right) \qquad \text{(Eq. 2)}$$

$$P\left(h_j^i|h^{(i+1)}\right) = \sigma\left(b_j^i + \sum_k^{i+1} W_{kj}^i\, h_k^{i+1}\right) \qquad \text{(Eq. 3)}$$

The Greedy trained manner was utilized for training RBMs of DBN. The RBM generates features and recreates inputs (*Wang et al., 2021*). Thus, the contrastive divergence method has been utilized for training the RBM. The utilized Gibbs Sampling-based contrastive divergence technique is as follows.

- Initiation of the parameters.
- Define the activation probability of hidden layers utilizing (Eq. 4):

$$P\left(h_j|X\right) = \sigma\left(b_j + \sum_{i=1}^m W_{ij}\, X_i\right) \qquad \text{(Eq. 4)}$$

- Define the activation probability of the input layer utilizing (Eq. 5):

$$P(X_i|h) = \sigma\left(a_j + \sum_{j=1}^n W_{ij}\, h_j\right) \qquad \text{(Eq. 5)}$$

- Upgrade the edge weight utilizing (Eq. 6):

$$Wij = Wij + \alpha\left(P\left(h_j|X\right) - P(X_i|h)\right) \qquad \text{(Eq. 6)}$$

At this point, α refers to the rate of learning. Afterwards, trained the initial RBM, the edge weights are frozen. Then, it can be trained in the succeeding RBM resulting in similar contrastive divergence phases. However, the resultant preceding trained RBM was utilized as the input of the succeeding RBM. Afterwards, after the practical training of stacked RBM, the DBN feature was removed in the topmost hidden layers. As data shared on the blockchain is tamper-evident and accessible to those that have the proper permission to see it, the consortium should consider what type of data should be on-chain, what data need to be accessed by whom, for how long and for what purpose, and what data should be limited to one-to-one transactions as depicted in Fig.3:

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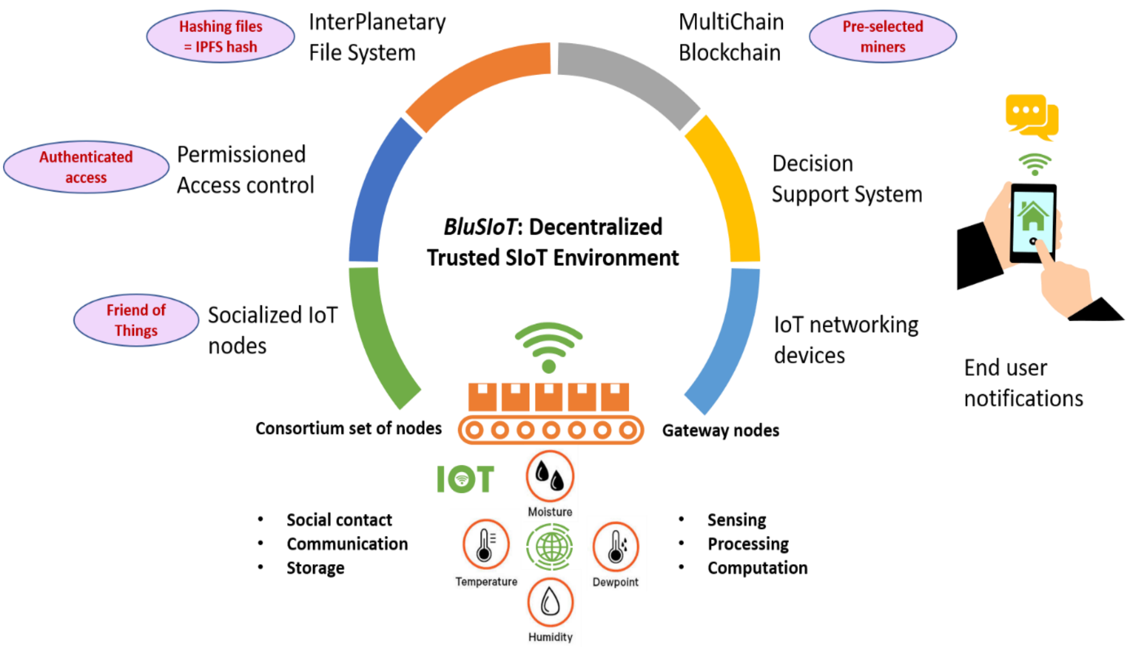

Fig.3 BluBSIoT: Environmental Aspects
Source: Own edition

5. Integrating SIS into green and blue resources for sustainability SWOT analysis

Our system uses blockchain technology, smart contracts, and tokens to enable safe and secure data sharing, guaranteeing control and auditability while protecting privacy. The technology allows organizations and individuals to set pricing and trade data without losing control of their data assets. Smart contracts allow data owners to program the conditions of access, which are then executed with precision. This gives data owners and buyers transparency, security and guarantees of payment and use. This framework is a safe, borderless data-sharing system that unlocks sharing and access to data, allowing consumers and authorized society to benefit from the green and blue economy. It allows for building data services. The system allows people to unlock the data's value without necessarily unlocking it itself. It is a substrate to finally realize the potential of an open permission-less data economy while still preserving privacy. BluBSIoT is a decentralized data exchange protocol to unlock data for decision-making. Through blockchain technology, smart contracts, and tokens, the frameworks connect data providers and consumers, allowing data to be shared while guaranteeing traceability, transparency, and trust for all stakeholders involved. It allows data owners to give value to and control their data assets without being locked into any marketplace by bringing together decentralized blockchain technology, a data-sharing framework, and an ecosystem for data and related services in a blue and green economy that touches every single person, locality and device, giving power back to data owners, enabling people to reap value from data to better the agriculture world.

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Our framework sets standards and demonstrates how to share data safely and securely without compromising privacy or ownership. The work involves ground for a series of private and public partnerships from the research, insurance, retail and healthcare sectors to deploy their Proof-of-Concept solutions on the blockchain-enabled data-sharing platform. Sharing is enabled without exposing the data or taking a copy, thereby retaining privacy, ensuring regulatory compliance, and freeing up data to advance data analytics and solve problems for the economy and society through decision-making capabilities. The various inter-ledger approaches are compared in this paper in terms of the following features: i) whether they support the transfer of value or the exchange of value, ii) the interconnection trust mechanism, iii) complexity, iv) scalability, and v) transaction cost. Approaches that perform the exchange of value across two or more chains rely on the consensus mechanisms of the chains that are involved, which provides decentralized trust, thus avoiding the need for a single trusted entity which is tabulated in *Fig. 4*:

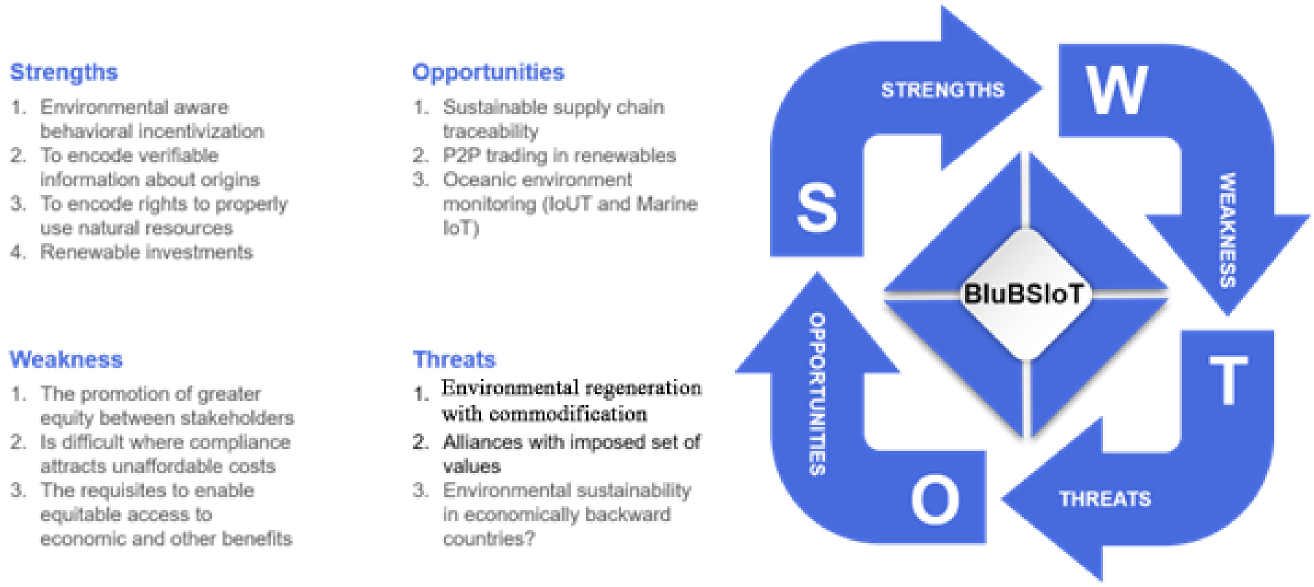

Fig. 4 SWOT Analysis of BluBSIoT

Source: Own edition

The interconnected trust mechanism defines where the immutable state of the transactions across chains is recorded; this is related to the mechanism which ensures the trusted execution of these transactions without relying on a single trusted entity. The complexity of the inter-ledger approach is determined by the amount of data (transactions) from each interconnected chain that the approach needs to process to ensure the trusted commitment of transactions across chains. Scalability refers to the total number of transactions a solution can support per unit of time and how the incremental cost for supporting additional transactions depends on the total number of transactions per unit of time. Finally, the transaction cost refers to the aggregate cost of all transactions, which depends on the percentage of transactions inside the main chain or inside the sidechains and the transactions across the two.

6. Framework for implementations

The hardware components designed for IoT applications consist of two devices: a Raspberry Pi and a Photon IoT microcontroller. The system's usability is boosted by the inclusion of an Android smartphone, featuring a Snapdragon

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900 MHz processor and 1 GB of memory, which provides a versatile interface for real-time monitoring and display of data acquired by the electrochemical and environmental sensors, as well as for system control using a mobile app (*Table 3*):

Table 3. Development Environment

Component	Devices	Specifications
	Raspberry Pi	Processor: ARM Cortex-A7 900 MHz Memory: 1 GB
Hardware	Photon IoT	Processor: ARM Cortex-M3 120 MHz Memory: 1 MB flash, 128 KB RAM
User interface	Smart Phone	Android device Processor: Snapdragon 900 MHz Memory: 1 GB
Connectivity standard	Wi-Fi module	Wi-Fi router with SoC m processor
Library and framework	Python API libraries	
Resources	Electrochemical and environmental sensors	

The smartphone leverages Wi-Fi connectivity to transmit commands to the Raspberry Pi and Photon IoT devices, enabling remote system control and providing seamless connectivity. The Wi-Fi module is linked to a Wi-Fi router with an integrated SoC (System on a Chip) processor to ensure consistent and reliable connectivity. The development framework incorporates Python API libraries for software development. The DApp is built upon a MultiChain framework that provides a range of features and functionalities for creating distributed applications. The Savoir library is employed to facilitate the information flow from the decentralized application to the storage area to streamline the development process (*Table 4.*):

Table 4. Blockchain Development Environment

Component	Specifications
Processor configuration	Pre-selected miner: Intel Core i7, 4 cores @ 1.30 GHz; Peers: Intel Core i5, 2 cores @ 3.4 MHz
Memory configuration	Pre-selected miner: 32 GB RAM; Peers: 8 GB RAM
Operating systems	Windows 10, 64-bit
DApp framework	MultiChain V 2.0
Library support	Savoir library

The plot in *Fig. 5* depicts the correlation between propagation delay and maximum transmission unit with an experimental environment that holds channel bandwidth set at 250 kHz and transmission power at 18 dBm. It is observed that BluBSIoT has a comparatively low linear relationship in comparison with the standard IoT network. This suggests that the P2P cross-ledgering SIoT framework can achieve efficient transmission of data with reduced delay, which is crucial for ensuring that information is shared and stocked effectively for promoting sustainability in the green and blue economy.

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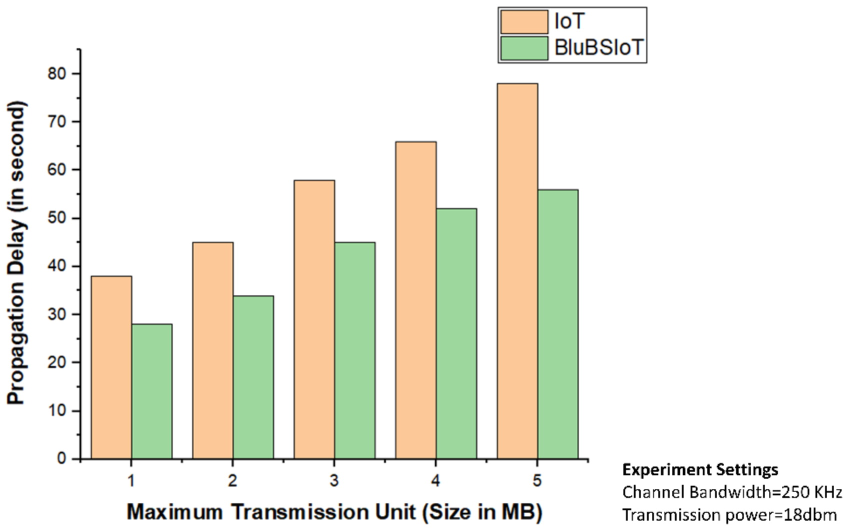

Fig.5 Impact analysis of delay in Transmission

In blockchain-based IoT applications, it is essential to consider the correlation between the number of nodes in the network and the average block time in milliseconds. The block time is the time to validate and add a new block to the blockchain. As per observation, the increase in the number of nodes in the network leads to an increase in the average block time. This is because each node has to validate and confirm the transactions before adding the block to the blockchain, and the validation process becomes time-consuming with an increase in the number of nodes. As a result, this can cause slower transaction processing and reduced efficiency. Therefore, it is vital to maintain a balance between the number of nodes and the average block time to ensure optimal performance in blockchain and IoT applications (*Fig. 6*):

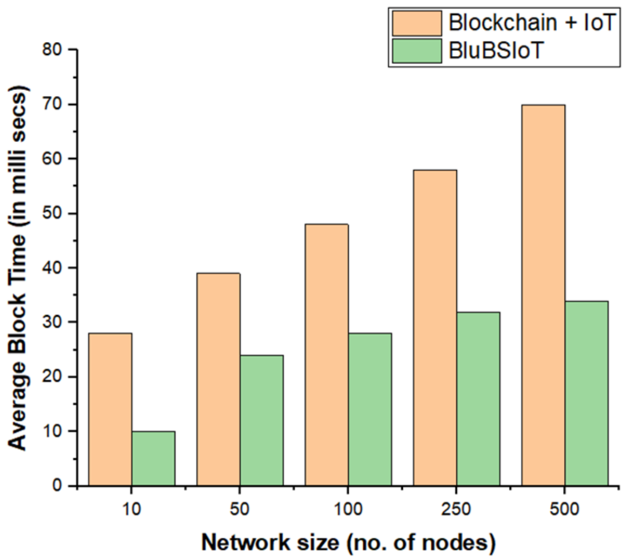

Fig.6 Impact analysis of block time to the size of the network

7. Conclusion

In the context of the Sustainable Development Goals (SDGs), BluBSIoT can be used to support progress towards several of the goals, including,

Goal 9: Industry, Innovation and Infrastructure – BluBSIoT can improve supply chain management, reduce fraud and corruption, and increase efficiency and transparency in industry and infrastructure.

Goal 16: Peace, Justice and Strong Institutions – BluBSIoT can help to create more secure and transparent governance systems, reduce corruption, and improve access to justice and accountability.

Goal 17: Partnerships for the Goals – BluBSIoT can facilitate more effective and secure partnerships between governments, businesses, and civil society organizations, by providing a shared, secure platform for collaboration.

In conclusion, BluBSIoT has the potential to enhance secured information storage and contribute to Sustainable Development Goals. By addressing issues related to interoperability, scalability, privacy, and stakeholder engagement, blockchain systems can be developed to support sustainable development and contribute to the decade of action towards achieving the SDGs.

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Agricultural and rural digitalisation in regional sustainable development: A comparative study between China and the European Union

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Abstract
Since the turn of the twenty-first century, digitalisation has gained widespread acceptance as a powerful tool for socioeconomic and environmental progress. Agricultural and Rural Digitalization (ARD) has been less researched than urban digitalisation, which received the most public interest. In this study, I addressed the advantages and significance of Agricultural and Rural Digitalization for regional sustainable development; and how our work can address the present implementation-related issues. The Digital Economy and Society Index (DESI) is an important indicator utilised to summarise digital performance in the European Union, and it is used in this research to assess the development of digitalisation. I made a comparison study to address the current issue and underline the relevance of agricultural and rural digitalisation by analysing official documents. Digitalisation proved to impact sustainable rural development positively, and a monitoring system can be used to produce policy-oriented recommendations. Our research aided people's understanding of China's program for smart and digital rural areas and provided policymakers with alternative strategies between China and the European Union when they needed a reference on the development of digital rural areas.
Keywords
Agricultural and rural digitalisation, Regional Development, Rural areas, Sustainability, Comparative analysis, Agricultural and Rural Digitalization, Digital Economy and Society Index

1. Introduction

Digitalisation refers to transforming every aspect of our economy, government, and society based on the widespread use of established and developing digital technology (*Randall et al., 2018*). In general, it is also referred to as the use of digital technologies to alter a business strategy or a conventional rule to reduce expenses or add value. Digital transformation, innovation, and sustainability are related to each other, and the increasingly complex problems such as climate change, environmental pollution, and pandemics are enhancing the importance of inter and transdisciplinary (*Ordieres-Meré et al., 2020; Szalmáné Csete, 2019*). Moreover, digital technologies, big data, Information and Communication Technologies (ICTs), and the Internet of Things (IoTs) are influencing our daily life (*Meneghello et al., 2019*). Policymakers and decision-makers also use digital tools to stipulate suitable and promising strategies (*OECD, 2019; Papageorgiou, 2020*). In practice, the European Commission included a section on the digital transition in its *Declaration on European Digital Rights and Principles* (*EC, 2023b*) to encourage the spread of digitalisation by 2030. Regarding the significance of digitalisation, 127 billion Euros are set aside for digital-related reforms and investments in each EU member state's *National Recovery and Resilience Plan* (*EC, 2022c*). In China, digital development has been recognised as one of the key elements to realising the national strategy (*Government of China, 2022*).

Digitalisation has been used in various industries to increase social production and optimise resource allocation. During the Covid-19 pandemic, the most prominent and practical digital technology was used in pandemic management to stop and control the spread of the virus (*Whitelaw et al., 2020*). Numerous insignificant concerns in governmental activities can be resolved with a few clicks on a mobile device, significantly reducing labour and time costs. Since most application scenarios are found in urban settings, Agricultural and Rural Digitalization (hereafter ARD) has not gotten much attention. However, ARD is essential for regional sustainable development. One of the 17 Sustainable Development Goals, the 10^{th} (Reduce Inequality), is the reduction of inequality within and between countries. Inequality can endanger social cohesiveness and political stability, but according to Iammarino's research (*Iammarino et al., 2019*), increasing internet access can also be effectively addressed. Similarly, digitalisation has played an essential role in policymaking, especially in the sectoral and spatial development programs in various scales of regions (*Buzási et al., 2021; Salvia et al., 2021; Szalmáné Csete, 2020; Nagy, 2021*), for example, study about the Visegrad Group of Central European Countries confirmed the strong relationship between digitalisation transformation and sustainability (*Esses et al., 2021*).

Sustainable development, acknowledged as humanity's inevitable path, is "*development that meets the needs of the*

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present, without compromising the ability of future generations to meet their own needs" (*Brundtland, 1987*). Additionally, because our planet has limited natural resources, sustainable development is crucial because it promotes the equal development of the environment, society, and economy. The United Nations created 17 Sustainable Development Goals (SDGs), often referred to as the *2030 Agenda* (*DESA, 2016*), which were expanded from the previous 10 Millennium Development Goals (MDGs). To see the relationship between agriculture and sustainability, Kinga Biró and Ottó Toldi have already analysed the impact of GHG emissions from the agricultural sector and stated the importance of agricultural innovation for sustainable development (Biró & Toldi, 2022). Therefore, to reach SDGs in the agricultural and rural sectors, the EU and China have taken action (*EC, 2022b; Government of China, 2022*) in ARD.

Moreover, as a new concept and valuable tool, Cognitive Sustainability helps us conduct interdisciplinary research on agricultural and rural digitalisation in the EU and China, where cognitive tools also serve digital development (Zöldy et al., 2022). Also, within five critical areas of Cognitive Mobility, cognitive sustainability supports understanding the interaction between mobility and economic processes. Cognitive mobility optimises using ICTs, including digital development (*Zöldy and Baranyi, 2023*). In this context, digitalisation in rural and agricultural areas turned into a preferred and essential tool for the European Commission and the Central Chinese government to promote sustainable development.

To assist the effective digitalisation of agriculture and rural regions in Europe, 26 European nations signed a Declaration of Cooperation on April 9, 2019, titled *A smart and sustainable digital future for European Agriculture and rural areas*. It acknowledges the potential of digital technology to address significant and critical economic, social, environmental, and climate concerns facing the EU's rural areas and agri-food sector. On September 3, 2021, the *Digital Rural Construction Guide 1.0* in China was published. It offered guidelines for promoting digital rural construction throughout the nation. The Ministry of Industry and Information Technology, the National Development and Reform Commission, the Ministry of Agriculture and Rural Affairs (MARA), and other departments collaborated to establish this document. The basic framework for the coordinated work schedules created by the various ministries and commissions to advance the digital village has emerged. The ARD's top-down discipline for regional sustainable development would be this rule.

China has the second-largest GDP in the world (14.7 trillion USD/country), whereas the European Union produces 15.3 USD trillion. According to the results of the 7th National Census in 2020 (National Bureau of Statistics of China, 2021), China, one of the largest developing nations, has a population of 1.4 billion, of which 510 million (36.11%) live in rural areas. In comparison, the EU, the largest developed region, has a population of 447.7 million, of which 30.6% (137 million) reside in rural areas (*Eurostat, 2022*). It is worthwhile to compare the digitalisation of agriculture and rural areas between China and the EU, given that they are both in similar but distinct developmental stages. On the one hand, some studies examine ARD in the EU or its member states, such as Popescu's case study of Romanian universities (*Popescu et al., 2020*), Dyba's study that focuses on financial support in the EU (Dyba et al., 2020), Garske's solution for digitalisation and AI in European agriculture (*Garske et al., 2021*), and Lioutas's research, which tried to solve the food problem by the use of digital technologies (*Lioutas et al., 2021*).

On the other hand, topics relating to ARD were also discussed in China. For example, Xia discussed the initiatives and policies of rural digitalisation in China (*Xia, 2022*), Xie discussed a case study about how smallholder farmers are involved in digital agriculture (*Xie et al., 2021*), Qu examined how to promote agricultural modernisation through ICT in China (*Qu et al., 2018*), and Chen discussed how data helps the efficiency (*Chen et al., 2022*). To our knowledge, the digitalisation of agriculture and rural areas in the EU and China has not yet been thoroughly studied.

This study explores the following questions to help people better and more insightfully understand China's agricultural and rural digitalisation and to provide alternative options/strategies for policymakers by comparing China and the EU.

1. *What are the benefits and the importance of agricultural and rural digitalisation to regional sustainable development in China and the EU?*

2. What are the current general problems that need to be solved during the implementation processes, and what needs to be done to solve these problems?

2. Importance of agricultural and rural digitalisation

From the economic perspective, a region's innovation and digital transformation level correlates with its economic position (*Afonasova et al., 2019*). The higher the level of digitalisation and innovation, the higher the level of economic development. According to the results of seven years of data, *Van Gaasbeck (2008)* discovered that broadband access has helped to increase overall economic growth and employment. Information and communication technology (ICT) also

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contributes to the development of rural areas (*Salemink et al., 2017*).

One of the main drivers of economic development has been recognised as digitalisation, and the European Commission recognised the importance of technological development and digitalisation for regional development in Europe as early as 2014 (*EC, 2014*). Despite this, rural areas continue to lag behind urban areas in terms of access to both private and public services (*Roberts et al., 2017*). The importance of agricultural and rural digitalisation in the EU has grown since publishing *A Better Life in Rural Areas: The CORK 2.0 Declaration* (*EC, 2016*) and *Shaping Europe's Digital Future* (*EC, 2020*). To narrow the gap between rural and urban areas and foster regional growth, two illustrative case studies were done in rural areas: one in Lippe/Höxter, Germany, and the other in Västerbotten, Sweden (*Löfving et al., 2022*).

The most well-known EU policy is the cohesion policy, which positively impacts regional development (Barbero et al., 2022). In contrast, the Trans-European Transport Network (TEN-T) project (*EC, 2022d*) aims to construct a Europe-wide transport network connecting all the central European cities as nodes by 2030 and all European regions by 2050, which will significantly improve the implementation of digitalisation in the EU. Along with the Recovery and Resilience Facility (*EC, 2022c*), which the European Commission put in place in 2022 to aid the EU in hastening its recovery from the pandemic, it stressed that member states must use at least 20% of the money to promote the digital transformation.

2.1 What effort has China made to improve rural digitalisation?

In ancient China, agriculture served as the pillar of society. Agriculture has traditionally been seen as the nation's cornerstone because of the enormous population that has to be fed (*Chen et al., 2021*). This resulted from a long-term economic strategy emphasising agriculture and suppressed trade. Furthermore, agricultural operations are often conducted in rural regions, which are subject to high obligations and duties and have less favourable regional development. Since the 1950s, rapid urbanisation and early digitalisation have led to a significant regional development imbalance in China between urban and rural areas (*Lin and Chen, 2011*). To tackle this problem, the 19th National People's Congress adopted the Rural Revitalization Strategy to lessen urban-rural inequities and boost agricultural and rural growth. This tactic made it clear that the issue of farmers in agricultural and rural regions is a significant issue affecting the national economy and people's means of subsistence (*Government of China, 2018*).

Immediately after the Rural Revitalization Strategy was set as the primary national strategy, the *Digital Agriculture Rural Development Plan (2019–2025)* was published to clarify the tasks and objectives of agricultural and rural digitalisation in regional development. "Smart village", as a critical concept in rural digitalisation, has been applied in sustainable development, and it has been approved that it has a positive effect in rural areas through smart village strategic planning and practice in China (*Zhang and Zhang, 2020*). In 2021, the Big Data Center of the Ministry of Agriculture and Rural Affairs (MARA) was established, the National Development and Reform Commission, the Ministry of Industry and Information Technology, the Central Network Information Office, and other departments collaborated to develop the *Guidelines for Digital Rural Construction 1.0*, which was made public on September 3, 2021. This document drew a general "construction map" for promoting digital rural construction nationwide.

2.2 Problems existed during agricultural and rural digitalisation development

There are still many problems with how agricultural and rural regions grow digitally. Salemink found that there are other problems, such as cultural, organisational, and technological ones, in addition to the fact that individuals in rural regions do not have the infrastructure or digital skills required to access services (*Salemink et al., 2017; Tolstykh et al., 2017*). When digital agriculture is considered for environmental sustainability, negative environmental consequences may also happen if digital technologies are not used properly due to a lack of strict regulations (*Soma and Nuckchady, 2021*).

Another notable concern in ARD is data ownership. Data is a type of valuable resource, and it is available on digital platforms that can be accessed by multi-national corporations that operate them (*Fraser, 2019*). Even though farmers agree to the terms and conditions of using digital agriculture platforms, they have little influence on determining consent rights to their data as agricultural companies remain unclear about data ownership and whether the data is used for other purposes, such as data sharing agreements with third parties (*Custers, 2016; Wiseman et al., 2019*). The collected data may threaten small and medium size farms with economic and environmental consequences (*Clapp and Ruder, 2020; Wiseman et al., 2019*).

Digital applications are ineffective because of workers' lack of e-skills. Artificial intelligence may use big data and real-time information from distant sensors to forecast potential social actions in various situations, but this raises serious concerns about privacy, data ownership, and usage (*Rolandi et al., 2021*). Some papers emphasise how digitalisation may be seen as a brand-new monitoring technique that exacerbates social disparities by prescribing and detailing a specific set of rules for what social interactions should look like (*Klauser, 2018*). Investing in agricultural digitalisation may discourage private capital from this industry due to the nature of agriculture, where the operational cycle is sometimes one year or even longer in animal husbandry. For some specific species, the return on investment carries a more significant risk (*Belhadi et al., 2021*). Specific brand or system of agricultural digital technologies requires significant capital investment, which forces the farmer to loan (*McMichael, 2013; Rotz et al., 2019*), and these debts will be a potential risk for farmers, especially in the 21st century when extreme weather is more frequent (*McKinnon, 2019*).

The main issue in China is the lack of comprehensive planning and design. China is currently in the bottom-up phase of independent investigation by various areas for developing smart villages (*Zhang and Zhang, 2020*). The problem of regional imbalance and significant rural heterogeneity is another noteworthy one. There are varied foundations for rural information technology in different parts of China. The eastern part of China has a reasonably strong foundation for information technology, but the middle and western regions are largely underdeveloped due to the varying rates of economic development.

3. Methodology

Although comparative analysis has clear uses, there is no universally accepted definition. For instance, the comparative analysis may compare the benefits and drawbacks of two or more study objectives and their differences and similarities. Furthermore, interpreting useful data by establishing the link between study objectives is another crucial and beneficial function of comparative analysis. Additionally, one of the key components of comparative analysis is articulating the justifications for analysing a particular feature and the inferences that may be drawn from the comparison (*Pickvance, 2001*). Therefore, a comparative analysis is used in our research in order to determine the differences and similarities in ARD between the European Union and China. Additionally, I analyse the key sectors and their benefits and drawbacks between the EU and China using official papers and publications as our sources of information.

3.1 Compare the reasons and aims of ARD between the EU and China

Information was gathered on the motivations and objectives of ARD in the EU (*EC, 2022b*) and China (*MARA, 2020*). Table 3 illustrates each country's stance toward ARD graphically. Since all ensuing initiatives and policies are built on this concept, I would want to compare their initial points of thought and work priorities in this manner.

3.2 Compare the Digital Economy and Social Index (DESI) compass targets between the EU and China

Since 2015, the European Union has built a comprehensive and successful indicator system to assess and track the digital growth associated with sustainable development in the EU. There is already research that utilised DESI 2022 (*EC, 2023a*) as an indicator to assess the development level of digital transformation in Europe and summarised clearly and useful results (*Esses et al., 2021*). The regularly updated DESI report supports our comparison study inside our framework since the classifications of these indicators could fully reflect the level of digitalisation. It is scientific and professional (Appendix.1). Official reports and materials released by the government or relevant ministries were examined to match each indication in the DESI assessment method even though China does not have the same DESI report as the EU (*MARA, 2020; CAICT, 2022*). This will allow us to compare the ARD levels in the EU and China (*Figure. 1*) and examine those numbers' discrepancies. The digital compass targets in DESI 2021 concerning the four dimensions of the index were also used to simplify the DESI indicator system for easier comparison between the EU and China. These targets (*Table 1*) are used to evaluate the digital development of the EU and China and conduct a comparative analysis.

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Table 1: Digital compass targets in DESI

Human Capital	At least basic digital skills ICT specialists Female ICT specialists
Connectivity	Gigabit for everyone 5G coverage
Integration of digital technology	SMEs with a basic level of digital intensity AI Cloud Big data
Digital public services	Digital public services for citizens Digital public services for businesses

Source: (EC, 2022a: 13)

3.3 Other methods applied in our research

Essentially, this secondary research incorporates data collecting, reading, and analysing policies and articles. To further highlight the ARD of the EU and China, I also created a SWOT analysis (*Table 3*) based on in-depth literature readings, policy interpretation, and data processing.

4. Results

4.1 Comparison of the reasons and aims of ARD between the EU and China

The comparison result of reasons and aims of ARD between the EU and China (Table 3) shows consistent attitudes and different approaches to the digitalisation of agriculture on both sides. For instance, the EU and China are pursuing sustainable rural development since protecting the environment has already become a consensus, and both want to apply digital technologies to increase efficiency in agricultural production. Another similar reason is the labour losses in rural areas since people living there have no attractive and lucrative job opportunities. Obviously, the reasons why the EU and China want to develop ARD are the same, as the differences are minimal, so I will not discuss them here.

As a multi-ethnic, multicultural, and multi-national organisation, the European Union must consider each member state's unique capabilities and developmental stage when adopting policies like the Common Agricultural Policy (CAP). Similarly, China is a multi-national and multicultural country with 56 nations and a spacious territory. There are comparatively less developed places in the Northwestern and Central portions of China, where there is uneven urban and rural digitalisation development, in addition to developed regions in the Southeastern part of China, where there is a high degree of digitalisation in both urban and rural areas. The ARD difference between the EU and China is that the EU emphasises innovation more than China. On the contrary, as a developing country, China focuses on developing infrastructure and ending poverty in rural areas, while most EU regions are developed.

Table 2: Comparison of the reasons and aims of ARD between the EU and China

European Union	China
Reasons	
1. Farmers lack precise and sustainable instruction.	1. Rural infrastructure is weak.
2. Insufficient science in agricultural decision making	2. Current agriculture is outdated.
3. Conventional agriculture is unsustainable.	3. Urban-rural development disparities
4. Labours outflow from rural areas	4. Agricultural production is unsustainable.
5. Digital technologies are needed to make rural communities more attractive, intelligent and sustainable.	5. ARD is an essential part of achieving the rural Revitalization Strategy (Liuet al., 2020)
6. Improving access to remote services	6. The young generation does not want to work in the agricultural sector.

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Aims	
Strengthen research support. ◆ Smart farm ◆ Stimulate the use of digital tech ◆ Keep EU at the forefront of progress in smart farming ◆ Support RDI actions ◆ Give priority to SMEs in digital farming	**Sustainable rural development** ⓾ Develop creative sightseeing agriculture ⓾ Increase the construction of rural Internet of Things (IoT) ⓾ Establishment electronic traceability supervision system for agricultural inputs
Establishing an innovation infrastructure ◆ Identify large-scale experimentation and testing facilities ◆ At least one digital innovation hub in each Member State ◆ Develop a network linking the dedicated agri-food digital innovation hubs ◆ Make the rural population involved in digital transformation ◆ Promote AI and IoT development in rural areas ◆ Achieve full deployment of broadband connectivity in rural areas ◆ Strengthening synergies between funding instruments	**Urban and rural common prosperity** ⓾ Upgrade rural network facilities ⓾ Improve information terminal and service supply ⓾ Accelerate the digital transformation of rural infrastructure ⓾ Coordinate the development of digital villages and smart cities
Creating a European data space for smart agri-food applications ◆ Promoting cross-border platforms and databases ◆ Make use of European space programmes	**Convenient public service** ⓾ Promote rural construction and planning management information technology ⓾ Improve the convenience of the masses
Maximise impact ◆ Drawing up the CAP (Common Agricultural Policy) Strategic Plans ◆ Designing the financial structure of the CAP Strategic Plans ◆ Increase CAP administration	**Increase rural region's income by ICT** ⓾ Promote the integration between ICT and agricultural production ⓾ Enhance the development of smart agriculture ⓾ Innovative rural logistic service system

Sources: EC, n.d.; MARA, 2022.

4.2 The level of infrastructure and economic development

These results are consistent with China's and the EU's distinct economic progress and advantages. According to the *Digital China Development Report 2021* (CAC, 2022), China has 1.032 billion Internet users, approximately 73.7% of the population, and 74.4% of these users have at least basic digital abilities, compared to 55% of the people in the EU (*Figure 1a*). Due to the developed infrastructure and government subsidies, China has 100% 5G coverage and gigabyte for everyone, compared to 14% and 59% in the EU, respectively. Furthermore, China has Internet giants like Tencent, Baidu, and Alibaba, which offer significant technological assistance. The results of SMEs with basic levels of digital intensity and big data are 82% and 90%, respectively, higher than the corresponding figures for the EU, 59% and 35.6%.

Nonetheless, the EU has a higher rate of development in AI and cloud technology, with 25% and 25%, respectively, compared to China's 8.6% and 16%. In addition, despite having a population of 447.7 million and 1.4 billion populations, the EU has 8.6 million ICT professionals compared to China's 4.87 million (*Figure 1b*). In addition, there are 2.37 million female ICT professionals in China compared to 1.6 million in the EU. In order to conclude from this finding, *Figure 1b* shows that the EU has a more significant percentage of ICT professionals than China, but fewer women. The EU receives a score of 75 on digital public services for citizens and 82 for businesses, whereas China receives a score of 90.5 on these services for individuals and 73 for corporations, as shown in the final figure (*Figure 1c*):

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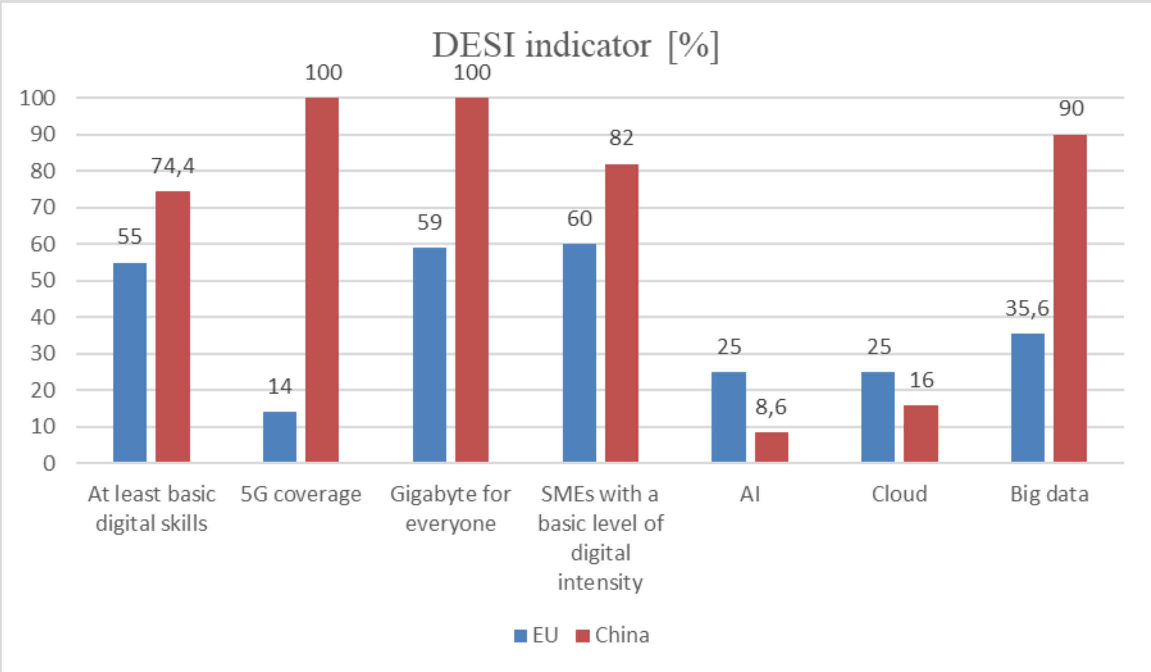

Figure 1a. Achievements of ARD of the EU and China

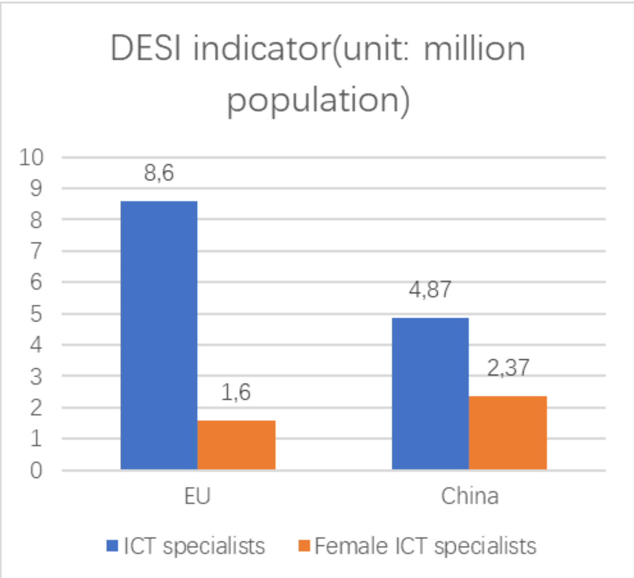

Figure 1b: Achievements of ARD of the EU and China [%]

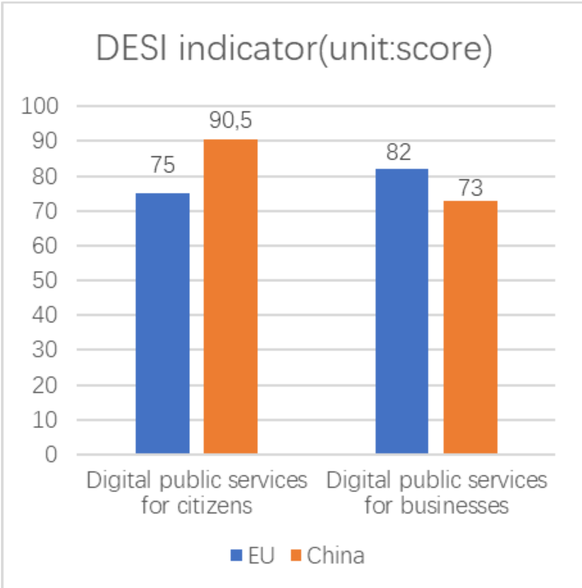

Figure 1c: Achievements of ARD of the EU and China (unit: score)

Sources: Figure.1a, b, c are compiled from the following documents: "CAICT, 2022; CAC, 2022; National Bureau of Statistics,2021; MARA, 2020; The Digital Economy and Society Index (EU, 2022), Thematic Chapters

4.3 China's Long-term plan for ARD

The central government of China has created several programs from diverse angles concerning the long-term development of ARD (*Table 4*). Big data, one of the most significant resources in the Internet era, can be applied efficiently in rural regions for agricultural production and rural life. Thus, China wants to develop a database that contains as much information as possible to assist in data utilisation. Digital technologies are gradually being implemented in practice to raise the standard of agricultural produce. The long-term plan must include two crucial components: strengthening important technologies and creating cutting-edge equipment. Moreover, monitoring and evaluating how the entire plan is executed is the key to ensuring success. In the end, it was also written in the plan.

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Table 4. China's long-term plan for ARD

Build a basic data resource system
■ Building big data on:
1) Agricultural, natural resources,
2) Significant agricultural germplasm resources, Rural collective assets
3) Rural residential bases
■ Complete big data on farming households and new agricultural business entities.
Promote the digital transformation of management services
■ Establishing a sound technical system to support agricultural and rural management decisions
■ Establishing monitoring and early warning systems for the whole industrial chain of important agricultural products
■ Build digital agriculture and rural service system
■ Establish an intelligent monitoring system for rural habitat environment
■ Build a rural digital governance system
Accelerate the digital transformation of production and operation
■ Planting industry informatisation
■ Intelligent animal husbandry
■ Intelligent fisheries
■ The digitalisation of the seed industry
■ Diversification of new business mode
■ Quality and safety control throughout the process
Strengthen key technology and equipment innovation.
■ Strengthen critical standard technology research and development
■ Strengthen strategic frontier technology layout in advance
■ Strengthen technology integration application and demonstration
Accelerate the application of agricultural artificial intelligence research and development

Source: Own compilation from MARA, 2022.

5. Discussion and limitation

Based on the discussion, I would like to make a few recommendations. In order to assist scholars in gaining a convenient and thorough knowledge of China's digital progress, it would be a good idea for the Chinese government to build an indicator system akin to the DESI in the EU. Second, it is helpful to develop an assessment system to determine whether policymakers need to adapt and improve the program after implementing digitalisation. In addition, I developed a SWOT analysis (Table 2) to illustrate more clearly how ARD is now developing in the EU and China. On the one hand, the EU has the European Network for Rural Development (ENRD) and the European Agricultural Fund for Rural Development (EAFRD), while China has the Rural Revitalization Strategy, representing the most significant opportunities. While China has particular geographical resources that may have enormous potential, the EU has its advantage in the abundance of ICT professionals. On the other hand, complicated interpersonal ties in rural regions are China's most significant deficit.

There is still a long way to go until this issue is fixed since many Chinese communities, especially those in rural areas, are too traditional to embrace or encourage digitalisation. The EU has flaws regarding member-state conflicts of interest and regional development gaps between Northwest and Middle Eastern Europe. The refugee crisis impacts the EU's economy and society, the energy crisis, and the possibility of conflict. According to an old Chinese proverb, "The Chinese do not suffer from lack but from unevenness," China faces an unanticipated threat from the rising regional disparity in development. Therefore, a SWOT analysis is required in this article since it can effectively highlight ARD's positive and negative aspects. This SWOT analysis is beneficial because it enables ARD's stakeholders to capitalise on their strengths, learn from others, and distinguish between potential dangers in the future so they may effectively avoid them.

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Table 3. SWOT analysis of ARD in the EU and China

European Union	China
Strengths	
A large number of ICT specialists Mature policy support (CAP) Abundant financial capital Advanced development experience Experienced societal operation	Unique regional resources Agricultural-related universities, research institutes, and vocational schools Well-established infrastructure 100% Internet coverage
Weaknesses	
Disputes of interest between member states Regional development disparities Scattered funding landscape of SMEs Relying on resource import High labour cost Low ratio of digital skills education Weak transportation channels	Weak information infrastructure Limited digital literacy levels in rural areas Complex interpersonal relationships in rural areas Vase less-educated population in rural areas Fewer job opportunities in rural areas Disparate population density gap Complex geographic Complex geographical environment
Opportunities	
Policy support 5G network installation Emerging of AI, IoT, big data	Policy support 5G network construction The Rural Revitalization Strategy
Threats	
Extreme weather Covid-19 Regional war/conflict Energy crisis Refugee crisis Cybercrimes Inconsistent policy execution Dependent on foreign technologies	Low level of digital governance in rural areas Poor adaptability of smart equipment in agriculture Imbalance of digital development between urban and rural areas Fewer talents study agricultural science Talent's Loss in rural areas Cybercrimes Lockdown due to Covid-19

Source: Self compilation

I want to underpin the scientific importance of this work and the components that can support subsequent research in light of the SWOT analysis. This article researched agricultural and rural digitalisation in China and the European Union and conducted a comparison. Our studies offer alternate recommendations for policymakers and other researchers and demonstrate ARD's significance in regional sustainable development. In the future, I hope this study will be a helpful resource and contribute to more fruitful and beneficial scientific research.

There are some limitations of this research. Since the DESI data for China is approximative, there is no standard method of evaluation for the Digital Economy and Social Index (DESI) between the EU and China, which results in some bias. Due to a lack of time and funding, I could not conduct an empirical study on digital development in rural areas of the EU and China. Aside from that, there are still many flaws and weaknesses regarding problem-solving and detail processing because of the author's inadequate scientific quality and understanding. Additionally, further research can be done about starting a Life Cycle Cost (LCC) assessment on applying digital technologies in agricultural production to conduct a comparative benefit-cost analysis between digital and conventional agriculture.

6. Conclusion

Our goals for this research have been accomplished based on the result section. I provided a complete introduction to the central government of China, its successes in agricultural and rural digitalisation, and the long-term goals of ARD. In the analysis above, I offered recommendations for further development tactics that the comparative research between China and the EU may refer to. Additionally, from an economic, social, and environmental perspective, agricultural and rural digitalisation favours regional sustainable development.

To answer the question, "*What are the benefits and the importance of agricultural and rural digitalisation to regional sustainable development in China and the EU?*" our research indicates that the most significant advantage is reducing regional development inequalities, which may lessen social disputes. In order to attain as many SDGs in rural regions as feasible, ARD is also important in fostering economic and sustainable development. I conclude that ARD is crucial and the best path to achieving wealth for all Chinese citizens. Additionally, ARD supports agricultural output growth, a key component of the entire food supply chain. The more developed and sophisticated agricultural digital technologies are used, the better and more food can be produced in terms of quality and quantity.

Moreover, I have several issues with related solutions to answer, "What are the current general problems that need to be solved during the implementation processes, and what should I do to solve these problems?". The construction of broadband and signal base stations is a top-to-bottom infrastructure development program spearheaded by the government. In some isolated and undeveloped places, the central government can finance digital knowledge teaching and professional support to help those without formal education acquire essential digital skills (often in rural areas). A comprehensive legislative framework should be built to control the management of personal information related to the use of digital technology to address the problem of privacy-violence. The government should encourage banks to loosen the limits on SMEs participating in digital agricultural production to solve the issue that major firms often do not participate in agricultural digitalisation owing to the nature of agriculture. The absence of comprehensive planning and design in China may be remedied by encouraging the development of smart villages. If comprehensive, unified smart village planning and design are urgently required, the rural areas can carry out pilot work on smart villages with the cooperation of the central government. Additionally, given that China has difficulty balancing economic growth with digital development, I propose that various smart towns concentrate on particular subsectors. For instance, some towns may have somewhat advanced agriculture suitable for smart agriculture, while others may have a richness of tourism resources suitable for smart rural tourism.

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Appendices

Appendix.1: DESI indicator system

	Human Capital
❿	At least basic digital skills (% individuals)
❿	Above basic digital skills (% individuals)
❿	At least basic software skills (% individuals)
❿	ICT specialists (% individuals in employment aged 15-74)
❿	Female ICT specialists (% ICT specialists)
❿	Enterprises providing ICT training (% enterprises)
❿	ICT graduates (% graduates)
	Digital Public Service
❿	e-Government users (% internet users)
❿	Pre-filled forms (Score 0 to 100)
❿	Digital public services for citizens (Score 0 to 100)
❿	Digital public services for businesses (Score 0 to 100)
❿	Open data (% maximum score)
	Integration of Digital Technologies
❿	SMEs with at least a basic level of digital intensity (% SMEs)
❿	Electronic information sharing (% enterprises)
❿	Social media (% enterprises)
❿	Big data (% enterprises)
❿	Cloud (% enterprises)
❿	AI (% enterprises)
❿	ICT for environmental sustainability (% enterprises having medium/high intensity of green action through ICT)
❿	e-Invoices (% enterprises)
❿	SMEs selling online (% SMEs)
❿	e-Commerce turnover (% SME turnover)
❿	Selling online cross-border (% SMEs)
	Connectivity
❿	Overall fixed broadband take-up (% households)
❿	At least 100 Mbps fixed broadband take-up (% households)
❿	At least 1 Gbps take-up 1.3% (% households)
❿	Fast broadband (NGA) coverage (% households)
❿	Fixed Very High-Capacity Network (VHCN) coverage (% households)
❿	4G coverage (% populated areas)
❿	5G readiness (Assigned spectrum as a % of total harmonised 5G spectrum)
❿	5G coverage (% populated areas)
❿	Mobile broadband take-up (% individuals)
❿	Broadband price index (Score 0-100)

Source: The Digital Economy and Society Index (DESI) 202, Thematic Chapters

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The green light for air transport: sustainable aviation at present

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Abstract
In the nearly 120 years of aviation history, the industry and technology have evolved with the world. In the early decades, the focus was on preparing aircraft for passenger transport, and gradually the industry developed different areas such as airports, navigation, in-flight services and air traffic control. The aviation industry has faced quite many challenges in different periods. At the beginning of the JET era, the first very controversial factor, noise pollution, was already apparent. The gas turbines of the time were much less efficient than today', and although the technology worked, some factors were less considered by developers, such as the noise and environmental impact mentioned above. As we moved into more modern times, the focus shifted more and more to the pollutants emitted by aircraft, which has become one of the most studied factors to date. This research examines the sustainability of aviation, past, present and future, in the light of global warming. It presents technologies that already work in the present, but their possible spread only points to the near or even distant future.
Keywords
Sustainability, sustainable aviation, hydrogen. electric propulsion

1. Why is aviation important to the environment?

Our research is based on a study of the amount of CO_2 emitted by humans, gas in the atmosphere in concentrations that make it the most greenhouse gas. *Figure 1* shows that, according to the Air Transport Action Group (ATAG), the amount of CO_2 emitted by aviation accounts for 2 % of the CO_2 emitted by human activity globally. On a global scale, aviation is responsible for 12 % of CO_2 pollution from transport, while 74 % stems from road transport and 14 % from other forms of transport. It is important to note that approximately 80 % of the CO_2 emitted by aviation comes from flights of more than 1,500 km, where no practical alternative travel mode can be envisaged (*Čokorilo, Ivković, Kaplanović, 2019*). On a per-passenger-kilometre basis, rail transport results in lower carbon emissions, but it is also essential to consider the social and economic impacts of the development of the rail network. Flights less than 500 km represent only 1-2 % of all European air travel. Constructing railway lines is highly environmentally damaging, but the negative impact on wildlife is also significant (*Oxera, 2023*).

Aircraft are essential tools for landscape protection (*Bakó et al., 2021*). Aerial monitoring is a scientific, well-documented, verifiable method that enables continuous mapping and verifying the accuracy of data gained from other sources. For example, due to the rapidly spreading invasive species, vegetation can drastically change between preparing two environmental management plans. These fast changes can be monitored efficiently from above. When analysing the changes in grassland dynamics or mapping the upper canopy level of forests, the results turn out to be much more accurate (patch size and accuracy of boundaries of 20–50 cm) than it is feasible using GPS devices, total stations, field-work and investing the same amount of time. Field-work supported by aerial remote sensing with a few centimetres of spatial resolution range allows for more frequent, more accurate data collected from a wider area. This way, interpretive evidence and decision-support information can be obtained, and a periodic landscape change becomes widely understood and considered. It should be noted that in addition to the consequences of strong anthropogenic impacts, monitoring certain natural processes – in which human

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influence is not evident or moderate – may also be an important task from a nature conservation point of view. Surveys applying airborne and unmanned aerial systems (UAS) are increasingly crucial for controlling invasive plant species and infestations for forestry and conservation (*Müllerová et al., 2017; da Silva et al., 2023*).

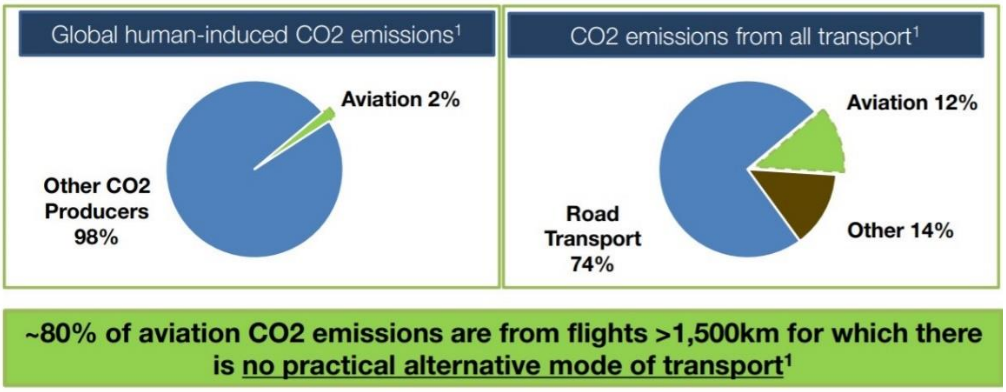

Figure 1. The role of aviation in carbon dioxide emissions (ATAG, 2023)

In 2020, the pandemic reduced the industry's CO_2 emissions by almost a third compared to the previous year, equivalent to 1997 levels. Compared to 2019, annual passenger numbers fell by 60 % by 2020 and 49 % by 2021. Carbon dioxide emissions have risen again as aviation industry indicators are rising in passenger and flight numbers. In 2019, the industry emitted 914 million tonnes of CO_2 out of 43 billion tonnes of CO_2 emitted globally each year, as shown in *Figure 2* (*ICAO, 2023a*). Natural carbon sinks can remove approximately 9-10 Gt of carbon from the atmosphere yearly, with CO_2 emissions reaching 36 Gt in 2019 (*Edgar, 2021*). At the International Air Transport Association 2022 conference, airlines agreed to commit to achieving climate neutrality by 2050. This implies the need to introduce technologies that can significantly positively contribute to reducing emissions.

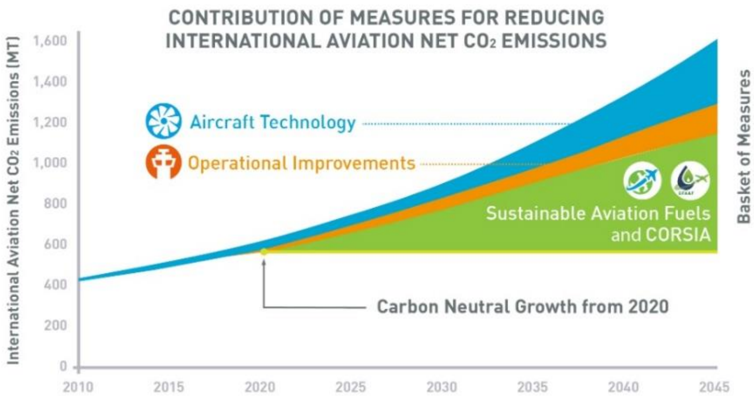

Figure 2. Aviation CO_2 emissions by year (*ICAO, 2023a*)

Today's aircraft have 80% better fuel efficiency per passenger kilometre than the types introduced in the 1950s at the dawn of the JET era. In 2019, the immediate year before the epidemic, 4.5 billion passengers used air transport, of which 1.9 billion were international and 2.6 billion were domestic. The figures (*Figures 1. and 2.*) show that the sustainability of air transport is an important issue. This research presents the possible alternatives to traditional fuel, such as electric propulsion, sustainable aviation fuel (SAF), and hydrogen operations, which are future technologies. It also compares with conventional JET fuel, i.e. kerosene, in terms of emissions.

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3. Technological enhancement in aviation

This chapter presents state-of-the-art research results in this field, focusing on the most important technical characteristics.

3.1. Electric propulsion

The growing attention paid to electric propulsion is no longer just a novelty: it is the technology that market players expect to bring the most significant reductions in emissions, noise and operating costs once the barriers are broken (*Ficzere, 2021*). However, significant hurdles must be overcome to achieve zero CO_2 emissions by 2050. More than 300 electric aircraft projects and nearly 200 start-ups were launched between 2016 and 2022 (*Ying, 2022*).

3.1.1. The economics of electric aircraft

Experience with the operation of pure electric aircraft has been very positive. The energy cost of a two-seater Pipistrel electric-powered aircraft is about $1 per hour, while a conventional two-seater Cessna C152 with an internal combustion piston engine costs about $34, according to pre-Russian–Ukrainian war estimates. Moreover, the total operating cost per hour estimate for a fossil-fuelled aircraft is 3.6:1 for a modern electric-powered aircraft. It can therefore be concluded that for these models, the energy cost per hour of operation of an electric aircraft is thirty-fourths of that of a conventional aircraft, but even when the total operating cost is compared to a fossil fuel-powered aircraft, it is almost a quarter of that (*Ying, 2022*).

3.1.2. Range and payload

Physical characteristics, such as payload, cruising speed and range, are significant difficulties for the spread of zero-emission systems. Today's advanced lithium batteries are about 50 times heavier than aviation fuel under given conditions. Even then, if the weight of JET engines is substituted for that of electric motors, the excess is 25 times greater (*Ying, 2022*). These are the difficulties electric aircraft developers face, and their results are as follows.

A prototype of a shoulder-winged composite plane with a twin-bladed propeller from the Liaoning General Aviation Research Institute in Senjang was analysed. Developed from an earlier two-seat model, the RX4E has a maximum take-off weight of 1200 kg and a wingspan of 13.5 m. It can fly for an hour and a half on a single charge and has a maximum speed of 200 km/h. The maximum distance it has flown from Senjang is 300 km. The battery capacity required is almost 70 kWh (*Asia Times, 2019*).

The ACCEL (Accelerating the Electrification of Flight) programme has developed a more advanced aircraft battery than ever before, which will enable the Rolls Royce – Spirit of Innovation aerobatic aircraft to fly a London to Paris route, which is around 345 km (*Rolls-Royce, 2021*).

The Alice twin-engine twin-jet from Eviation, an Israeli-based company based in the Seattle area, is a six to nine-passenger business jet with a payload of 1200 kg. This load will have a range of 815 kilometres at a speed of more than 400 km/h. These figures can be achieved by charging the aircraft for about thirty minutes (*DHL Group, 2021; Villamizar, 2022*).

3.1.3. Top speed of electric aircraft

The Rolls-Royce – Spirit of Innovation (*Figure 3*) aerobatic aircraft is part of the ACCEL (Accelerating the Electrification of Flight) programme. The development, supported by a government grant from the UK Government's Department for Innovation, involved two other smaller UK companies that are partners of Rolls-Royce. The aircraft's high-performance, ultra-lightweight electric propulsion system delivers 400 kW (500+ hp) of power, which has helped the aircraft set three new world records. These are still under review by the Fédération Aéronautique Internationale (*FAI*).

At 15:45 GMT on 16 Nov 2021, the aircraft reached a top speed of 555.9 km/h over 3 kilometres, beating the previous record by 213.04 km/h. In subsequent runs at the UK Ministry of Defence's Boscombe Down experimental aircraft test range, the Spirit of Innovation achieved a speed of 532.1 km/h over 15 kilometres, 292.8 km/h, faster than the previous best, and reduced the fastest time to climb to 3,000 metres to 202 seconds,

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beating the previous record by 60 seconds. During the record-breaking final runs, the aircraft reached a top speed of 623 km/h. The FAI has not yet validated these results (*Rolls-Royce, 2021*).

Figure 3. Spirit of Innovation electric aircraft (*Rolls-Royce, 2021*)

3.1.4.Approach to the objective

It can be concluded that technology development requires either a significant reduction in the electricity consumption of electric traction motors for a given power output or a significant increase (at least by one order of magnitude) in the capacity-to-weight ratio of batteries. For example, there are significant developments in solid-state batteries (SSB), which promise four times higher energy density than Li-ion batteries. *Table 1* shows the current energy density values of energy sources. These will become commercially available for electric vehicles in the next decade. Until this happens, the use of electric propulsion in aviation is severely limited. However, electric propulsion can already be considered a cost- and emission-reducing auxiliary propulsion system. An optimised hybrid electric aircraft in parallel operation using sustainable aviation fuels (SAF, 50% blend) can achieve a 90% reduction in emissions (*Ying, 2022*).

Table 1. The energy density of energy sources (*Tran et al., 2018*)

Fuel	Energy Density (MJ L^{-1})	Energy Density (MJ kg^{-1})
JP-8 JET fuel	34.5	43.4
Diesel	36.2	42.5
Gasoline	32	44
Hydrogen (liquid)	120	8
Methanol	15.6	19.7
Lithium-ion battery	N/A	0.6

3.2. Sustainable Aviation Fuel (SAF)

Sustainable Aviation Fuel (SAF) can play a significant role in the relatively rapid emissions reduction. SAF is an alternative fuel that can be produced from wood waste, algae, alcohol, sugar cane, cooking oil, etc. The carbon in the fuel is derived from biomass, and the engine releases CO_2 extracted by vegetation back into the atmosphere. Sustainability can be achieved if the biomass comes from sustainable farming. If this can be achieved, it can reduce the entire life cycle measured CO_2 emissions by 80-90% compared to kerosene (*Khadilkar, 2021*). The target blend rate with kerosene is 1–5% by 2025, rising to 15% by 2030. In the summer of 2022, the world’s first 100% SAF fuel aircraft, operated by BRA, completed its first flight (*CO_2 Value Europe, 2022*).

On 1 Dec 2021, United Airlines became the first airline in the US to carry passengers using 100% SAF fuel in one of its engines. The Boeing 737 MAX 8 aircraft departed from Chicago and was destined for Washington DC, with over 100 passengers on board. The other engine was conventional kerosene. During the flight, it was found that

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there was no difference in the operation of the two engines using different types of fuel. Replacing kerosene with SAF could result in an approximate 80% reduction in carbon dioxide emitted by the aviation industry from the fuel when considering the entire life cycle shown in *Figure 4* (*Levingston, 2022*):

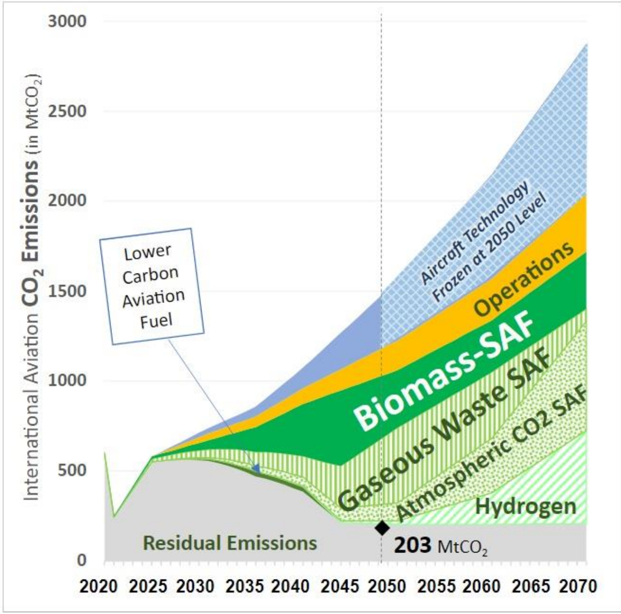

Figure 4. The future of aviation CO_2 emissions according to ICAO estimates (ICAO, 2023b)

In practice, SAF blending up to 50% can be observed when blended with conventional JET A or JET A-1 fuel. SAF fuel is fully interchangeable with kerosene without any engine modification. Currently, alternative fuels can be produced at 3 to 6 times the cost of traditional kerosene. Through continuous development and commercialisation, the technology will become cheaper and more affordable in small steps. It is already available at more than 60 airports, but it is currently impossible to produce sufficient quantities of sustainable fuels from plant derivatives, and synthetic production is needed. By 2050, SAF fuel could account for approximately 15% of total aviation fuel consumption (*Gül et al., 2021*).

3.3.Hydrogen-powered aircraft

Hydrogen can play a significant role in meeting the energy needs of aviation. Experts consider it essential to focus on using renewable energy to produce hydrogen produced by water decomposition. According to ICAO, the use of hydrogen in propulsion will not have a significant impact on carbon dioxide reduction until 2050. It is estimated to account for approximately 1.9% of the energy mix. These figures could increase significantly after 2050 (*ICAO Committee on Aviation Environmental Protection Report, 2022*).

3.3.1. Hydrogen-fueled gas turbines

The industry needs time to build airport infrastructure and hydrogen transport, but some aircraft manufacturers, such as Airbus, prioritise this type of technology as a long-term carbon reduction option. According to the manufacturer, the first hydrogen-powered passenger aircraft could operate scheduled flights by 2035, with up to 200 passengers on board and a maximum range of 3,500 km. The storage of liquid hydrogen faces many obstacles. Designing and integrating fuel tanks in aircraft is one of the most critical processes for testing aircraft with new technology. Airbus plans to test hydrogen tanks stored at extremely low temperatures of around -252 degrees Celsius by 2025 (*Airbus, 2021*).

3.3.2.Hydrogen fuel cell propulsion

Hydrogen can be used not only as a fuel for gas turbines, where the combustion products exiting the engine are used to provide some thrust but also for fuel cell engines of propeller rotation design that the green fuel can power. In fuel cells, an electrochemical reaction converts hydrogen into electrical energy to turn a propeller by an electric

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motor. The converted A380, which Airbus is testing hydrogen technologies on, is being used for various tests to monitor the engines' operating parameters and the liquid hydrogen distribution and storage systems. The technology does not emit carbon dioxide in its combustion products, its main by-product being water. Fuel cell technology has the advantage of zero nitrogen oxide emissions and no contrails. Airbus expects to launch the ZEROe programme in the late 2020s. The fuel cell aircraft to be developed in this programme are expected to have a range of nearly 2000 km, carrying approximately 100 passengers. Using a propeller has limitations compared to JET technologies: lower cruising speed and altitude.

4. Conclusion

The technologies described above are based on the benchmarks of today's well-established forms of aviation, such as conventional kerosene-fuelled gas turbines or internal combustion engines fuelled by AVGAS or diesel. Fossil fuel-burning aircraft have a high emission and environmental impact but have become a safe and widespread form of air transport, flying at relatively high altitudes, high speeds and long distances, carrying hundreds of passengers or many tonnes of cargo. The future technology aims to reduce emissions by orders of magnitude, focusing on carbon dioxide gas, without compromising these flight characteristics. The challenge for practitioners and policymakers is to develop a roadmap for implementing mature technologies in aviation over the coming decades so that the industry can reach the realistic emission levels we are now setting ourselves in the name of sustainability.

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