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Research article

Can Central Bank Digital Currencies be green and sustainable?

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Abstract: Within digital finance, CBDCs are booming. As there are currently four operational CBDCs and as many as ninety-four central banks, jurisdictions or currency areas are testing or investigating the launch of a retail CBDC. The study was based on a sample of 34 countries or currency areas, which were classified into three groups. This research aimed to answer the following research questions: 1. Can CBDCs be considered green and sustainable? 2. How can we determine whether a CBDC is green and sustainable? 3. Which countries are closest to having green CBDCs? It has been calculated the total and the percentage of CBDCs that could be considered green or sustainable according to each country or currency area; in this model, it has been considered one monetary unit issued in a green/sustainable CBDC format for each point that a country obtains in this model that is adjusted according to four variables: Electricity prices for households and for businesses, renewable electricity production and CO_2 emissions. The countries that could launch a higher percentage of green/sustainable CBDCs in circulation would be the countries in the Eurozone and the United Kingdom, with these countries exceeding 70%. This was followed by Sweden (60%), Australia (58%) and the Bahamas (close to 54%). Only the Bahamas has its CBDC already launched and operational. Jamaica is also in the top ten and has its CBDC up and running. Japan closes the top 10 with just over 51%. Those countries with cleaner sources of power generation will be able to keep their CBDCs operating more sustainably. The environmental impact, however, will vary depending on the design choices of a CBDC and the country where it operates, according to the variables of this model.

Keywords: green finance; CBDC; green CBDC; sustainable CBDC; digital finance; sustainable digital finance

JEL Codes: E50, E52, E58

1. Introduction

Since 2008, when a person or a group, under the pseudonym Satoshi Nakamoto, conceived a decentralized digital currency based on a payment system without a central bank or a single authority called Bitcoin, cryptocurrencies have grown exponentially. In 2009, Bitcoin began to operate following a message sent to the metzdowd.com cryptocurrency mailing list, which was signed with the alias Satoshi Nakamoto and entitled "*Bitcoin P2P e-cash paper*" (Nakamoto, 2008). Its price went from USD 1 in February 2011 to a peak of USD 69,000 in November 2021. Not only has the growth of its price been exponential, but so has the number of users, which was estimated to be 5 million in 2016 and around 220 million in 2021 (Auer et al., 2023). It is also the cryptocurrency with the largest market capitalization, with a value of over USD 300 billion (CoinMarketCap, 2023). After Bitcoin, many more cryptocurrencies appeared, such as Ethereum, Ripple and Litecoin, to name a few. In the last 14 years, cryptocurrencies have evolved from being a new technology oriented to peer-to-peer payments without the supervision of a centralized authority to become financial assets that are traded by millions of users worldwide (Kyriazis, 2021). Two countries in the world have declared Bitcoin as a legal tender. The first is El Salvador (Alvarez et al., 2022). The second country is Central African Republic, which, in April 2022, announced a surprise vote on a law to legalize Bitcoin in the country as a legal tender (Odeh, 2022). The emergence of cryptocurrencies and the threats they may pose by competing with central bank-backed money (Nabilou, 2019; Náñez Alonso et al., 2020) have aroused the interest of central banks around the world in digital currencies; this has led to the emergence of digital currencies backed by central banks (Auer et al., 2020) and are called Central Bank Digital Currencies (CBDCs) (Kumhof & Noone, 2021). However, as with cryptocurrencies, their degree of adoption and implementation varies widely from region to region, as not all regions have the same characteristics or motivations for implementing a CBDC (Náñez Alonso et al., 2021; Allen et al., 2022). A CBDC, although its design and characteristics may differ considerably, is a digital currency that is universally accessible and could be exchanged among peers; but in this case, it would be issued and backed by a central bank or a monetary authority (Cunha et al., 2021; Náñez Alonso et al., 2021; Ozili, 2022). There are currently three countries and one currency area that have already implemented a CBDC that is operational. The first of these countries is the Bahamas, which launched its CBDC called Sand Dollar in October 2020. The second is Jamaica, which launched its CBDC called Jam-Dex in 2022. The third is Nigeria, which launched its CBDC called e-naira. The fourth includes member countries of the Eastern Caribbean Central Bank (ECCB) whose CBDC is called D-Cash (Náñez Alonso et al., 2023). In addition, according to a report of the International Monetary Fund, in September 2022, almost 100 CBDCs were in the research or development phase worldwide (International Monetary Fund, 2022). There are several reasons for launching a CBDC. One of them is to improve financial inclusion (Náñez Alonso et al., 2020; Ozili, 2021; Ahiabenu, 2022; Ozili, 2022). Other reasons include to maintain control over monetary policy and macroeconomic policy (Yang & Zhou, 2022) and to reduce (through its implementation) the use of other means of payment related to illicit activities (Ozili, 2022). On top of all these reasons, there is a growing concern for the environment and for green and sustainable finance, which CBDCs should not be oblivious to (Yang et al., 2023).

In this article, I aim to answer three questions. First, can CBDCs be considered green and sustainable? Second, how can we determine whether a CBDC is green and sustainable. Third, which countries are closest to having green CBDCs? To answer these three questions, this article is structured as follows: In the introduction, an analysis is conducted on the emergence of CBDCs and their rise in the wake of cryptocurrencies, proposing sustainability and concern for the environment as a motive for their launch. The literature review analyzes the concern for green finance and the theory provided by the works published to date. In the Materials and Methods section, I explain the sources from which I extracted data to generate my model. For the methodology, I explain the model applied to launch a green/sustainable CBDC. In the Results section, I classify the countries that could launch a higher percentage of a green/sustainable CBDC in circulation, both globally and according to the degree of development of their CBDC (already underway or pilot test completed; proof of concept already completed or to be implemented soon; and in advanced stages of research). Finally, the results, limitations and gaps of my study are discussed and the conclusions are drawn.

2. Literature review: CBDCs and sustainability

Central Bank Digital Currencies (CBDCs) are all the rage. According to a report by Auer et al. in 2020 and an updated report in February 2023, there are four operational CBDCs in the world, including in the Bahamas, in the Caribbean in countries under the umbrella of the Eastern Caribbean Central Bank (ECCB), Nigeria and Jamaica. This makes the Caribbean the current epicenter of operational CBDCs (Náñez Alonso et al., 2022; Náñez Alonso et al. 2023). However, in addition to the above, there are currently pilot projects in 34 jurisdictions, covering both wholesale and retail CBDCs. Despite the fact that there are countries where CBDCs are already in operation and others have pilot projects at an advanced stage, the speed of implementation in some cases is slow and, in other countries, such projects have been stalled because they present some problems (Bindseil, 2022). In many cases, these problems are related to the reasons for issuing a CBDC; they vary from country to country (Bijlsma et al., 2021; Maryaningsih et al., 2022; Náñez Alonso et al., 2020), as do policy approaches and technical designs. Not all countries or currency areas are equally optimal for implementing a CBDC (Náñez Alonso et al., 2021). In this article, I focus on the sustainability of CBDCs. Although CBDCs are not cryptocurrencies, their operation does require the use of energy.

Cryptocurrencies have accelerated the process of digitalization and democratization of money (Temperini and Corsi, 2023). However, within the scientific community, there is ongoing debate and concern regarding the potential environmental ramifications of virtual currencies.

Truby (2018) draws attention to the environmental impact of Bitcoin mining and, by extension, other cryptocurrencies. The discourse revolves around the consequences of mining activities and the extent to which the rapid expansion of this practice could impede the achievement of established goals aimed at mitigating climate change. In their investigation, Mora et al. (2018) and Dittmar and Praktiknjo (2019) emphasize that energy-related emissions from cryptocurrency mining might contribute to pushing global warming beyond the critical threshold of 2 °C. Martynov (2020) quantifies this impact economically, illustrating a scenario where each 1 USD of cryptocurrency coin value created could be accountable for 0.66 USD in health and climate damages. Based on their study focusing on the United States, Goodkind et al. (2022) further assert that Bitcoin incurs social costs surpassing the market price during most considered periods. Contrastingly, Masanet et al. (2019) argue that implausible projections are exaggerating Bitcoin's CO_2 emissions in the short term, while Houy (2014) and Houy (2019) criticize the inclusion of unprofitable mining platforms, leading to a substantial overestimation of emissions. The energy sources utilized in cryptocurrency mining, as noted by Fadeyi et al. (2019), Goodkind et al. (2020) and Goodkind et al. (2022), can result in increased pollution, with air pollution being a notable concern. Leslie (2020) adds to the discourse by pointing out the rise in electronic waste and the additional energy requirements to counteract the heat released from these platforms.

This ongoing debate regarding the environmental and social costs associated with decentralized finance has not only brought attention to the financial sector but also extended its implications to Central Bank Digital Currencies (CBDCs), as highlighted by Yang et al. (2023) and Mincewicz (2023).

CBDCs should not be oblivious to the situations described above with regard to cryptocurrencies. Different organizations and institutions have included sustainability among the objectives of their future CBDCs. In the United States of America, the design of a future digital dollar has been proposed, while aiming to respect the principles of sustainability (U.S. Committee on Financial Services, 2021). In Europe, there are various sectors and reports that advocate that the future digital euro should respect and guarantee its sustainability, as well as the lowest possible environmental impact (European Green Digital Coalition, 2023). Even a joint report by the Bank of Canada, the European Central Bank, the Bank of Japan, the Sveriges Riksbank, the Swiss National Bank, the Bank of England, the Board of Governors of the Federal Reserve System and the Bank for International Settlements (BIS) states that one of the guiding principles of CBDCs should be their sustainability (Bank for International Settlements, 2020). In fact, the BIS itself has included its objectives for 2022 and beyond the promotion of green and sustainable finance, including CBDCs (Bank for International Settlements, 2022). In short, it is a matter of linking the development of CBDCs with the Sustainable Development Goals (SDGs) listed by the United Nations (UN). Thus, I found authors who directly link achieving financial sustainability and the development of green finance with CBDCs as a key player (Chu, 2023; Ozili, 2023c; Paradise, 2022), specifically the Sustainable Development Goal number eight: "Promote inclusive and sustainable economic growth, employment and decent work for all" (Ozili, 2023a). Considering that the largest number of users of digital finance are young people, especially those under 35 years of age (Alonso et al., 2023), raising awareness and promoting the notion of sustainability among young people would lay the foundation for greater future sustainability. Also, Ding et al. (2022) and Náñez Alonso et al. (2020) report the positive effects that CBDCs could have on rural and underdeveloped environments. Promoting green and sustainable finance via CBDCs as well should be a priority of public policies, as stated in a study (Ren et al., 2022). In fact, a study by Chen (2018) indicates that CBDCs can be used as a means to "decarbonize" the economy. In this sense, it is interesting to highlight the work of Yang et al. (2023), who indicate that "a CBDC reduces SO_2, NOx and smoke emissions, and improves the proportion of green land, which is beneficial for sustainable development", concluding that a CBDC is useful to accelerate green finance. The same conclusion is reached by Maltais and Nykvist (2020) in their study on green bonds in Sweden, as a rapidly growing green bond market is affecting citizens' commitment to sustainability in a positive way. Even other authors, such as Dziwok and Jäger (2021) and Feng et al. (2023) talk about developing a "green" monetary policy where CBDCs would undoubtedly play a key role.

However, in many cases, environmental sustainability is not shown as a priority for the acceptance and use of CBDCs (Liu et al., 2022; Náñez Alonso et al., 2020).

At this point, and in view of the importance that green finance currently has and will have in the future, a reality to which CBDCs should not be oblivious, the following question arises: What factors influence whether a CBDC is more or less sustainable?

Based on a study by Lee and Park (2022), there are several factors that influence the sustainability of a CBDC, including the source of energy generation needed for CBDC operations, energy prices and CO_2 emissions.

A source of energy is needed to operate CBDCs in the first place. If the power generation in a country where a CBDC is intended to be implemented is green or sustainable, then the impact of the CBDC on the environment will be reduced, thereby ensuring sustainable economic growth (Batrancea et al., 2019; Dash et al., 2022; Warjiyo, 2023).

The prices of energy needed for CBDC operation should be taken into account. As with cryptocurrencies (but in a much less intensive way), CBDCs need energy to operate. Hence, given that the cost associated with electricity is a pivotal determinant that influences mining decisions, as emphasized by de Vries (2018), Li et al. (2019) and Malfuzi et al. (2020), Central Bank Digital Currencies (CBDCs) should conscientiously take this factor into account and not overlook its significance. Both Distributed Ledger Technology (DLT)-based and non-DLT-based CBDCs have the potential to entail lower energy consumption for basic processing functions, compared to traditional means of payment and also cryptocurrencies (Agur et al., 2023). In fact, authors like Tiberi (2021) estimate that CBDCs even have the potential to consume less energy than credit card payment processes, a position that is reinforced by Sedlmeir et al. (2020), Platt et al. (2021) and Schroeder (2023), who indicate that blockchain-based solutions still require more energy than centralized architectures without blockchain. This corroborates with the estimates reported by Lee and Park (2022), where means of payment based on networks similar to credit cards consume less energy than those based on blockchain; so, the final cost will also be lower.

Bitcoin	700
Ether	30
Mastercard	0,0006
Paper money (US)	0,044
Ripple	0,0079
Visa	0,0008

Figure 1. Electricity consumption per transaction (kWh) by means of payment used. Source: own elaboration based on data from Lee and Park (2022).

Another potential benefit of CBDCs and their aid to sustainability comes from cost savings regarding printing banknotes in circulation (physical currency) (Fabris, 2019). In fact, in a study by Rochemont (2020), the average cost of electricity for the US Bureau of Engraving and Printing banknote manufacturer corresponds to 11.38 cents/kWh. Other authors indicate figures similar to those shown in Figure 1. These figures would be higher than the cost in terms of energy for a central bank to operate and maintain a CBDC network in operation.

The energy consumption required to use mobile devices to operate a CBDC should not be overlooked either, which would be borne by users. Payments would mostly be made through a mobile application called “digital wallet”, which consumes energy. However, authors such as Alotaibi et al. (2020) and Jiang et al. (2016) indicate that digital wallets are similar to other applications in energy consumption, and this energy consumption would be considered negligible; in fact, Wilke et al. (2013)

estimate that the minutes of use of an application to perform a transaction via a digital wallet can be measured in the order of 10^{-7} kW/h.

Emissions of CO_2 and other polluting gases are another factor that will influence the sustainability of a CBDC. This is directly related to the way in which electricity is generated in each country or currency area where the CBDC is implemented. Thus, those countries with cleaner sources of power generation will be able to keep their CBDC in operation in a more sustainable way. A study by Yang et al. (2023) states that "a CBDC reduces emissions of SO_2, NO_x and smoke". This situation is reinforced by Ding et al. (2022), who report in their study in China that, under certain circumstances, digital finance can improve the CO_2 reduction capacity. In their study, Zhao et al. (2021) also indicate that digital finance has a significant inhibitory effect on carbon emissions. In sum, as Ozili (2022) notes, the emergence of CBDCs offers central banks the opportunity to make an important contribution to the transition toward a circular and sustainable economy.

3. Materials and methods

3.1. Materials

To determine which countries could issue a "green" or "sustainable" CBDC, I started with a sample of 34 countries. These countries were selected from four sources (Atlantic Council, 2023; Auer et al., 2020; Kiff, 2023; Mikhalev et al., 2023). They were classified according to the degree of development of their CBDC and divided into three groups:

1. Eight jurisdictions where the central banks (CBs) have already implemented, or pilot tested a CBDC (or will do so shortly).
2. Twenty jurisdictions where the central banks have conducted proofs of concept or prototypes (or will soon do so).
3. Six jurisdictions where the central banks have their CBDCs in advanced stages of research and development.

Additionally, data were sourced from the "Environmental Performance Index 2022" (University of Yale, 2023) concerning the chosen group of nations. This index offers a numerical foundation for the assessment, examination and comprehension of the environmental practices across 180 countries. It serves as a metric to gauge which countries are deemed the most sustainable and environmentally conscientious. In the assessment of nations eligible to introduce a green/sustainable Central Bank Digital Currency (CBDC) or to circulate a substantial quantity of a green/sustainable CBDC, it becomes imperative to take into account countries exhibiting higher levels of sustainability according to the Environmental Performance Index (EPI) and other pertinent factors. First, data on energy prices for businesses were extracted from the Globalpetrolprices consortium database and expressed in kW/h in US dollars (Globalpetrolprices, 2023a). Also, data on energy prices for households were extracted from the same database (prices per kW/h in US dollars) (Globalpetrolprices, 2023b). In the third instance, the percentage of electricity production derived from renewable sources was considered. This information was sourced from data provided by the World Bank and compiled using statistics from the International Energy Agency (IEA) and the OECD (The World Bank, 2023b). Fourth, data on CO_2 emissions (expressed in metric tons per capita) were obtained (The World Bank, 2023a). In order to determine how many CBDCs in circulation could be considered green or sustainable, it is necessary to know the level of reserves in each country. For this purpose, I also used total reserves, including gold, which were denominated in USD at current prices, as research material. All these made it possible to generate a dataset with records, which is presented in the Annex as Table A.1.

3.2. Methodology

After consolidating all requisite data into the database, as outlined in the appendix in Table A.1, I initiated the construction of my model. I started with a hypothesis and a method similar to Jaimes Becerra et al. (2023), where I tried to calculate the total and the percentage of CBDCs that could be considered green or sustainable. However, in my method, I considered one monetary unit issued in the CBDC format as green/sustainable for each point that a country obtains in the adjusted Environmental Performance Index, a method already followed for the case of cryptocurrencies by Náñez Alonso et al. (2021). Thus, if a country or jurisdiction obtains 55 points in the $CBDC_{gs}$, it means that 55% of its reserves would be considered green or sustainable if they were issued via a CBDC. To conduct my method, first, I had to adjust the EPI with the rest of the variables via linear regression (Abu-Bader, 2021; Náñez Alonso et al., 2021; Vilà Baños et al., 2019) using Equation 1. I approximated the dependence relationship between my dependent variable CBDCgs (which, in my case, would indicate a more sustainable country via a higher $CBDC_{gs}$) and the 4 independent variables, with W and a random term ε, as follows:

$$CBDCgs = w_1 \cdot EP_b + w_2 \cdot RE_p - w_3 \cdot CO_2e - w_4 \cdot EP_h + \varepsilon \tag{1}$$

Since the parameters W_0, W_1... are unknown constants, they must be estimated using the sample data I collected (Abu-Bader, 2021; Denis, 2021 Náñez Alonso et al., 2021), where:
$CBCD_{gs}$ is a CBDC that is green and sustainable.
EP_b is the price of electricity for businesses.
RE_p is energy production from renewable sources.
CO_2e is CO2 emissions.
EP_h is the price of electricity for households.

Commencing with the utilization of the linear regression model and its application to the data shown in Table A.1 of the Annex, I derived the descriptive statistics presented in Table A.2 of the Annex. The sample for my statistical analysis (N) encompassed 34 countries with complete data. Following the application of linear regression to the variables, I established the model detailed in Table 1.

Table 1. Green and sustainable CBDC model.

Model	R	R square	Adjusted R-squared	Standard error of the estimate	Durbin-Watson
1	0.780	0.608	0.554	9.14749	2.148

Source: own elaboration based on data shown in Table A.1 of the appendix and using IBM SPSS Statistics 28.

The following were used as the predictors: Constant, electricity prices for households (kWh, U.S. dollar), renewable electricity production (% of total electricity production), CO_2 emissions (metric tons per capita) and electricity prices for businesses (kWh, U.S. dollar). The dependent variable was the Environmental Performance Index.

Upon the application of the aforementioned model, I successfully calculated the parameters W_0, W_1... utilizing the sample data I gathered and analyzed using SPSS (Abu-Bader, 2021; Batrancea, 2021). These outcomes are delineated in Table 2.

Table 2. Estimation of the parameters W of the green and sustainable CBDC model.

	Unstandardized coefficients		Standardized coefficients	t	Sig.	95.0% confidence interval for B		Collinearity statistics	
	W	Error	Beta			Lower limit	Upper limit	Tolerance	VIF
(Constant)	23.682	4.283		5.530	<0.001	14.923	32.441		
Electricity prices for businesses (kWh, U.S. dollar)	33.601	23.946	0.284	1.403	0.017	−15.374	82.576	0.330	3.028
Renewable electricity production (% of total electricity production)	0.074	0.052	0.174	1.412	0.016	−0.033	0.181	0.893	1.119
CO2 emissions (metric tons per capita)	0.770	0.345	0.269	2.235	0.033	0.065	1.475	0.936	1.069
Electricity prices for households, (kWh, U.S. dollar)	53.112	21.474	0.497	2.473	0.019	9.192	97.032	0.335	2.989

Source: own elaboration based on data from Table A.1 and using IBM SPSS Statistics 28.

If I take the data on the unstandardized coefficients W from the above table, my model is represented by Equation 2:

$$CBDCgs = 23{,}682 + (23{,}946 * EPb) + (0{,}074 * REp) + (0{,}770 * CO2e) + (53{,}112 * EPh) \quad (2)$$

4. Results

As depicted in Table 2, my model achieves an R-squared coefficient of 0.608, signifying that it accounts for approximately 60.8% of the variance in the accurate classification of a CBDC as green or sustainable through the rescaled EPI. Additionally, the Durbin–Watson test result in the same table is 2.148, indicating minimal autocorrelation in the employed regression model as it is close to the critical value of 2. Conversely, as illustrated in Table 3, the p-value (Sig.) of the ANOVA test is below 0.05. Consequently, the presented hypothesis can be affirmed, suggesting that at least one of the parameters significantly differs from “zero”, thereby validating the overall model.

Table 3. Anova results.

CBDCgs		Sum of squares	gl	Root mean square	F	Sig.
1	Regression	3760.281	4	940.070	11.235	<0.001
	Waste	2426.619	29	83.677		
	Total	6186.899	33			

Source: own elaboration based on data from Table A.1 and using IBM SPSS Statistics 28.

The following variables were used as the predictors: Constant, electricity prices for households, (kWh, U.S. dollar), renewable electricity production (% of total electricity production), CO_2 emissions (metric tons per capita) and electricity prices for businesses (kWh, U.S. dollar). My dependent variable was $CBDC_{gs}$. Finally, when I checked the p-value (Sig.) of the independent variables in Table 3, they are all statistically different from zero (Sig < 0.05), so they can remain in the model (Abu-Bader, 2021; Denis, 2021). Table A.3 in the appendix shows the statistics of the residuals.

With respect to the statistical results, I observe that the R-squared coefficient is 0.608. According to authors such as Tarling (2008) and Ozili (2023b), an R-squared coefficient of 0.6 or higher in social science studies, as in my case, is acceptable.

Regarding the skewness and kurtosis of the variables under study, they show the following results. First, total reserves exhibit a remarkably positive skewness (3.859) and a high kurtosis (17.422), which point to a distribution with a pronounced right tail. This phenomenon suggests a concentration of values toward the upper end of the range, indicative perhaps of a significant disparity in reserves. In contrast, when analyzing the Environmental Performance Index (EPI), I observe a smaller positive skewness (0.272) and a negative kurtosis (−0.157). These indicators suggest a slightly skewed distribution to the right, but with less pronounced tails. This could imply greater homogeneity in the EPI data, with a higher concentration around the average. Electricity prices for firms exhibit a positive skewness (1.048) and a kurtosis (0.353) that is close to normal. This configuration indicates a right tail in the distribution of prices, although the shape of the distribution more closely resembles a normal bell. This trend could reflect some variability in electricity prices for businesses, but there were no significant extremes. In the renewable electricity production domain, a negative skewness (−0.970) and a negative kurtosis (−0.548) stand out. This suggests a distribution skewed to the left, indicating that most countries tend to have a lower percentage of renewable electricity production, with less variability at the upper extremes. Finally, CO_2 emissions exhibit a pronounced positive skewness (1.360) and high kurtosis (2.253). These results suggest a distribution with a heavier right tail, indicative of significant disparity in CO_2 emissions, with some countries emitting substantial amounts, while others maintain lower emissions. This pattern may reflect inequalities in the environmental policies and carbon footprint of different nations. I used the variance inflation factor (VIF) following previous research (Batrancea et al., 2021; Batrancea, Rathnaswamy and Batrancea, 2021) to detect possible multicollinearity in the variables. The VIF calculations are presented in Table 3. None of the results obtained exceeds a coefficient of 1. This indicates no correlation between a predictor variable and any other predictor variables in the model; therefore, there is no multicollinearity.

Applying the rescaled CBDCgs equation to the dataset shown in Table A.1 of the Annex for each country enables the creation of a visual ranking. This ranking provides insights into countries where a higher issuance of green/sustainable CBDCs might be feasible. As can be seen in Figure 2 and Table A.4 in the Annex, the countries that could launch a higher percentage of CBDCs in green/sustainable circulation would be countries in the Eurozone and the United Kingdom. These countries exceed 70%

and are well ahead of the rest of the countries included in this study. Sweden ranks third with just over 60% of its CBDC considered green/sustainable, followed by Australia with 58% and the Bahamas with around 54%. The countries that occupy the top positions are European countries along with one country from Oceania and another from the Americas. Only the Bahamas has already launched and is operating its CBDC. Jamaica is also in the top ten positions and has its CBDC in operation. Japan closes the top 10 with just over 51%. When I analyzed the situation by group, I obtained the results described below.

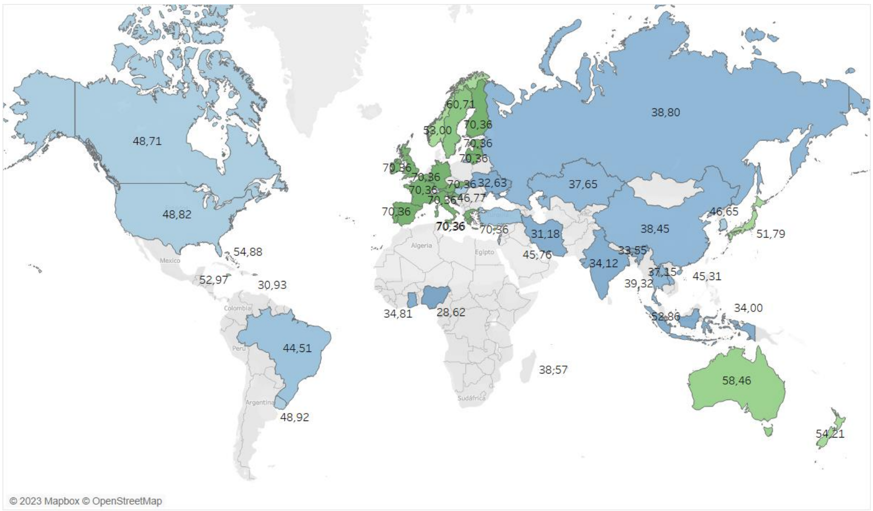

Figure 2. Percentage of total CBDCs that could be considered "green". Source: own elaboration based on data from Table A.4 and analyzed using Tableau Desktop Professional Edition v.2023.2.

Within the first group, which includes jurisdictions in which their central banks (CBs) have already implemented a CBDC or have conducted a pilot test (or will do so shortly), the Bahamas stands out, where nearly 54% of its CBDC could be called green/sustainable according to my model. This is followed by Jamaica, with about 53% and Uruguay, with about 49%. The rest of the other countries, including China (38.5%), are still far behind. This is shown in Figure 3 and Table A.4 in the Annex.

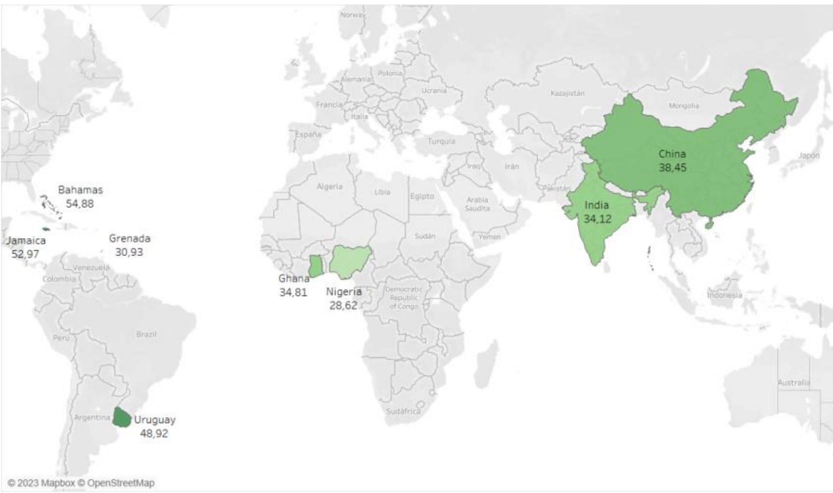

Figure 3. Percentage of total CBDCs that could be considered "green" in jurisdictions where central banks (CBs) have launched or piloted (or soon will). Source: own elaboration based on data from Table A.4 and analyzed using Tableau Desktop Professional Edition v.2023.2.

Within the second group, which includes countries where their central banks have carried out proofs of concept or prototypes (or will do so soon), the Eurozone stands out as more than 70% of its CBDC could be called green/sustainable according to my model. This is followed by Sweden with almost 61%, and then Norway (53%), New Zealand (54%) and Japan (almost 52%), whose CBDCs could be called green/sustainable according to my model. These results are shown in Figure 4 and Table A.4 in the Annex.

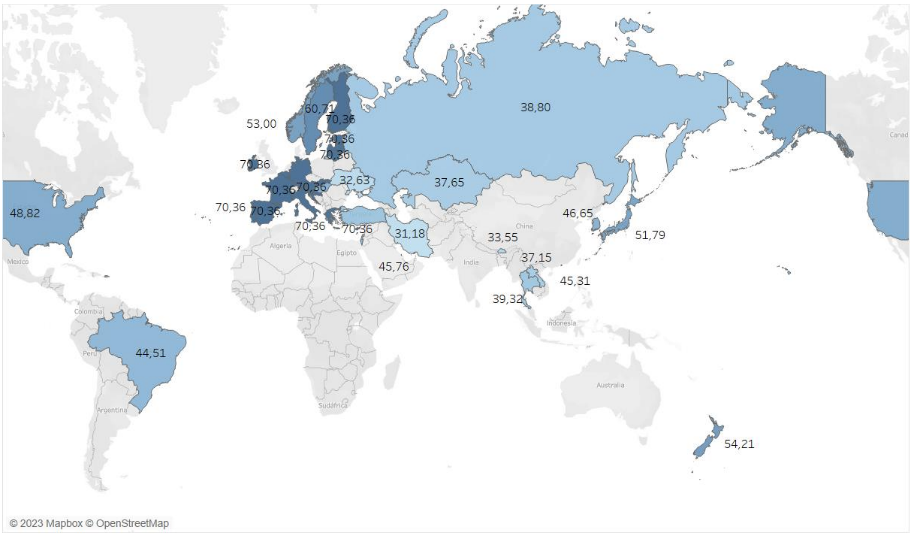

Figure 4. Percentage of total CBDCs that could be considered "green" in jurisdictions where CBs have conducted proofs of concepts or prototypes (or soon will). Source: Own elaboration based on data from Table A.4 and analyzed using Tableau Desktop Professional Edition v.2023.2.

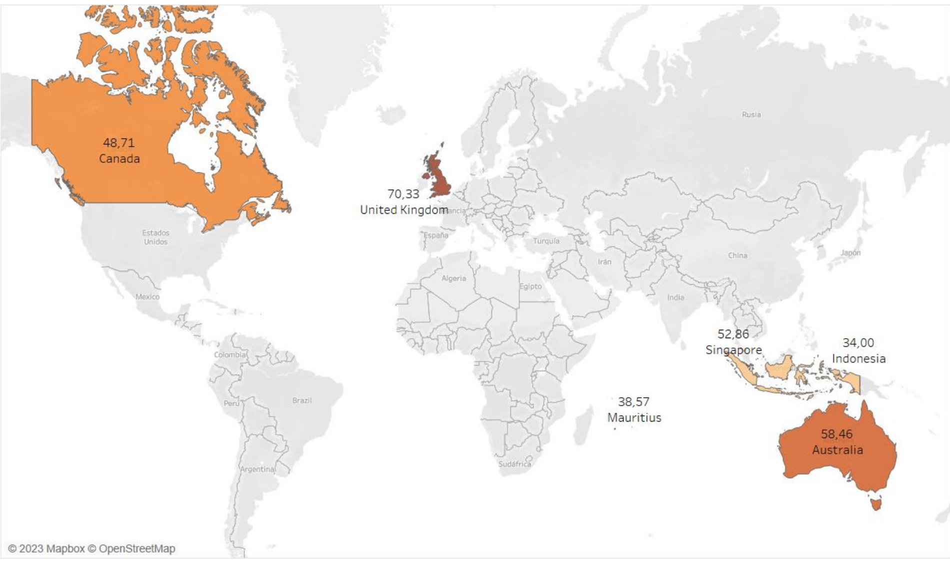

Figure 5. Percentage of total CBDCs that could be considered "green" in jurisdictions where CBs are in advanced stages of research and development. Source: own elaboration based on data from Table A.4 and analyzed using Tableau Desktop Professional Edition v.2023.2.

Within the third group are those countries where their central banks or monetary authorities are in advanced stages of research and development of their CBDCs. Here, the United Kingdom stands out as just over 70% of its CBDC could be considered green/sustainable according to my model. This is followed by Australia (58%) and Singapore (around 53%). These results are shown in Figure 5 and Table A.4 in the Annex.

I therefore see that the most sustainable countries for launching a green/sustainable CBDC would be mainly European countries (Eurozone), the United Kingdom, Norway and Sweden. Australia and New Zealand are also located in the high zone, and two countries in the Caribbean area, the Bahamas and Jamaica whose CBDCs are already in operation, stand out positively, with just over 50%. However, all of these countries still have some way to go to increase the amount of CBDCs that could be considered green/sustainable.

A discernible trend emerges in Europe: These nations demonstrate advanced capabilities in clean energy production, boast lower average electricity prices and exhibit a notable proportion of sustainable energy generation. Moreover, these countries prioritize investments in research and development along with human capital. This pattern extends to Asia and Oceania, where Japan, Australia and New Zealand also align with the aforementioned characteristics.

A parallel pattern is evident in both Europe and Asia: All these nations are located in the northern hemisphere, with the majority being situated in the northern part of this hemisphere (excluding Australia and New Zealand). When expanding the analysis to include fifteen countries, only one non-northern hemisphere country, Uruguay, appears in the list, deviating somewhat from the established trend. The additional countries on this list, alongside Uruguay, include the United States, Canada, South Korea and Hungary, which are detailed in Table A.4 in the Annex.

Conversely, there are countries on the opposite end of the spectrum where the issuance of a green/sustainable CBDC only constitutes a minority. Nigeria, with 28.6%, and the ECCB, with 30.9%, occupy the last two positions in the list of 34 countries. These are two countries that already have their respective CBDCs (e-Naira and D-cash) in operation. China, another country where several pilot tests have already been carried out, could call only 38.45% of its CBDC as green/sustainable, occupying the 24th position out of the 34 countries analyzed. The complete ranking can be found in Table A.4.

5. Discussion

There is no doubt about the current trend in CBDCs, especially when there are currently 94 central banks, jurisdictions or monetary areas that have issued, tested, piloted and/or are investigating the launch of a retail CBDC (John Kiff, 2023). Some of the possible difficulties in implementing a CBDC have been studied from various points of view. Kaczmarek (2022) and Tercero-Lucas (2023) indicate that without a central bank implementing a CBDC with the aim of having a positive net worth and the absence of bank runs, a high demand for CBDCs is a necessary condition to achieve both objectives. Also, ensuring privacy in transactions is a concern noted by Tronnier (2021) and Tronnier et al. (2022), which will greatly influence the adoption of a CBDC. Other factors that may pose difficulties in the adoption of CBDCs may be the national culture itself, as pointed out by Luu et al. (2022); the lack of digital skills of citizens where it is implemented (Ahiabenu, 2022; Alora et al., 2024); and the degree of competition that a CBDC has with other digital payment means in the country (Wenker, 2022; Alora et al., 2024). The trust that citizens have in their institutions, including their central banks, is also a limiting factor (Ngo et al., 2023; Ozili and Náñez Alonso, 2024). Adding to this is the current trend in finance in the pursuit of energy sustainability (Taghizadeh-Hesary & Yoshino, 2020), aiming to help meet and achieve the SDGs (Chu, 2023; Ozili, 2023c; Paradise, 2022). It is, therefore, a matter of achieving sustainable and inclusive economic growth (Desalegn & Tangl, 2022). A proof of this trend is the pronouncement of several international organizations through different bodies (Bank for International Settlements, 2022; European Green Digital Coalition, 2023; U.S. Committee on Financial Services, 2021) that clearly indicates that one of the guiding principles of CBDCs should be their sustainability and respect for the environment. The environmental impact, however, will vary depending on the CBDC design choices (Lee & Park, 2022).

In my study, I set out to answer three questions related to the sustainability of CBDCs: First, can CBDCs be considered green and sustainable? After conducting a literature review, I found that CBDCs cannot only come to be considered green and sustainable, but they are going to play a key role in the development of green finance. Chen (2018) indicates that the use of CBDCs is a means to "decarbonize" the economy, and Yang et al. (2023) indicate that CBDCs can reduce emissions of polluting gases into the atmosphere; therefore, promoting green and sustainable finance via CBDCs should be a priority of public policies, as stated in a previous study (Ren et al., 2022). However, in many cases, environmental sustainability is not shown as a priority for the acceptance and use of CBDCs by citizens (Liu et al., 2022; Náñez Alonso et al., 2020).

Second, how can we determine whether a CBDC is green and sustainable? To answer this question, I initially conducted a literature search to determine which factors could affect the operation of a CBDC. It was identified that both Distributed Ledger Technology (DLT)-based and non-DLT-based CBDCs have the potential to promote lower energy consumption for basic processing functions, compared to traditional means of payment and also cryptocurrencies (Agur et al. 2023). In fact, authors like Tiberi (2021) estimate that CBDCs even have the potential to consume less energy than credit card payment processes. A position that is reinforced by Sedlmeir et al. (2020) and Platt et al. (2021). Thus, energy and its price are configured as a key element. Emissions of pollutant gases are another determining factor selected as they will influence the sustainability of a CBDC. This is directly related to the way in which electricity is generated in each country or currency area where a CBDC is implemented. Thus, countries with cleaner sources of power generation will be able to keep their CBDCs in operation in a more sustainable way (Ding et al., 2022; Yang et al., 2023). Last but not least, it is necessary to consider where the source of energy needed to operate a CBDC comes from in the first place. If the power generation in the country where a CBDC is intended to be implemented is green or sustainable, then the impact of the CBDC on the environment will be reduced, thus ensuring sustainable economic growth (Batrancea and Tulai, 2022; Dash et al., 2022; Lee & Park, 2022; Warjiyo, 2023).

After determining these factors as being fundamental, I applied a hypothesis and a method similar to Jaimes Becerra et al. (2023), where I tried to calculate the total and percentage of CBDCs that could be considered green or sustainable. However, in my method, I considered one monetary unit issued in the CBDC format as green/sustainable for each point a country obtains in the adjusted Environmental Performance Index, a method already followed for the case of cryptocurrencies by Náñez Alonso et al. (2021).

Finally, and after applying the method described above, I answered the question, "Which countries are closest to having green CBDCs?" The results show that the countries that could launch a higher percentage of green/sustainable CBDCs in circulation would be countries in the Eurozone and the United Kingdom. These countries exceed 70% and are well ahead of the rest of the countries included in this study. Sweden ranks third with just over 60% of its CBDC considered green/sustainable, followed by Australia with 58% and the Bahamas with around 54%. The countries that occupy the top positions are European countries along with one country from Oceania and another from the Americas. Only the Bahamas has already launched and is operating its CBDC. Jamaica is also in the top ten positions and has its CBDC in operation. Japan closes the top 10 with just over 51%. Although my method differs from that applied by Jaimes Becerra et al. (2023), the results coincide in highlighting the countries of the Eurozone, as well as Norway and the United Kingdom, among those countries that could sustainably support a higher percentage of CBDCs. The results also coincide for Australia, New Zealand and South Korea. However, the results differ for China and Iran since, in my case, these two countries occupy a medium and a very low position, respectively, in terms of the percentage of green or sustainable CBDCs that could be supported.

This study is innovative and closes an existing gap in the field of CBDC sustainability. It is the second study known to date after the one published by Jaimes Becerra et al. (2023), which attempts to develop a method to classify countries according to the sustainability of their future CBDCs. The limitations of the study include the following: First, the sample of countries or currency areas is 34. Eight jurisdictions were selected where their central banks (CBs) have already implemented a CBDC or have conducted a pilot test (or will do so soon); twenty jurisdictions were selected where their central banks have conducted proofs of concept or prototypes (or will do so soon); and six jurisdictions were selected where their central banks have their CBDCs in advanced stages of research and development. As the number of jurisdictions in each group under study changes in future research, it is possible that the rankings will change, although the methodology will remain the same and can be replicated. Second, the variation in total reserves and the changes in the EPI annually in terms of the price of energy or gas emissions mean that the obtained results are the product of a specific year and may be different in the future with variations in the factors mentioned above. However, this article lays the foundations for subsequent studies on CBDCs and their sustainability. The authorities of each country should take energy production into account when designing policies related to the demand for future CBDCs, bearing in mind that green energy production contributes to conserving resources and reducing environmental degradation (Batrancea and Tulai, 2022). The growing adoption of CBDCs, with a focus on sustainability, points to a critical need to align financial policies with environmental objectives. The pressure to move toward a greener economy demands that governments carefully consider the environmental impact of their decisions related to CBDCs. In addition, citizens' trust in their institutions, including central banks, stands out as a key factor. Sustainability and respect for the environment have become guiding principles, as evident in recent pronouncements by international organizations. This implies that public policies should prioritize sustainability in the design and implementation of CBDCs.

6. Conclusions

Within digital finance, CBDCs are currently booming, and since there are currently four operational CBDCs and as many as ninety-four central banks, jurisdictions or monetary areas are testing or investigating the launch of a retail CBDC. As a future player in the global financial system, CBDCs must pursue energy sustainability and achieve environmental friendliness. I calculated the total and percentage of CBDCs that could be considered green or sustainable for each country or currency area according to my model. I considered one monetary unit issued in the CBDC format as green/sustainable for each point a country obtains in the Environmental Performance Index adjusted according to the following four variables: electricity prices for households (kWh, U.S. dollar), renewable electricity production (% of total electricity production), CO_2 emissions (metric tons per capita) and electricity prices for businesses (kWh, U.S. dollar). The countries that could launch a higher percentage of green/sustainable CBDCs in circulation would be countries in the Eurozone and the United Kingdom. These countries are above 70% and well ahead of the rest of the countries included in this study. Sweden ranks third with just over 60%, followed by Australia with 58% and the Bahamas with around 54%. The countries that occupy the top positions are European countries along with one country from Oceania and another from the Americas. Only the Bahamas has already launched and is operating its CBDC. Jamaica is also in the top ten positions and has its CBDC in operation. Japan closes the top 10 with just over 51%. Those countries with cleaner sources of power generation will be able to keep their CBDCs operating more sustainably. The environmental impact, however, will vary depending on the design choices of a CBDC and the country where it operates.

Use of AI tools declaration

The author declares he did not use Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

All author declares no conflicts of interest.

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