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Mitigating climate impacts incentives: An analysis of green investments in South America

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Abstract:
The vulnerability of countries related to climate change is driven by different conditions, with geographical location and lack of adequate infrastructure making South America especially vulnerable. Research highlights the importance of South American forests in mitigating climate change. The increasing frequency of climate events calls for preventive attitudes, focusing on sustainable financing. Developed countries have a particular responsibility to support developing countries in addressing the impacts of climate change. A recent study highlights the importance of foreign investment flows in BRICS countries. The article aims to compare the flows of foreign investments between different countries in South America in 2010, 2015, and 2020, using the theory of economic social networks to explore the financial relationships between them. The results indicate interesting changes in the flow of green investments for climate change mitigation, especially in South American countries.

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A country's vulnerability to climate change is a function of different conditions. Geographical localization and good infrastructure faults are some conditions that make South America especially vulnerable, according to Hardoy and Romero Lankao (2011). In this sense, it is important to highlight that much research shows the importance of South American forests in the climate change mitigation process (see Nathaniel et al., 2021, and Locatelli et al., 2011).

The most frequent climate events make precatory attitudes more important than ever, as pointed out by Schmidt et al. (2017), and Lunogelo and Baregu (2013). In this sense, more financial research about climate change focused on the comprehension and incentives for sustainable financing is being done, and a list of finance strategies is being formed, according to Moura and Gavira (2022).

As explained by Calvet et al. (2022), climate change presents a financial risk for firms and all world economies. Investors and financial institutions need to evaluate this risk and incorporate it into their investment decisions. Furthermore, transitioning to a carbon economy will require a major investment in green energy and sustainable technologies. This implies new financial sources and instruments.

The best example of strategy is carbon pricing, which incentivizes and reduces greenhouse gas (GHG) emissions. According to Calvet et al., carbon pricing can be done through carbon taxes, emissions trading programs, and other mechanisms. However, in this way, firms must assume responsibility for GHG emissions. This can involve the institution of emissions goals, transparent emissions disclosure, and investments in low-carbon technologies.

From the international perspective, Calvet et al. highlight that developed countries are responsible for supporting developing countries in facing climate change impacts. This was one of the appointments made in the most recent Conference of the Parties of the UNFCCC (COP27) held in Egypt in 2022.

More recently, Mousinho and Coelho (2023) presented an important discussion about the relationship between external investment and energy transition in BRICS (Brazil, Russia, India, China, and South Africa) countries. According to the authors, the financing options available, including those from the World Bank and the Asian Bank of Development, can be hard to obtain. They can impose unfavorable conditions on developing countries. In this sense, it is necessary to implement innovative strategies to support the energy transition jointly.

While the discussion on external financing and energy transition in BRICS countries is fundamental, assessing the flow of such financing in major South American countries is equally important. As Guerrero (2021) presents, South America has a great potential to develop renewable energy sources, such as solar and wind energy. Furthermore, understanding how the financial flow dedicated to the energy transition has behaved in the South American region will subsidize the creation of new ideas aimed at regional development.

This paper aims to compare the external investment flows between countries in 2010, 2015, and 2020 using the economics social networks theory and to explore the financial relations among South American countries. Economic social network theory seeks to understand the interactions between economic actors through connections in a network. In analyzing financial flows, this approach allows for identifying patterns of transactions, influences, and interdependencies between economic entities such as firms, financial institutions, and investors. Economic social network analysis helps to visualize and measure the importance of each actor in the network, facilitating the identification of hubs, clusters, and hotspots, which is essential for understanding the functioning of financial markets and making informed decisions in investments and economic strategies.

The results indicate significant changes in the flow of foreign investment directed toward climate change mitigation; these will be simplified here by the expression 'green investment flow', particularly in South American countries. The expansion of the network over the decade, along with China's increased influence, suggests further analyses are needed from this work. The need for more recent data on Venezuela makes it difficult to accurately compare economic and political conditions among countries that have shown changes in the network tied to South American countries. The composition of the bipartite network shows the importance of investments by developed economies in combating climate change, as pointed out at the last COP27. However, understanding what motivated the observed change in Venezuela's participation may be the key to changing this scenario.

The paper is organized into three distinct sections, each with specific objectives. The next section explains the research method used and the origin of the data collected. This part presents the procedures adopted in collecting, treating, and analyzing the data, providing a solid basis for understanding the results obtained. The research results are presented in the section 3, illustrating clearly and objectively the main findings and discoveries obtained through the applied method. Graphs and tables are used to reinforce the conclusions., The results are discussed and interpreted in depth in section 4. The implications of the findings and their connections with other research and theories, as well as the possible limitations of the study, are analyzed. This discussion allows for a critical and reflective analysis of the results obtained, contributing to advancing knowledge in the area in question.

2. Materials and methods

The data analyzed in this paper are available on the official data and statistics website of the Organization for Economic Co-operation and Development (OECD), 2023. This database consists of 13.784 observations and 38 variables. Given the many variables (information) and the low relevance of some of them for this work, the following variables were selected: Year, Provider (provider or external country or organization), Recipient (destination country of the resource), and the variable corresponding to the amounts, in US dollars, allocated to climate change mitigation and climate change adaptation.

The first data step for this analysis consisted of selecting the years used. We selected the years 2010, 2015, and 2020; for each year, we changed the finance institutions listed by the countries in which they are based. The variable corresponding to the money sent to other countries was adjusted for the integer form. Also, two new factor variables were created, one for identifying the countries by their continent and the other for use as a graphical instrument differentiating South American countries. The selection of the years 2010, 2015, and 2020 for analysis is justified by two main reasons. Firstly, 2020 represents the last year for which we had complete data available, allowing for an assessment of the network in its most recent state. Secondly, the choice of these specific years enables an analysis of the network's evolution throughout the decade, capturing potential transformations and trends that occurred during this period.

The Provider and Recipient vectors comprise countries and organizations like banks and foundations. This way, each institution in the data was identified, and "your name" was changed to the name of the country in which it is based. In addition, the individuals who could not associate with only one country but had a significant number of financial links were kept and associated with political regions (UE, UK). All processes listed until now are part of the extract transform and load (ETL) process (Souibgui et al., 2019).

After data processing, it was necessary to construct the adjacency matrix so that the financial flows could be represented in a graph. According to Maggioni and Uberti (2011), an adjacency matrix is a Boolean matrix with columns and rows indexed to the vertices. The row of the adjacency matrix represents the outputs, and the columns represent the inputs. In this study, this means that the matrix generated has, in its horizontal composition, the lines, the financial outflows, and in its vertical composition, the columns, the receivers of these remittances. Graphs, in turn, are an extension of adjacency matrices, since they can be defined as a data analysis technique that represents the objects under study and their relationships by a set of vertices (or nodes) connected by edges (or lines) (Maggioni and Uberti, 2011). Formally, let $D =$

$\{X_1, X_2, \dots, X_n\}$ set of n units linked by binary relations $R_t \subseteq D \times D, t = 1, \dots, m$ that determine a network, equation (1).

$$D = \{D, R_1, R_2, \dots, R_m\} \tag{1}$$

In the case of a binary network, the adjacency matrix could be represented algebraically by the function expressed in equation (2) when non-binary g_{ij} can also be a real number associated with the weight or intensity of the relationship between the respective individuals.

$$g = [g_{ij}]_{\{n \times n\}} = \{1, X_i\ R\ X_j\ 0\},\ c.c \tag{2}$$

There are several approaches to applying the graph method, among which we can highlight a common and widely used method: the analysis of social networks. In this method, each vertex or node represents an individual or an entity, and each edge represents a connection or interaction between them, such as a friendship or a financial transaction. Measures of centrality and graph structure, such as the degree of each vertex (the number of edges connected to it) and the distance between vertices, are then applied to identify network patterns and properties (Serrat, 2017).

Social network analysis can reveal clusters, groups, or communities of highly connected individuals or individuals with great influence or decision-making power in the network. This method is widely used in many fields, such as biology, sociology, economics, and computer science, to model and analyze complex data with network structures (Newman, 2003).

According to Newman, the metrics and properties used with this method can provide relevant information about the relationship between all individuals represented in the network, such as degree centrality and closeness centrality, also known as eigenvalues and eigenvectors, of the adjacency matrix. In addition to these attributes, the understanding of the analyzed network becomes even more efficient when the frequency distribution or relative probability of the degrees and the formation of local productive agglomerations (LPA) or communities are analyzed.

The degree centrality parameter is based on the node's number of connections. The more connections a node has, the higher its degree of centrality, as presented in equation (3). In equation (3), $d_{i(g)}$ represents the average distance from node i and all other nodes in the network g (Zhang and Luo, 2017).

$$CG_i = \frac{d_i(g)}{(n-1)(n-2)} \tag{3}$$

On the other hand, the closeness centrality parameter assesses how quickly a node can reach all other nodes in the network. The smaller the average distance between a node and the other nodes in the network, the higher its closeness centrality (Zhang and Luo, 2017). The closeness centrality is indirectly related to the centrality degree.

$$C_i = \frac{n-1}{\sum\ d_i(g)} \tag{4}$$

However, the frequency distribution or relative probability of the degrees will depend on both the size of the network and the presence or absence of hubs. According to Doostmohammadian et al. (2020), it is known that the degree distribution of a scale-free (SF) network follows the probability distribution function $f(k)$ of node degree k, where $2 < \sigma < 3$ is presented in equation (6). In such graphs, there are a few nodes with low degrees, a few hubs with low connectivity, or many with low degrees. With too many hubs, high-degree nodes are likelier to get new links, while low-degree nodes are unlikely neighbors of newly added nodes.

$$f(k) = k^{-\sigma} \tag{5}$$

Understanding these metrics contributes to a complete understanding of the role and potential of each node in the network formed by the financial flows analyzed. However, other important points must be investigated in one network graph. As explained by Tarjan (1972), a strongly connected network means that all nodes are interconnected for many directed connections. This right number of directed connections implies a high link density among each. This way, there is efficient, fast, and direct communication and intense collaboration if this network represents social or collaboration links. A connected attribute to this is the diameter measure. The smaller the diameter, the easier the connection between the nodes, wherever they are (Brandes, 2001).

The representation of these attributes in graphs is not new, starting with Erdős and Rényi (1960) and the discussion about the probabilistic structure of the random graphs. However, random graphs are not just a statistic or mathematical toy, and, as explained by Newman et al. (2001), they have been employed intensively in internet network studies or, more generically, in social networks research.

However, several other distributions can be used as graph structures – some more common: Kamada-Kawai, Circular, Hierarchical, Spring-Embedder, Fruchterman-Reingold, and Yifan Hu. The Kamada-Kawai determines the structure based on force (the length of the shortest path between vertices) and is indicated for smart networks, as pointed out by De Nooy (2018). The nodes are placed at a proportional distance in this distribution, theoretically minimizing the network topology's energy function (Cheong, Si, 2017). In the circular structure, the nodes are placed in a circumference, connecting the edges to conform to connectivity. The Hierarchical method organizes the nodes based on a clustering algorithm like a tree or tree structures. The Spring-Embedder, the Fruchterman-Reingold, the Kamada-Kawai, and Yifan Hu use force (the same cited as above) with an argument for placing the node structure in a network trying to maintain a balanced distance (Koning, 2005). In this work, we are using the Yifan Hu structure mainly because of the implementation facility but also because, although we are working with a network with more than 500 edges, it can still make a quick and efficient forecast.

To analyze the connections and attributes of the nodes belonging to South America, we used what is known as an ego network, even though the graphs are not presented in the results section. An ego network, or egocentric or focal network, is a specific representation of a social network that centers around a central individual or entity called the 'ego'. In this type of network, the ego is placed at the center, and only the direct connections between the ego and its direct contacts, known as 'alters', are analyzed. The alters, in turn, are not connected in the ego network representation (Gonzalez-Pardo et al., 2017).

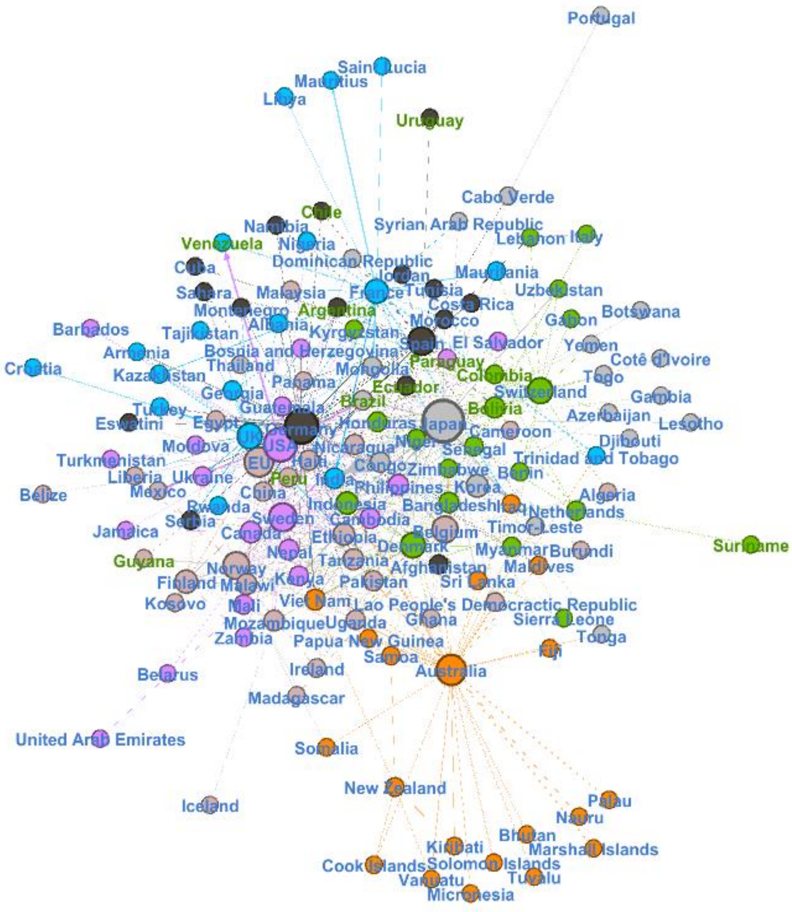
According to Gonzalez-Pardo et al., it is appropriate to use an ego network when one wants to understand a specific individual's direct relationships and interactions in a social network. This approach is useful for exploring the ego's position and influence in the network and analyzing the proximity and nature of the connections the ego maintains with its direct contacts. The ego network allows for a more detailed and focused analysis of the immediate interactions of the individual or entity in question, providing valuable insights into their social relationships.

To help comprehend the links, community, and changes over the years, the data available on CEPAL (2023) was used. These data comprise statistics and indicators about each country's environmental conditions, economics, and human development, especially the Latin American data.

3. Results: the green investment flow network (2010, 2015, 2020)

In the Extract Transform and Load (ETL) process, the finance relations cost more than one thousand dollars. After this process, the green investment flow network for 2010, figure 1, was obtained. This network comprises 179 countries, and the maximum distance between any two countries, that are far from one another, is two steps.

Figure 1 – *Directed Finance Flow Network, 2010*

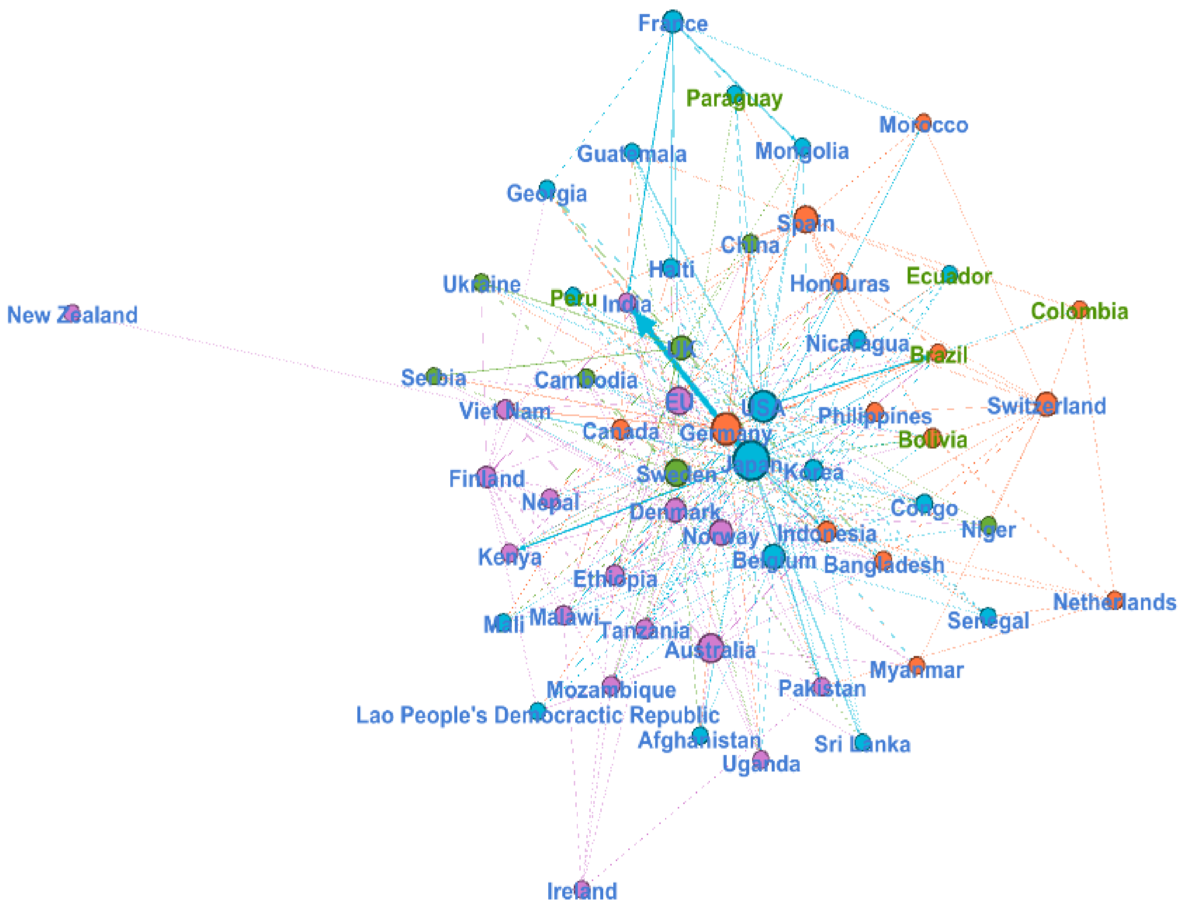


The colors in figure 1 express one clustering possibility for these countries, considering the financial relations in the data. The community structure was defined by hierarchical clustering, which considers the nodes, vertices, and edges to estimate the force attraction and, thus, groups.

The modularity network indicates dense connections between the country's community and spacious connections between countries in other communities.

There are some obvious communities in figure 1, like the countries with orange, green, blue, and purple nodes. However, the number of expressive countries makes identifying some standards for a good analysis difficult. They are using the degree attribute expressed by the size of the nodes to execute one more filter. They were maintained in countries with degrees greater than or equal to five (figure 2).

Figure 2 – *Network with countries with degrees greater than five, 2010*



After this second filter, the South American countries (with green labels) are more visible. It is possible to see in figure 2 that the South American countries are divided into two communities; in both communities, orange and blue, there are interactions between countries from almost all continents except Oceania. The Oceanic countries are present just in the purple community. The bigger difference between the orange and blue communities is the composition of each continent. Asian countries are prominently represented in the blue community, while there are no protagonists in orange. In the orange community, the participation of Asian countries is as good as that of European countries. The last community shown in figure 2 is the dark green community, composed of European, Asian, and African countries. The African countries there have a minimal participation, with just one country: Niger.

One other graph feature in figure 1 and figure 2 is related to edge thickness and disposal of the nodes. The more centrally located a node or country, the more influential the it is, and the more visible the edge, the more money is sent in this interaction. Figure 2 shows the influence of countries like Japan, Germany, and the USA and the expressive green investment sent to India, Kenya, and China.

The composition of the communities is expected to increase the influence of Asian and European countries on South American countries. This makes it possible to highlight Japan, Germany, Spain, and Switzerland as the continent's most influential countries inside these South American communities in 2010.

Figure 3 – *Directed finance flow network, 2015*

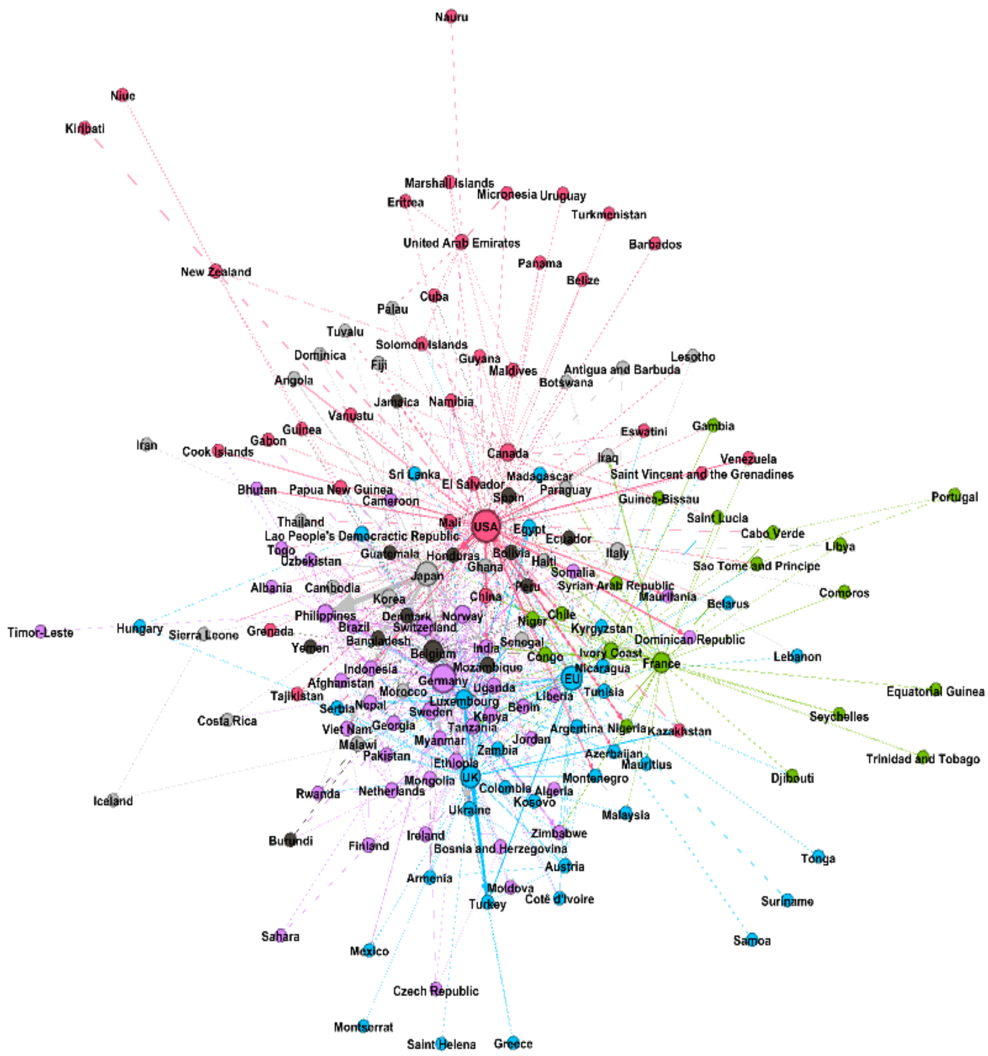
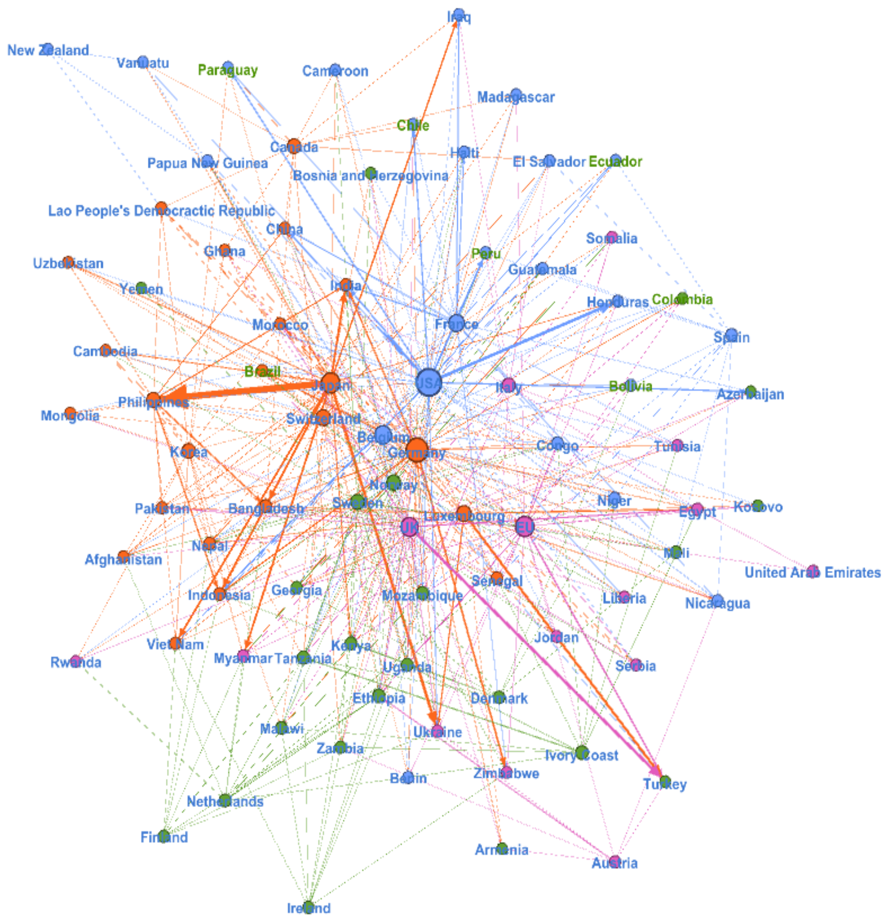


Figure 3 presents the complete green investment flow network for 2015. A first comparison between this and figure 1 shows that, in 2015, the countries had the most green investment interactions. Also, there are more detectable countries with more influence or bigger degrees in this network, but, as with figure 1, one more filter is necessary.

Applying the filter for degree, the countries with a minimum of five degrees were selected. In figure 4, this new network resulted in a three-dimensional appearance, where the South American countries are still divided into three communities. Brazil is now alone in the predominantly Asian community (orange). The other South American countries, Bolivia, Chile, Ecuador, Peru, and Paraguay, share the divided community by, in most parts, African, Oceanic, and North American countries, the violet community. The dark green community is mainly European, with heavy participation by African and European countries. Besides that, there is also an isolated South American country, Colombia, in the dark green community. No South American countries are in the purple community, which is almost equally divided between African and European countries.

Figure 4 – *Network with countries with degrees greater than five, 2015*



In five years, Brazil seems to have become closer to Asian than to European countries, while Bolivia, Chile, Ecuador, and Peru have become closer to North America and Oceania and farther away from Asian countries. This change can indicate a higher chance of Brazil receiving green investments from Asian countries than the others. The presence of new nodes, Paraguay and Colombia, means more representative earnings for them and the South American continent after five years. Paraguay is in the same community as Bolivia, Chile, Ecuador, and Peru, but the chances are the same with North American and Oceanic countries. Colombia, on the other hand, has a good chance of receiving green investment from European countries.

From the edges of figure 4, we can see that the green investment sent by the Asians to Ukraine, India, and, in particular, the Philippines was substantial. The Philippines, however, shares part of these investments from other Asian countries, all of them geographically located in areas that were part of the millenaries silk roads (an important trade route between the 2nd century BC and the 15th century AD – *Britannica*, 2024). It is important to highlight that, in 2010 (figure 2), Japan had a more intense relationship with India, losing its force compared to the new relationship with the Philippines.

The violet community has a strong edge connecting the USA to Honduras; this can be explained by the historical relation between the two countries, which has political and economic features (see Euraque, 1996; Wright, 1960). Most important in this analysis is a strong edge from the USA and a direct link to Peru. The relationship between both countries has a long, controversial history, which highlights the coca and cocaine investment by the USA in Peru, the intervention in family planning by the USA there, the bilateral agenda related to national security, free-market reform, narcotics control, and, more recently, the fight against transnational crime (see Borges and Venero Ferro, 2017; Euraque, 1996; Gootenberg, 2003; López, 2014; McClintock and Valias, 2018). Furthermore, there are other good interactions regarding the level of green investment sent to Chile and Paraguay from the USA, but nothing so expressive as the connections mentioned before. In 2010, the most expressive connection seen from the USA was with Brazil. The relation still exists but, five years later, much less expressively.

European' countries, even though in different communities, represent, in 2015, the continent with more expressive connections. Mostly, they are not as strong as the connections established by Japan or the USA with some countries, but they are similarly relevant. Regarding South America, only Brazil has a notable link with Germany, on the European continent. This link in 2010 appears more intense in 2015 and can reflect different topics like the colony's presence in the south Brazilian country or the nuclear agreement and relevance for both countries. However, the notable strong increase in this relation regarding green investment is linked with an agreement about climate change (see Gov, 2015; Patti, 2010; Rinke, 2014).

With more new connections, the green investment flow network in 2020 presented in figure 5 gives us a good idea of this relationship's general and most actual scenario. Comparing figure 1, figure 3, and now figure 5, it is possible to note that some countries kept their influence (in connection terms) while others did not. A résumé of the change of degree centrality in time can be seen in table 1, which shows how many connections each country is responsible for in the complete network. In recent years, the EU, Germany, the UK, and the USA lost some influence and power in the network, giving more space to Asian countries like Japan and Korea. The increase in the influence of the Ivory Coast can be explained by its hosting of the African Development Bank Group (AFDB).

Figure 5 – *Directed finance flow network, 2020*

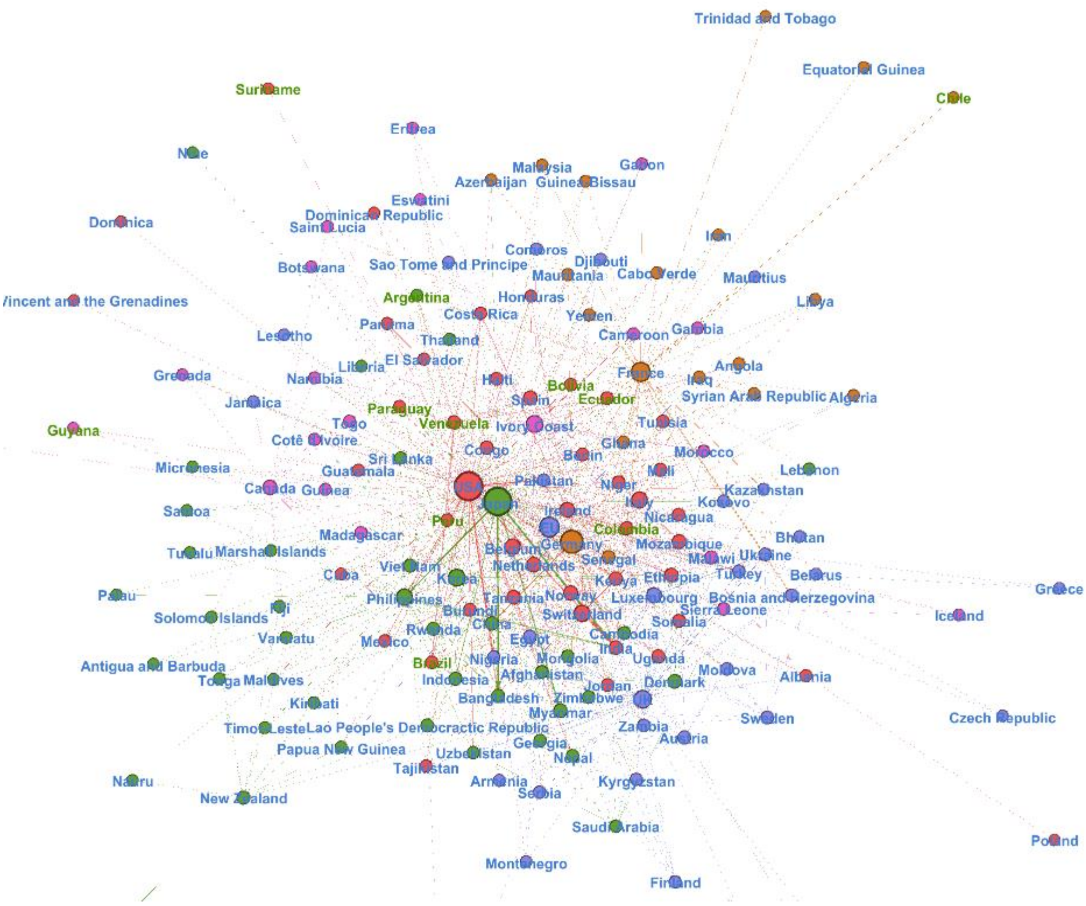


Table 1 – *Degree centrality of countries on complete networks (%)*

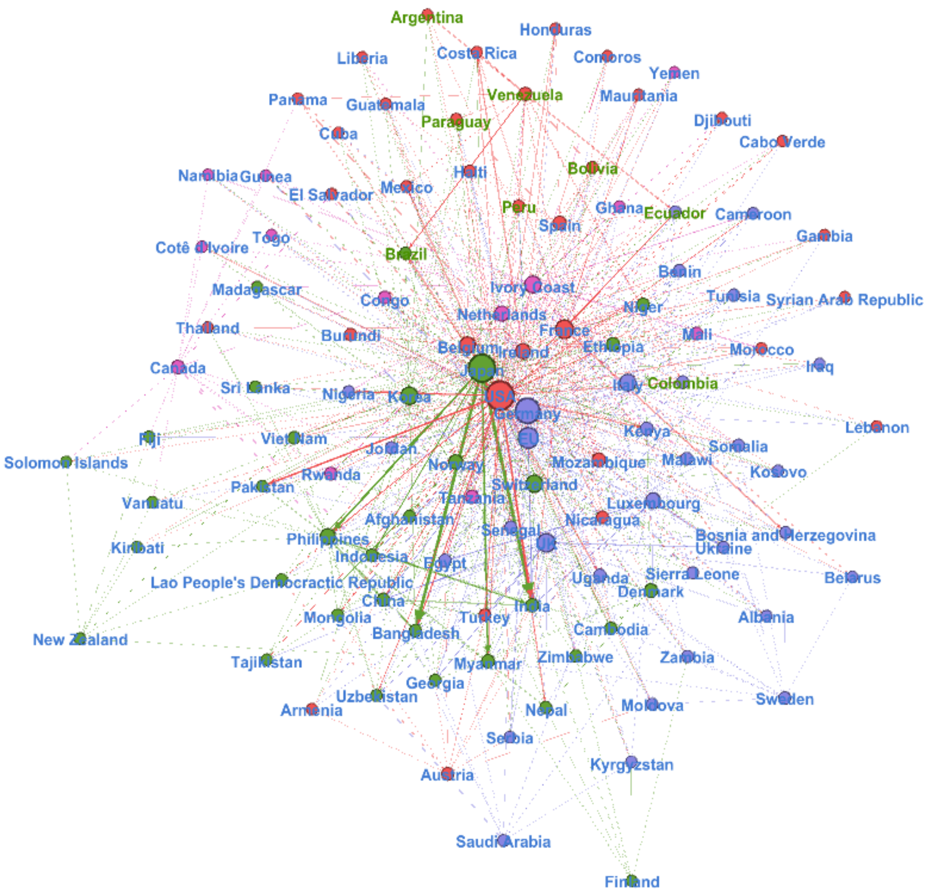
Country	Degree centrality			Final observed behavior
	2010	2015	2020	
EU	4.6	7.7	6.5	Down
France	1.3	5.2	5.9	Up
Germany	7.2	10.8	8.8	Down
Ivory Coast	0	2.3	4.3	Up
Italy	0.1	2.8	3.6	Up
Japan	7.3	7.8	12.7	Up
Philippines	3.3	3.4	3.9	Up
Korea	2.5	3.27	4.2	Up
Switzerland	2.9	4.3	3.7	Down
UK	3.1	6.6	4.9	Down
USA	7	13.6	13.2	Down

Note: "Up" expresses influence gain and "Down" expresses loss.

From table 1, and according to the previously presented section about the inverse relation between the centrality and closeness degree, we can identify an important feature of Japan and the USA in this network. From this perspective, besides these factors being more influential in 2020, they share less closeness with other countries of network and have more difficulty reaching everyone quickly.

The same filter step was done in this last network. Figure 6 presents the actual green investment network with nodes with a minimum of five degrees. Colombia is still part of a community where European countries have more influence, and Ecuador has been closer to North American countries (violet community). Brazil is still isolated from the other South American countries in this flow in terms of communities. The Brazil position does not change, remaining in Asian influences (dark green community). The purple community is almost entirely composed of African countries, not South American ones. Argentina, Paraguay, Bolivia, Peru, and Venezuela are in the orange community, constituting South American participation.

Figure 6 – *Network with countries with degrees greater than five, 2020*



The absence of Chile in the network indicates a loss of green investment connections destined for it and for other South American countries. More specifically, if compared to figure 5 and figure 4, Chile was part of the North America connections in 2015 but is no more. There is another interesting new feature about South American countries: Unlike before, there are now connections between some countries in South America. All these connections start from Venezuela, a new South American country participant. Venezuela does not receive substantial green investment from any other country but it helps all other countries on the same continent; among them is its connection with Brazil and Argentina.

There are notable changes in other communities, such as the less strong connection between Japan and the Philippines, the USA and Paraguay, and the USA and Chile, and, lastly, the connection between Germany and any other country. Even though it seems like bad news for some countries, increasing the number of new connections can indicate a more democratic green investment.

4. Discussion of the results

The efforts to raise awareness of climate change in countries worldwide work. The biggest number of countries in the finance flows destined for climate change mitigation and adaptation is good evidence of this. Also, the frequency and intensity of climatic events and their proven association with climate change, according to Luber and McGeehin (2008), may have forced more attention.

The complete networks (2010, 2015, and 2020) did not include all possible connections between countries. However, it was observed that the network in 2015 had more connections than in 2010, and by 2020, even more connections had been established.. When we limited the degree to more than five, we obtained results that converged with those obtained by Schiavo et al. (2010). Developed countries are better connected and form communities with stronger links.

When analyzing and focusing on South America, we can see some losses. The absence of Chile in the network in 2020 was investigated regarding economic growth (GDP) increasing, energetic autonomy, mean temperature variation, internal regulation instruments, and external financial dependence according to CEPAL (2023) data. Based on CEPAL data, there was an improvement in economic growth, green energy autonomy, and instruments of environmental regulation in Chile, but the conditions related to mean temperature variation and external financial dependence have remained the same. On the other hand, Venezuela presents a reduction in the application of its environmental regulation instruments, and, compared to other countries, it is a country with more external dependence. In terms of GDP from 2014 until 2017 (the most recent data), Venezuela's GDP decreased systematically, with a small recuperation in 2016 before decreasing further. In any case, the difficulty of obtaining current information on Venezuela makes it difficult to detect the reasons for the change in the network structure. However, the country's participation proved relevant in bringing South American countries together.

The bipartite structure observed by separating countries into South American countries and the rest of the world in 2010 and 2015 highlights that developing countries face significant challenges in finding effective solutions to the impacts of climate change and that developed countries can play a crucial role in strengthening the capacities of recipient countries to address these challenges. In this sense, understanding what motivated the observed change in Venezuela's participation in the 2020 network can be important in establishing links between developing countries.

5. Conclusions

This research proposes to compare green investment flows between countries in 2010, 2015, and 2020, using the theory of economic social networks to explore the financial relationships between South American countries. The results indicate interesting changes in the directed external investment flow destined for climate change mitigation, mainly in South American countries.

In addition to the clear perception of network expansion from one decade to the next, China's influence suggests other possible analyses from this work. In South America, the need for more recent data on Venezuela makes it difficult to accurately compare the economic and political conditions between the countries that made the changes in the network noticeable.

The network composition, the bipartite structure observed by separating countries into South American countries and the rest of the world in 2010 and 2015, shows the importance of investment from developed economies in tackling climate change, as pointed out in the last COP27. However, understanding what motivated the observed change in Venezuela's participation may be the key to changing this scenario.

As in any scientific study, it is important to highlight the limitations of the technique used. Firstly, access to accurate and up-to-date data on financial flows between countries can be challenging, especially regarding confidential information from financial and government institutions. The lack of transparency or availability of complete data can make it difficult to build a comprehensive and accurate socio-economic network. Moreover, by focusing only on direct financial flows, one may lose sight of other forms of economic interaction between countries, such as trade agreements and investments in foreign companies. This can lead to an incomplete view of global economic dynamics. The analysis of direct financial flows may only partially capture these transactions' indirect or secondary effects, which can play an important role in international economic relations. Therefore, it is important to complement this approach with other methodologies and data sources, to obtain a more comprehensive and holistic view of financial interconnectedness between countries.

This work can be extended to explore the motivation for green investment and to understand the communities formed by directing investments to climate change mitigation and adaptation sub-areas. This can be an important step for better understanding the effectiveness of their implementation.

Future research could explore alternative approaches, such as incorporating trade agreements and indirect investments, to provide a more comprehensive picture of economic interactions and their impact on climate change mitigation. Furthermore, a deeper investigation into the factors influencing Venezuela's participation in the green investment network could shed light on potential strategies for enhancing regional collaboration and promoting sustainable development. Additionally, aggregating the network analysis and indicators by regions could reveal distinct patterns and trends in green investment flows, offering valuable insights into the diverse economic and political contexts across different regions.

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