Global Environmental Change 74 (2022) 102518

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Finding the right partners? Examining inequalities in the global investment landscape of hydropower

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ABSTRACT

Clean and affordable energy is crucial to achieve a sustainable future. Despite being controversial, hydropower remains the predominant low-cost and reliable source of energy at global level, as it stabilizes the provision of electricity and it bears the power peaks without losing efficiency. However, hydropower requires huge upfront investments and patient functional capital. Under the Paris Agreement, countries committed to direct financial capital flows towards a low-emission pathway in order to enable the transition. Furthermore, private capital strongly engaged with a transition towards a climate-smart economy. The aim of this work is to study the investment system behind hydropower, investors' behaviour and the optimal allocation of finance to favour the deployment of capital flows. We use Bloomberg Energy Finance database to track public–private investments over the past century (1903–2020). We use network models to represent the hydropower project financing landscape as a network of co-investments. We find that investors are highly localized, with continental players mostly interacting with counterparts in the same area of the world. Powerful exceptions are international organisations and multilateral banks which coinvest across the globe. They also tend to support low-income and fragile countries, meeting their mandate of sustainable development champions. Multilateral banks and international organisations are the most critical actors in enabling public–private co-investments; they activate partnerships with a wider diversity of investors within the network creating more opportunities for blended finance tools. Our results offer a novel perspective on finance for the energy transition: it challenges the idea that more capital invested is better and calls for a more efficient allocation of the available resources.

1. Introduction

Supporting the transition towards a carbon neutral global economy requires the conversion of our energy systems to fully renewable sources (Bogdanov et al., 2019; McCollum et al., 2018). To work, this transformation calls for the mobilization of required financial capital, beside technological and knowledge transfers (IRENA, 2019; Van de Putte et al., 2020). Over the past decades, solar and wind technologies have witnessed growth in investment and capacity (IEA, 2020) and their role is expected to increase in the future (McCollum et al., 2018). However, hydropower remains the primary renewable energy technology by capacity and generation (IEA, 2020) accounting for approximately 60% of international investment flows in renewable energy (Renewable Energy Agency, 2020). In particular, hydropower is at the core of several developing countries' energy systems (IEA, 2020), where it provides the base for energy security and makes progress towards the UN Sustainable Development Goals. As such, hydropower helps to fill the "transition gap": it supplies low-cost clean electricity and continuous power with existing infrastructure while countries integrate other emerging and clean technologies into their energy systems.

Despite its importance in the overall energy mix, capacity additions and investments in hydropower have been showing a decreasing trend for the last five consecutive years (2019 global net additions declined 45% with respect to 2018 (IEA, 2020). The need for significant capital investment, along with the controversial socio-economic and environmental impacts of hydropower facilities, constrain project development (Ansar et al., 2014). Indeed, financing hydropower projects requires investors to pay large upfront capital and lock-in their capital for decades (hydro projects can last for 100 years), while also bearing high investment risks (Markkanen et al., 2020). A large hydropower dam on average costs more than a billion dollars (Ansar et al., 2014), carries relevant construction/development risks, domestic risks associated with emerging economies (macroeconomic conditions, business confidence, policy uncertainties and regulatory frameworks), and has a long-term repayment period (Markkanen et al., 2020). These factors imply that financial actors must be assembled to ensure access to finance for hydro projects and have patient capital to stay through the natural cycle of the investment. As a result, a complex architecture of investors, project

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https://doi.org/10.1016/j.gloenvcha.2022.102518
Received 25 May 2021; Received in revised form 21 March 2022; Accepted 4 April 2022
Available online 18 April 2022

financing structures and efficient capital allocation are vital to enhance future hydropower development.

Currently we have limited understanding of these aspects, as the focus on increasing the financial flows for the transition has diverted attention away from who is operating in this space and how (Mazzucato & Semieniuk, 2018; Polzin et al., 2019). Few researchers have investigated the complex landscape of finance for low-carbon technologies (Buchner et al., 2019; Hong et al., 2020; Mazzucato & Semieniuk, 2018; Naran et al., 2020; Nelson & Pierpont, 2013; Zhang, 2020), and there is scarce evidence on which financial actors and investment models (e.g. public and private partnerships, blended finance (UNEP, 2016), private or public sector leadership (Geddes et al., 2018; Kumar, 2015)) are more relevant to enhance equitable financial access and energy security around the globe. For instance, North and Sub-Saharan Africa, together with South Asia collectively received only 15% of global climate financing flows between 2013 and 2018 (Naran et al., 2020). Current literature also lacks a technology-specific financial outlook (Mazzucato & Semieniuk, 2018) and tends to assess the importance of different actors by using aggregated international financial flows as a key metric (Naran et al., 2020).

Our study responds to these crucial policy questions by showing how a just transition can be accelerated around the world through improving access to finance for hydropower. We explore which investment models and co-investment patterns have driven hydropower deployment over the past century (1903–2020) and what are the implications for its future financing. First, we detect how different actors co-mobilised the capital needed for hydropower projects at global level. Second, we zoom into the most critical investors who hold the project finance landscape together, allowing capital to flow from developed to developing nations. Finally, we investigate investors' facilitator role in the investment chain and assess their ability to activate public–private partnerships (PPPs) over time.

Our results show that public and international institutions are the critical actors driving hydro finance through multilateral and bilateral financing mechanisms and global PPPs. These investors interact both within and across distant communities (meant as clusters of highly connected investors) acting as connectors and allowing finance to reach the most vulnerable areas. They integrate climate objectives into their development goals by mandate, enhancing economic prosperity and sustainable growth, while also boosting clean and affordable energy sources. This virtuous investment cycle is enabled by the diversity of partnerships activated by international institutions, who pave the road for banks and private actors across multiple countries.

As one of the biggest challenges in sustainable energy transitions is likely to be in developing countries, our effort serves as a policy base to ensure equitable access and effective capital allocation for hydropower, the principal energy source in these regions. A strong investment architecture and effective investment channels will accelerate sustainable power deployment while leaving room for new technologies in the energy transition.

2. Data and methods

Our analysis is based on small and large hydro investments over the past century (1903–2020) (Bloomberg New Energy Finance dataset), which combines information about project finance, the economic actors involved and the related transactions. In particular, key project information includes its value, capacity, and location, financing structure used, and actors involved (e.g. current owner, project developer). In addition, details of companies and organisations involved in developing and financing hydropower projects, such as their country and business description, as well as transaction-specific data, such as the type of finance: debt and equity.

We focus the analysis on completed small and large hydropower projects. We merge the project, transactions, and organisations database to obtain a complete overview of hydropower project financing at global level. After merging and cleaning, we obtain a dataset of 3610 observations, where each record represents a financial transaction referring to a specific project as described by a unique ID. We assign categories (Table 1) to each investor to reflect their nature and business, through a combination of automated and manual routines based on Bloomberg's categorization data (e.g. "Public" and "Private"). We filled the missing company-reported information by analysing the companies' abstract reported in the Bloomberg database and through a manual search.

We represent the hydropower project financing landscape as a set of interactions (links) between investors (nodes) (Fig. 1). At the micro level, investors raise (equity) and borrow (debt) capital to finance projects (Head, 2006) depending on their heterogeneous preferences, market expectations and risk appetite (Barazza & Strachan, 2020; Bergek et al., 2013; Kaminker et al., 2015; Mazzucato & Semieniuk, 2018). Nodes belong to two disjoint and independent sets and they are linked through a direct connection from equity (Q) to debt (B). Hence, links between nodes materialise in the presence of at least one loan or bond between an equity and debt investor. Links are all equal (i.e. the network is unweighted) and they form a complex network of interactions,

Table 1
Investor categories.

Type	Ownership	Sub-activity	Description
Non-financial types	**Private**	*Renewable Energy Company*	Core focus on renewables. Typically, component manufacturers, project developers, O&M services in RE
		Energy Company	Core focus on traditional energy sources. Can have renewables in portfolio, but they are highly involved in conventional energy. Typically, component manufacturers, project developers, O&M services in conventional energy
		Private Utility	Main business is the generation and distribution of energy. They are not state-owned, nor public. Generation and distribution are two necessary conditions
		Diversified	All remaining private non-financial companies, including engineering and construction companies whose main business is not in the energy sector
	Public	Public Utility	Main business is the generation and distribution of energy. Owned by largest share by public actors
		Government Agency	Government ministries, authorities, municipalities, councils, research institutions, universities
		State-owned Institution	All remaining state-owned non-financial companies e.g. oil and gas exploration companies. These institutions are both private and public
Financial types	**Private**	*Commercial Bank*	Main business is commercial banking
		Institutional Investor	Non-bank financial companies e.g. private equity firms, pension funds, investment funds, insurance companies
		Non-profit investor	Foundations, co-operatives, community organisations
	Public	*Public Bank*	State-owned commercial banks, national development banks, export credit agencies
		International and multilateral actors	Multilateral development banks and funds, organisations and institutions

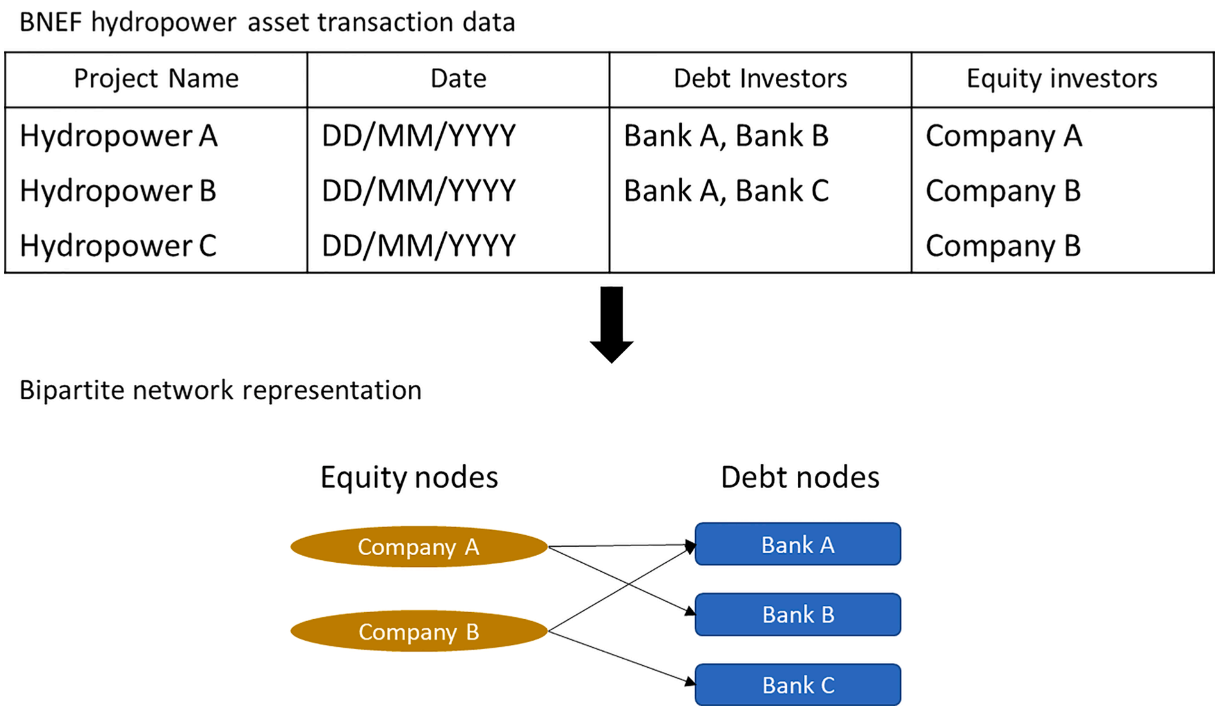

Fig. 1. Representation of bipartite network structure derived from BNEF asset transaction data.

organized in structures, namely communities. Communities are groups of investors more densely connected than the rest of the system (Newman, 2006). Communities also simplify the study of the system by acting as meta-levels and highlighting properties that would otherwise have been neglected (Newman, 2006).

We identify communities by clustering links between nodes to assess whether investors belong to overlapping communities, a commonly observed feature in real world networks (Palla et al., 2005, Palla et al., 2007). We extract link communities from the empirical network by mirroring existing literature (Ahn et al., 2010; Kalinka & Tomancak, 2011). We measure the similarity between pairs of links e_{ik} *and* e_{jk} sharing at least a node k. Similarity is obtained from the Jaccard coefficient, which measures the asymmetries between two variables (see Supplementary material for details). Pairwise similarities are the seeds of a hierarchical dendrogram where branches describe communities. Communities are formed by links occupying a unique position and nodes assigned to multiple clusters. This setup responds to an economic intuition: investors may potentially belong to multiple groups (regions, countries, legal status, mandate). On the contrary, links between them exist for a particular purpose (de-risking investments, forming a new partnership). Hence, connections are unique, while investors populate different clusters.

To further understand the financing structure behind hydropower investments, we compute a community-based centrality score (CC). The CC is strongly anchored to the link community structure. In fact, well-connected investors are not just the ones with many active co-investments, but rather those who operate in communities with high connecting power. Investors with high CC score will belong to communities capable of reaching distant groups of actors, hence spreading the available financial resources to different players. We express CC (equation a) as the weighted sum of communities a node belongs to over the X communities weighted by the average similarity between pairs of communities:

where the communities X to which node i belongs to are summed together; $S(j,k)$ is the similarity between community $jandk$ defined as the Jaccard coefficient for the shared nodes between each pair of communities. The summation is averaged over m communities paired with community j where node i also belongs.

Finally, we measure the ability of each investor to form public–private partnerships (PPPs). Public-private partnerships (PPPs) are becoming an increasingly popular investment model to bridge different expertise and knowledge gaps (Head, 2006; Reagans & McEvily, 2003). Investors act as brokers of information: the more diverse their network, the lower their risk on investing in low-return projects (Reagans & McEvily, 2003). PPPs also support coordinated objectives by crowding in private finance to maximize the provision of capital. In the climate finance domain, being connected to diverse stakeholders helps de-risk projects, ensures the sustainability of long-term commitments (Bayliss et al., 2020; UNDP, 2020) and triggers virtuous learning mechanisms via co-investments (Geddes & Schmidt, 2020).

We introduce a novel metric, the Partnership Index (PI), to assess the strength of each investor in forming connections with diverse stakeholders (equation b). The PI acknowledges the role of network structure in influencing the resource transfer process (see details in Supplementary material). The metric builds upon the intuition described by Burt (1983) in social networks and applied by Reagans & McEvily (2003), where investors connected to multiple groups access a wider pool of information and do not process redundant knowledge. The PI is an investor-specific measure of diversity: the wider the set of connections with different actors, the higher the index. Given the capital and time-intensive nature of hydropower projects, diverse co-investments allow each player to solve multiple challenges.

We compute the PI (equation b) for the whole time series and across different time splits. Hence, we checked whether investors opened market opportunities to incumbents overtime, leading to a crowding-in effect and pooling together private and public finance.

This metric is the ratio of two sums. The numerator counts investor i's connections with N_k distinct categories of investor, where $z_{ij} = 1$ if the connection to category j exists and 0 otherwise. The denominator counts the N connections of node i with all other investors q. The ratio describes the extent to which the connections of node i are spread between different categories of investor.

3. Results

3.1. How investors group together and why it matters

Our dataset well represents the distribution of hydropower facilities at global levels. Our dataset is widely dominated by smaller projects (in value) especially prior to 2000s (Fig. 2). Small hydropower projects range between 0.070 and 674 MW and include Run of River, Existing Dam and New Dam projects. We observe a substantial interest in East Asia and the Pacific and a growing wide investment trends in Latina America and the Caribbean (with Brazil as a hydropower champion).

We find that renewable energy firms are the dominant players of the equity market (Fig. 2a, Supplementary material), followed by private utilities. This is striking in the top three countries (per transaction value): Brazil, China and United States. The market structure differs in Japan, where private utilities take the largest share. Public banks and commercial banks shape the debt market (Fig. 2b, Supplementary material). Different countries have distinct market structures: while some are oriented towards a more publicly-owned form of debt (Brazil and Costa Rica), others are stimulated by loans and bonds provided by commercial banks (i.e. Turkey and Spain).

We move to the study of the characteristics of the network of hydropower finance investments to detect possible regularities and important features of the global landscape. We find a strong presence of hubs in the debt network. Hubs are nodes with a number of links that greatly exceeds the average. The topological analysis reveals the existence of a community structure. Hubs act as connectors of often distant groups of investors. We find 95 overlapping communities (groups of related investors (Girvan & Newman, 2002)), where different players connect for a common goal (e.g. forming a new partnership) rather than reflecting their specific characteristics (business nature or mandate).

The investor community analysis reveals geographical investment patterns. In far-east Asian countries (Korea and Vietnam) the interactions between domestic investors (i.e. community density) are more frequent compared to the rest of the world. In India, the financial landscape is dominated by domestic state-owned banks, while Japan has a strong presence over the continent through the investment made by its second biggest bank, namely Sumitomo Mitsui Banking Corporation and a private utility (Kansai Electric Power Co Inc.). Brazil has a similar investment architecture, where investors act through the BNES, which facilitates transactions in both large and small hydropower projects. Investors mainly cluster together at national and regional level confirming the existence of a “home bias” in investments (Lindblom et al., 2018).

Multilateral, bilateral and blended finance agreements constitute a powerful exception to home-bias (Fig. 3) and they reveal important insights about different contract structures in the hydropower financing. Multilateral development banks provide mainly multilateral finance to host countries directly. While bilateral finance includes primarily loans and debt reliefs to finance large hydropower projects in low-income African (Angola, Cameroon, Uganda and Zambia) and Asian middle-income countries (Indonesia and Thailand) by far-East actors (China, Korea and Japan), as well as in selected East European countries (Armenia and Georgia). Finally, blended finance agreements include bilateral finance institutions, governmental budget and private companies. These contracts are usually complex in their nature as they often rely on a set of mixed actors and subsidiaries of the national governments. They increase beneficiaries’ public debt and they have a strong uptake in the African continent (Mali, Burundi, Senegal and Uganda) and in low-income Asian countries (i.e. Pakistan). We observe a strong presence of foreign investors in lower-income countries. These players are not limited to the pool of international institutions and organisations, but they also include private utilities, commercial banks and renewable energy firms.

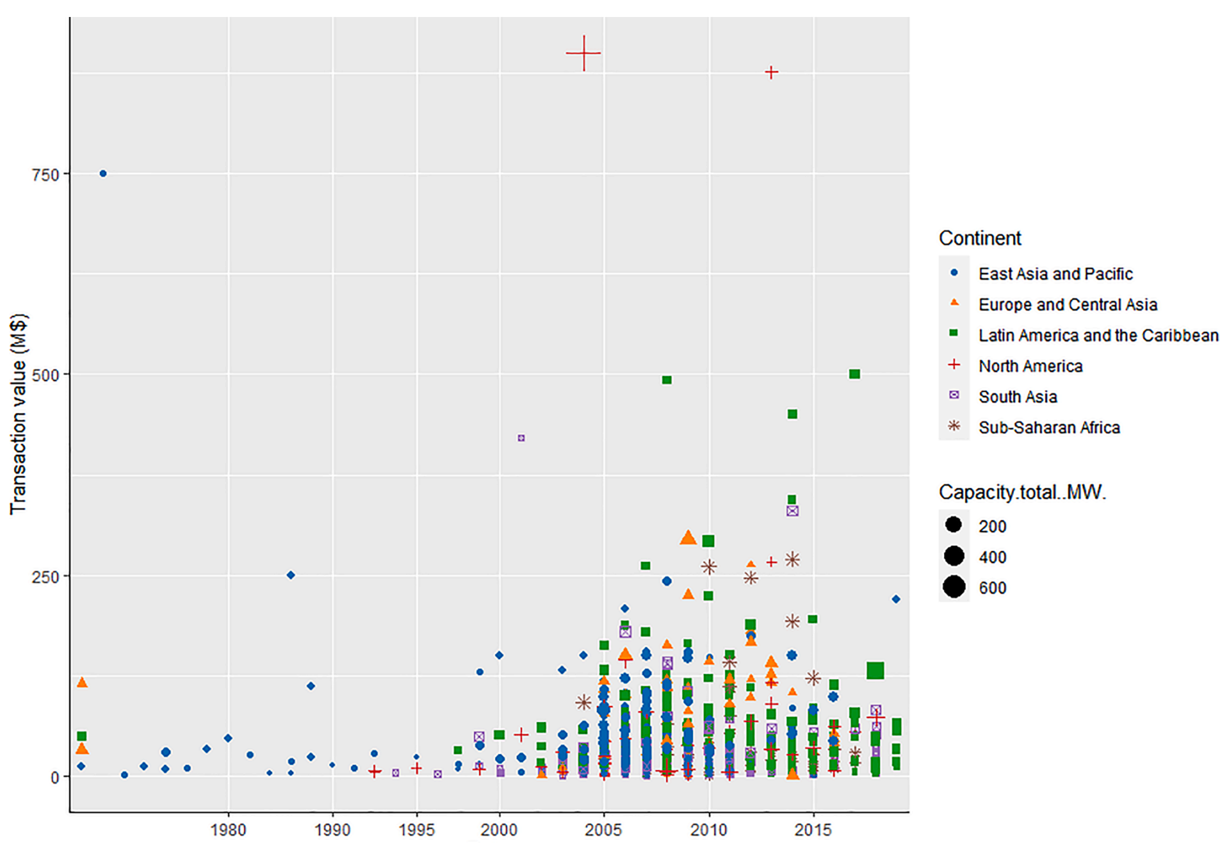

Fig. 2. Distribution of hydropower facilities per continent, capacity and transaction value.

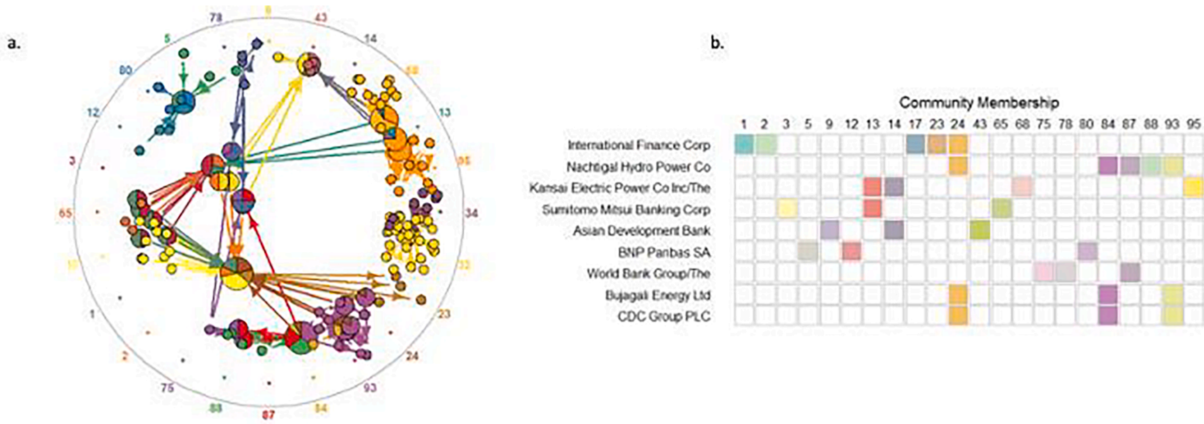

Fig. 3. a. The most connected communities in the hydropower investment landscape. Community density signals the presence of a strong geographical home bias, with few actors (here with pie charts) connecting distant communities: b. the most central actors as key links across geographies. They predominately link investors operating in Africa, far-east and south-east Asia.

Multilateral and bilateral institutions are also highly ranked by CC values: 40% of the highest 20 ranked investors by centrality score are international actors and multilateral organisations. We find that by connecting investors in distant geographies, they boost hydropower deployment globally and embody the globalized nature of the financial system. Moreover, highly central actors are involved in at least one large (>50 MW) hydropower project, where the highest capital disbursement is concentrated.

The International Finance Corporation (IFC) ranks first in terms of CC and connects several overlapping communities (including South America and Africa). It enables co-investments between governmental agencies (e.g. Uganda Development Corporation), renewable energy firms (e.g. Nachtigal Hydro Power Co), international development agencies (e.g. Aga Khan Fund for Economic Development) and institutional investors (e.g. CDCD Group). Highly ranked investors also affect other investors' centrality, revealing a strong network effect. For instance, the second ranked investor is Nachtigal Hydro Power Company (NHPC), a private company jointly owned by Electricité de France (EDF, 40%), International Finance Corporation (IFC, 30%) and the Republic of Cameroon (30%). NHPC shares with the IFC the interests in the African continent and operates with other international organisations (i.e. European Bank for Reconstruction and Development, African Development Bank, OPEC Fund for International Development) in other continents.

Our community findings highlight the challenge of mobilizing funds for developing countries. Since most finance is sourced domestically and mature capital markets are mainly in developed countries, the most central group of investors (e.g. multilateral and bilateral institutions) play a key role in redirecting financial flows across borders. The mismatch between geographical location of investment needs and available capital, also implies the need to find novel mechanisms to attract and crowd-in private finance especially in developing countries, underlining the complexity behind project finance for the energy transition.

3.2. Partnerships as crucial leverage to ensure access to finance globally

We observe that many of the most central investors facilitate connections between financial actors operating under a diverse governance (national, regional and international) and legal (public and private) structure. These relationships help to raise public and private funds for strategic objectives (e.g. climate and development), while attracting new stakeholders in the form of partnerships.

Multilateral and bilateral institutions, alongside commercial banks are the top investors per PI (Table 2). Multilateral and bilateral institutions, as well as development agencies, typically form consortia to

Table 2
The top ten investors by partnership index across the whole timeframe.

Investor	Centrality	Partnership Index	Category
African Development Bank	1	0.875	International and multilateral actors
European Investment Bank	2.9	0.852	International and multilateral actors
Nederlandse Financierings-Maatschappij voor Ontwikkelingslanden NV	2.8947	0.837	Public Bank
International Finance Corporation	5.5651	0.835	International and multilateral actors
BNP Paribas SA	3.5714	0.833	Commercial Bank
Sumitomo Mitsui Banking Corp	3.6349	0.83	Commercial Bank
Inter-American Development Bank	1	0.82	International and multilateral actors
Asia Development Bank	3.6071	0.817	International and multilateral actors
Societe de Promotion et de Participation pour la Cooperation Economique SA	1	0.815	Public Bank
Export Import Bank of Thailand	2.8889	0.815	Public Bank

provide debt financing to renewable energy companies or governmental agencies of the host country. Commercial banks interact with other banking entities and form partnerships with multilateral institutions. Commercial banks trigger a project financing structure that enables large hydropower projects across the world. The top ten investors by PI promoted projects located mainly in developing and emerging countries (e.g Uganda, Peru, China, India and Vietnam) (Fig. 4). This signals their role in enabling capital to flow: by reaching the most vulnerable and triggering investments where financial infrastructures are more fragile. Fig. 5..

The role of actors in activating partnerships has evolved overtime. Prior to the 1970s and up to the 1980s, multilateral banks (e.g. The Asian Development Bank, the IFC, the World Bank Group) have played a central role in enabling partnerships across the world. The hydropower project financing infrastructure changed over the 1990s especially in developing countries, with the entrance of private utilities, renewable energy firms and commercial banks as key facilitators of PPPs in Africa and far-east Asia. In the first decade of the new century, we observe a renewed interest of multilateral and bilateral institutions, including

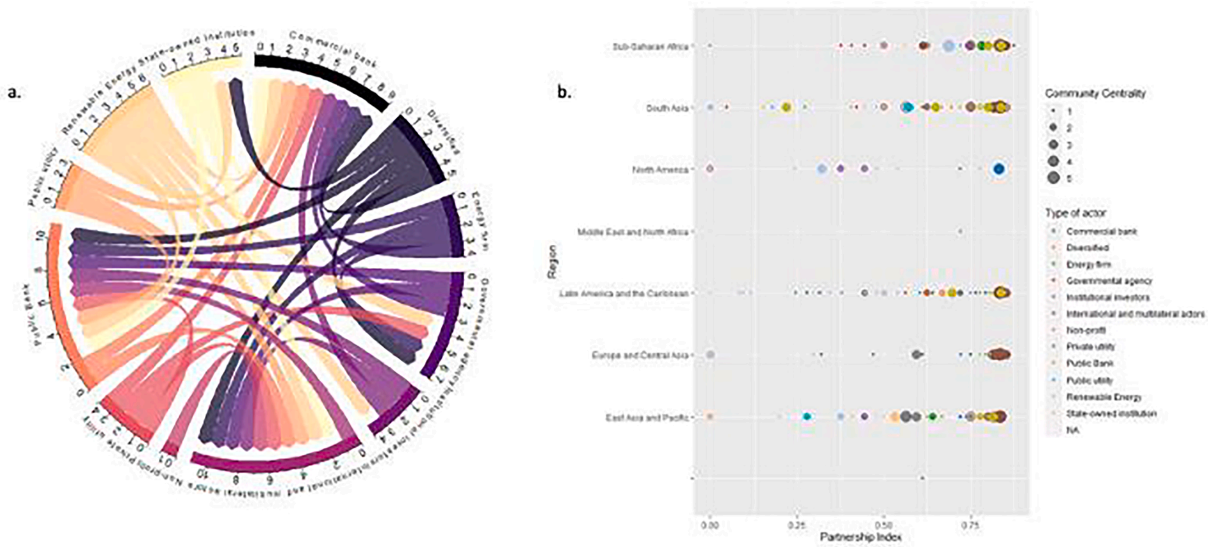

Fig. 4. a. International and multilateral investors are the top connected among other categories and help linking private and public actors across geographies. b. The top central investors are mostly public organisations, with multilateral donors and bilateral institutions driving the development of hydropower facilities in emerging economies.

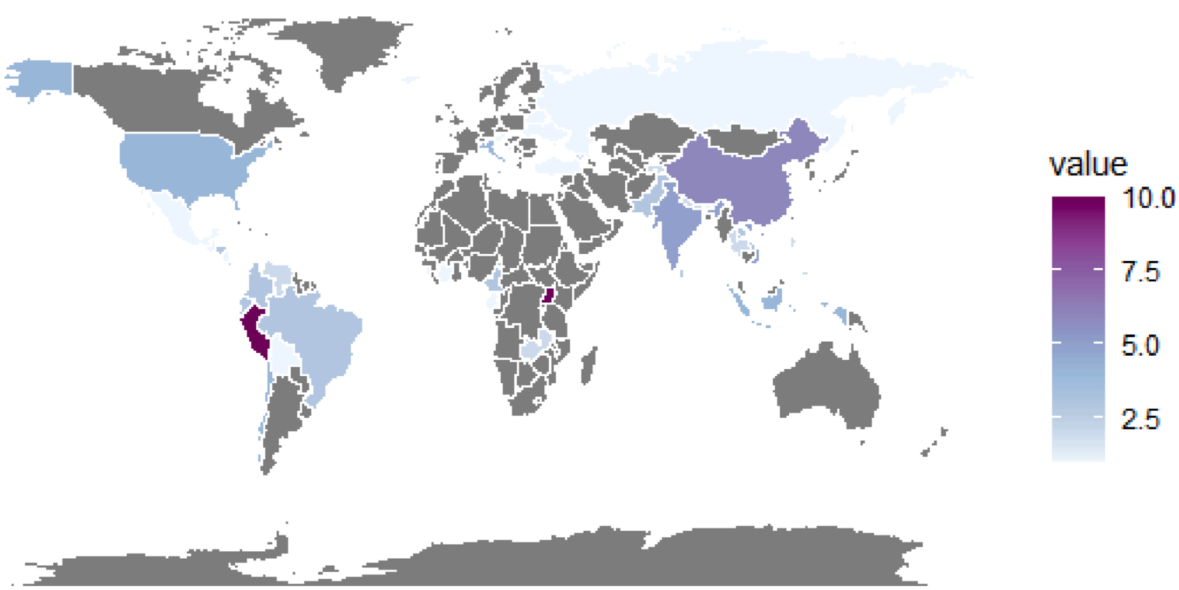

Fig. 5. The location of investments: colors indicate the frequency of partnerships in a given country as activated by the top ten actors.

European players (e.g. European Bank for Reconstruction and Development, European Investment Bank), which is consistent with the need to support developing countries in both "management and development" (The World Bank, 2003) of their resources. The 2010s presents a mixed public–private project financing infrastructure. Largely, multilateral and bilateral institutions enabled business opportunities for incumbent and smaller players, widening the diversity of active investors in hydropower project financing.

Our analysis shows the relevance of different investors in activating and promoting PPPs for hydropower projects as important mechanisms to access finance globally – they indeed leveraged private capital, especially in the areas with most need. The effectiveness of PPPs is strictly linked to the underlying project financing structures and seems essential to ensure a just transition where climate objectives go together with other SDGs.

4. Discussion and conclusions

The Paris Agreement recognises the need to align finance consistently with "climate-resilient development" (UNFCCC, 2015). The wake-up call is coherent with other existing frameworks (e.g. the Addis Ababa Action Agenda (United Nations, 2015a) and the 2030 Agenda for Sustainable Development (United Nations, 2015b)), but it is still far from being sufficient. Maximising the uptake, spread and efficiency of renewable technologies is a key challenge, especially in the most vulnerable areas of the world. Finance supports the shift: enhancing a sustainable and just transition strongly depends on a more equitable access to finance. This analysis moves the attention towards which investment channels and actors maximise the available financial resources for hydropower. Rather than asking how much more capital we need, our approach points to who is better to spread the capital. This is essential in hydropower resources given the technology suffers from declining investment trends (IEA, 2020) despite its role in supporting several developing economies.

Our work reveals the systemic complexity of hydropower project financing models. It highlights how investors cluster together and identifies the key actors in crowding-in public and private efforts to reach the most vulnerable. As finance is dominated by strong home bias, investments in such areas still depend on effective public–private partnerships (Ahmad et al., 2019; Hodge et al., 2018) that cross borders and connect diverse stakeholders. Partnerships are also crucial in promoting learning through co-investments and in supporting systemic transformations (Geddes & Schmidt, 2020). We find that international actors, multilateral development banks and bilateral institutions have been critical in widening the market for incumbents, crowding-in different active investors in hydropower project financing. Our findings reinforce the need for a global policy agenda (Finance in Common, 2020; G20, 2017), but also highlights the importance of the commercial banking sector in boosting a more equal deployment of financial resources.

Strong partnerships have also allowed countries to make progress towards their NDCs, especially where hydropower played a central role in the energy system. For instance, in its updated NDC, Vietnam identified the maximization of hydropower production as a key priority, in line with improved mobilization of capital "for investments in developing the power sector" (The Socialist Republic of Vietnam, 2020). India also presented hydropower as an essential energy source in its NDC (India, 2016), which is consistent with its pressing domestic energy security objectives. As highlighted by the NDC Partnership Forum (UNFCCC, 2020), solid partnerships are critical to boost a sustainable economic recovery after the COVID-19 pandemic to meet the objectives declared in the single NDCs while restructuring economic prosperity after the shock.

Our findings open new research questions. Partnerships could be also powerful tools to align the energy transition objectives with debt sustainability. If successful in building mature markets, partnerships can promote a sustainable domestic environment for investments, reducing the occurrence of debt instruments. Indeed, while creating a space for a tighter climate-development nexus, the strong dependency of developing countries on public resources can increase the pressure on public debt. International, bilateral and multilateral actors are increasingly deploying finance through non-concessional resources (OECD, 2018), which ultimately contributes to higher levels of indebtedness among many developing countries. Understanding the consequences of term and development loans and which financing mechanisms ensure debt sustainability, has to become part of the energy transition agenda (Buhr & Volz, 2018).

Finally, future assessments of equitable project finance for hydropower will need to account for changing climate conditions. Past, present and future projects require updated projections of water availability to estimate the return on investments under different conditions (Farinosi et al., 2020) hence altering the profitability of different investment models. The use of systemic approaches can incorporate these questions in the policy agenda and fill the existing transition gap that threatens the success of a just transition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 802891).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gloenvcha.2022.102518.

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