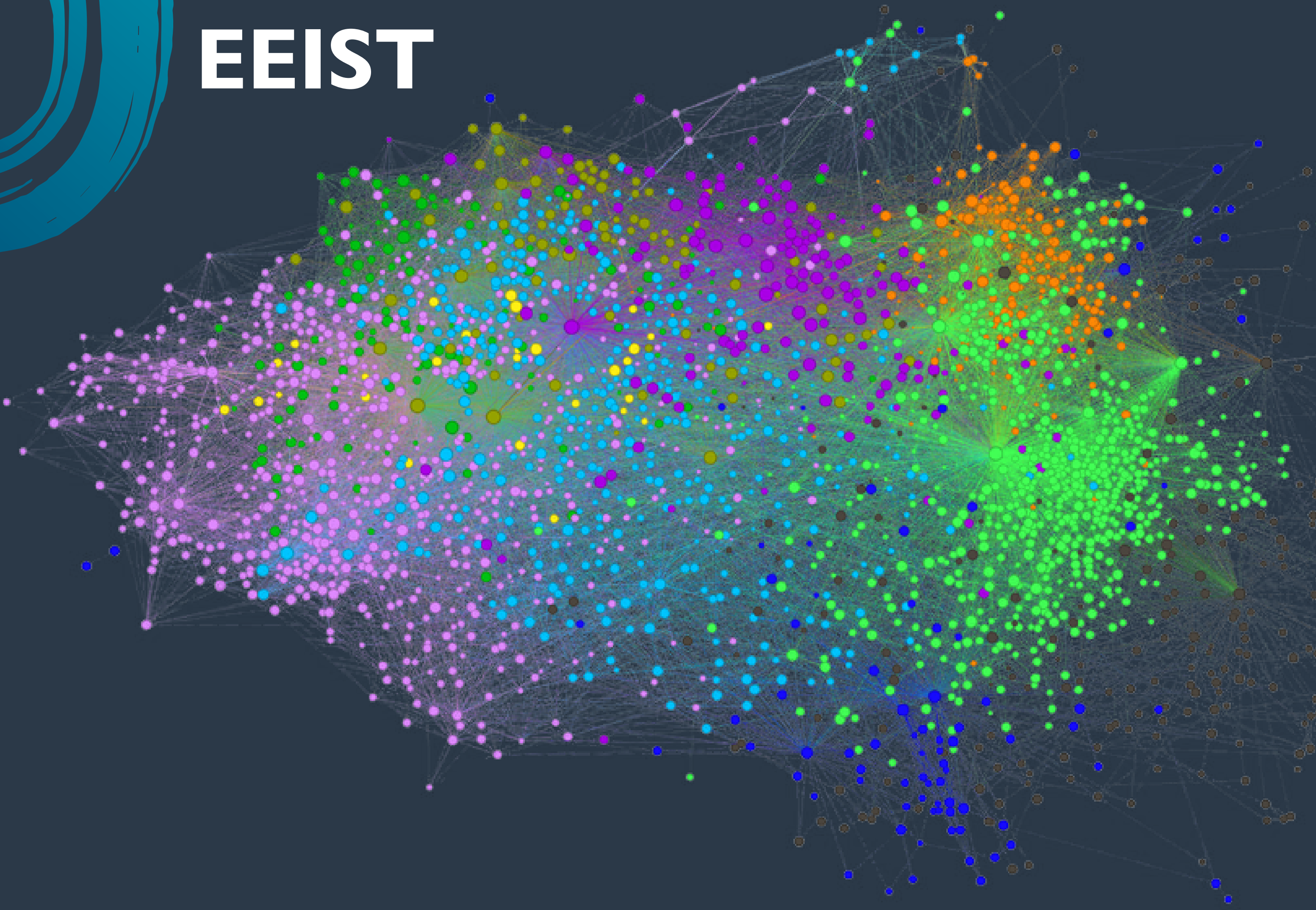
EEIST



FINANCE
CASE STUDIES

This document presents only the modelling case studies related to the finance sectors in the 'New economic models of energy innovation and transition: Addressing new questions and providing better answers' report, produced by the EEIST project.

To view other parts of the full report, including case studies on the global energy transition, the power and industrial sectors, transport, agriculture, impacts of the transition and national decarbonisation plans, go to https://eeist.co.uk/eeist-reports/new-economic-models-of-energy-innovation-and-transition/

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FINANCE

About

The Economics of Energy Innovation and System Transition (EEIST) project develops cutting-edge energy innovation analysis to support government decision making around low-carbon innovation and technological change.

By engaging with policymakers and stakeholders in Brazil, China, India, the UK and the EU, the project aims to contribute to the economic development of emerging nations and support sustainable development globally.

Led by the University of Exeter, EEIST brings together an international team of world-leading research institutions across Brazil, China, India, the UK and the EU.

The consortium of institutions are **UK**: University of Exeter, University of Oxford, University of Cambridge, University College London, Anglia Ruskin University, Cambridge Econometrics, Climate Strategies, **India:** The Energy and Resources Institute, World Resources Institute, **China:** Beijing Normal University, Tsinghua University, Energy Research Institute, **Brazil:** Federal University of Rio de Janeiro, University of Brasilia, Universidade Estadual de Campinas (UNICAMP) **EU:** Scuola Superiore di Studi Universitari e di Perfezionamento Sant'Anna.

Contributors

EEIST is jointly funded through UK Aid by the UK Government Department for Energy Security & Net Zero, and the Children's Investment Fund Foundation (CIFF).

Contributing authors are drawn from a wide range of institutions. For full institutional affiliations see **www.eeist.co.uk**

The contents of this report represent the views of the authors, and should not be taken to represent the views of the UK government, CIFF or the organisations to which the authors are affiliated, or of any of the sponsoring organisations.

Acknowledgements

The authors wish to thank the UK Department for Energy Security & Net Zero, the Children's Investment Fund Foundation (CIFF), the Quadrature Climate Foundation and Founders' Pledge for their support as sponsors of the EEIST project. We also wish to thank all those who contributed their time and expertise to developing and refining the analysis, concepts and ideas presented in this report, and in bringing it to publication. This includes, but is not limited to: Jacqui Richards and individuals from the Communities of Practice in EEIST partner countries, the EEIST Senior Oversight Group, and the UK government.

CASE STUDY:

Closing the Green Financial Gap in the UK: Low-carbon electricity transition and economic implications

SARAH HAFNER (ANGLIA RUSKIN UNIVERSITY), ALED JONES (ANGLIA RUSKIN UNIVERSITY)

Policy question: What are the macroeconomic implications of a UK low-carbon electricity transition implemented in conjunction with and without a policy designed to close the green finance gap?

Region: UK

Method: System Dynamics model

Key findings: Closing the green finance gap policy scenario alongside a low-carbon power scenario leads to the co-benefits of lower power system costs and lower unemployment, as well as increases in GDP.

Engagement: This case study analysed 31 policy reports from multi-stakeholder groups or organisations that represent wider stakeholders within the finance community, alongside 17 structured interviews with private investors, asset owners and managers, banks and pension fund representatives, and actuaries. Roundtable discussions also fed into this work through events hosted by the Aldersgate Group, World Bank, the Institute and Faculty of Actuaries and the Observer Research Foundation (India). This work builds on previous engagement through the Capital Markets Climate Initiative (CMCI) led by the then Minister for Climate Change at the Department for Energy & Climate Change.

Summary: The authors use a System Dynamics model to consider whether policies are aimed at the energy sector enough to support a low-carbon transition in the UK. Specifically, the study presents the Green Investment Barrier Model, which focuses on the modelling of the financial sector, including variables such interest rates and exchange rates, and links this to investment in the energy sector to model the interplay between the two sectors passing through the real economy. Unlike traditional models that focus solely on the energy sector, we find that energy policies alone are not enough to achieve net zero ambitions in energy and that financial regulation is needed alongside energy policies to increase the available capital from institutional and private investors.

Introduction

Meeting its climate policy objectives requires the UK to rapidly decarbonise its energy sector. This demands high levels of investments into low-carbon energy infrastructure. For example, DECC[267] estimated the required investments into low-emission energy infrastructure, including transmission and generation, is £130bn by 2030. Other sources, such as the Committee on Climate Change (CCC)[268] and Vivid Economics[269] estimated the required investment to be higher, ranging up to £300bn by 2030. Traditional sources of capital (e.g. project finance) will not be enough to cover the required energy infrastructure investments. Therefore, additional funding sources, such as finance from institutional or private investors (e.g. mainstream investors or high-net-worth individuals) are required to cover the green finance gap.[270] However, currently private and institutional investors are not investing sufficiently into green energy infrastructure, for example due to lack of confidence given the technology risks, unstable policies, high up-front capital requirements of renewables or lack of information.[271][272]

While current energy-economy models reveal a variety of different aspects/implications of low-carbon energy transitions (and apply a large range of different focuses), to date none of them – with the possible exception of the extended EIRIN model[273] – demonstrate how policies contribute to scale up the green investment necessary to finance the low-carbon energy infrastructure and show what the related macroeconomic implications are. Our study aims to fill this gap and thus extend the current existing energy-economy modelling landscape. We focus on the following question:

- What are the macroeconomic implications of a UK low-carbon electricity transition implemented in conjunction with and without a policy designed to close the green finance gap?

To address this question, we apply the extended Green Investment Barrier Model (GIBM)[274] which includes key results from the qualitative investigation on the green finance gap by Hafner et al.[275]

Current energy policies, such as feed-in-tariffs, contract-for-difference or subsidies, focus primarily on energy firms' investment decisions. However, the policy scenarios presented in this case study additionally aim to influence the finance decisions of private and institutional investors required to provide finance to energy firms or invest directly into energy infrastructure.

Modelling approach

The model presented in this study is a descriptive simulation model as opposed to the more common equilibrium and optimisation models. SD is a suitable tool to investigate key mechanisms of complex systems that are characterised by feedback loops, uncertainty and path-dependency, and to manage and/or improve these systems by intervening at leverage points that either strengthen desirable or weaken undesired feedback loops.

GIBM is calibrated to the UK context and allows for the simulation of different low-carbon electricity transition scenarios.[276] The model includes the endogenous simulation of key macroeconomic variables such as GDP or unemployment, emissions (as key environmental indicators) emitted by the electricity supply sector, and electricity system costs. The economic model sectors of GIBM can be said to be embedded in a post-Keynesian/ecological macroeconomic framework. Specific model equations build generally on different non-equilibrium modelling approaches, including post-Keynesian economics, ecological economics or system dynamics, but also equilibrium approaches (e.g. Constant Elasticity of Substitution – CES – production function). The model has a narrower scope than large-scale models, such as, for example,

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[267] UK Department of Energy & Climate Change. (2014). Energy Investment Report, April 2014. https://www.gov.uk/government/publications/energyinvestment-report-april-2014 (Accessed April 19, 2019)

[268] Committee on Climate Change. (2013). Next Steps on Electricity Market Reform – Securing the Benefits of Low-Carbon Investment. Committee on Climate Change. https://www.theccc.org.uk/wp-content/uploads/2013/05/1720_EMR_report_web.pdf. (Accessed May 1, 2019).

[269] Vivid Economics. (2012). Energy and the Economy - The 2030 outlook for UK Businesses. A London School of Economics Report Commissioned by RWE NPower. Available at: www.vivideconomics.com/publications/energy-and-the-economy-the-2030-outlook-for-uk-businesses (Accessed May 4, 2019)

[270] OECD. (2016). Fragmentation in Clear Energy Investment and Financing. Available at: http://www.oecd. org/investment/investment-policy/BFO-2016-Ch5-Green-Energy.pdf (Accessed July 4, 2018).

[271] Hafner, S. et al. (2019). A Scoping Review of Barriers to Investment in Climate Change Solutions. Sustainability, 11(11), 3201.

[272] Hafner, S. et al. (2020). Closing the Green Finance Gap – A Systems Perspective. Environmental Innovation and Societal Transitions, 34: 26-60.

[273] Dunz, N. et al. (2019). Climate Transition Risk, Climate Sentiments and Financial Stability in a Stock-Flow Consistent Approach. Journal of Financial Stability 54: 100872.

[274] Hafner, S. et al. (2021). Modelling the Macroeconomics of a 'Closing the Green Finance Gap' Scenario for an Energy Transition. Environmental Innovation and Societal Transitions, 40: 536-568.

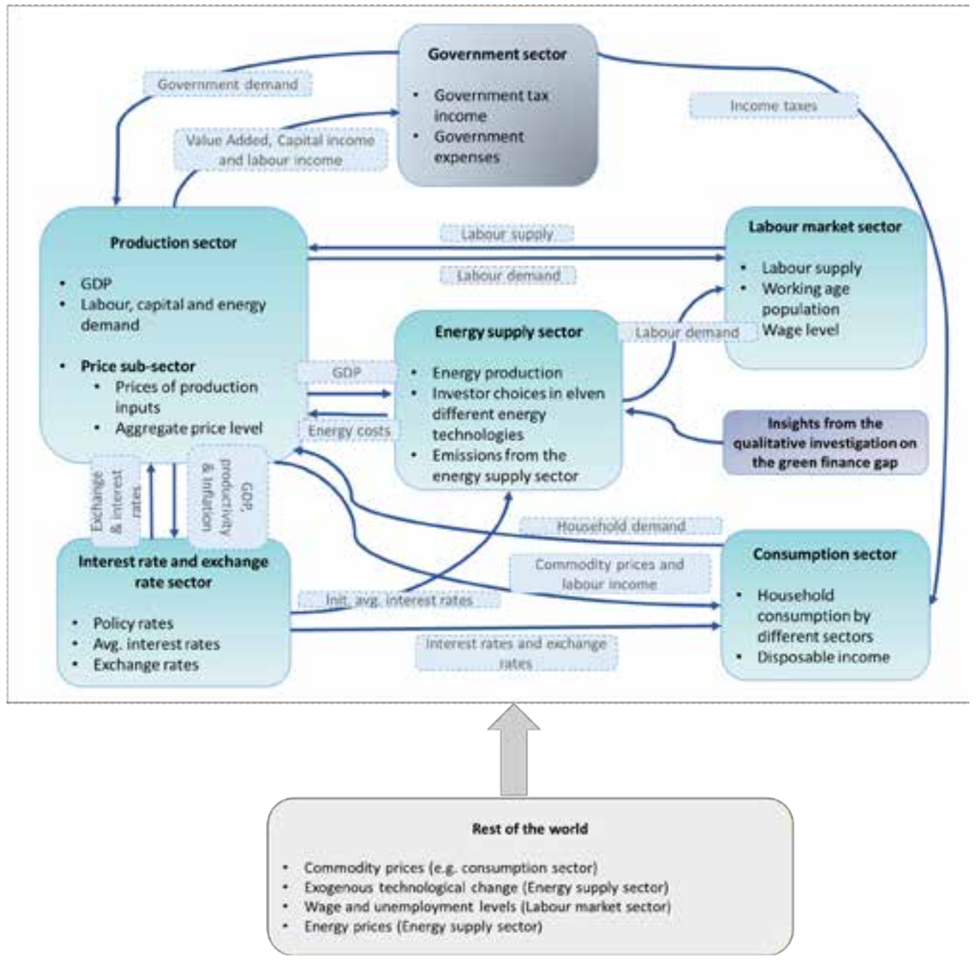
[275] Hafner, S. et al. (2020). Closing the Green Finance Gap – A Systems Perspective. Environmental Innovation and Societal Transitions, 34: 26-60.

[276] Hafner, S. et al. (2021). Economic Impacts of Achieving a Net-Zero Emissions Target in the Power Sector. Cleaner Production, 312: 127610.

the Cambridge Econometrics E3ME model, but is wider in scope than a stylised mathematical model. Specifically, GIBM includes 313 stock variables and more than 3,000 variables in total. The simulation horizon for this study included the period from 2016 to 2050, with time steps of 0.25 years.

Figure 84 gives an overview on GIBM and its key macroeconomic sectors (e.g. production, consumption and labour market), the public sector and electricity supply sector. The model allows us to understand what the macroeconomics implications and electricity system costs of different electricity transition scenarios are.

Figure 84: Overview of GIBM. The main causal relationships between model sectors. GIBM is visualised in the dashed box, i.e. the rest of the world is outside the GIBM. The model sectors in the parenthesis in the 'Rest of the world' box indicate that additional exogenous inputs from the rest of the world enter the model. The production process at the macroeconomic level is represented with a demand-led CES production function – that is, the production inputs, labour, capital, energy and intermediate inputs are not (necessarily) fully utilised. The production sector also includes the simulation of prices; the consumption sector simulates household consumption per industry; the labour market sector determines employment and simulates unemployment as the difference between labour demand coming from the production sector and the available labour force. In addition, the labour market represents the wage level and includes a sub-sector that simulates the UK working population endogenously; the exchange and interest rate sector includes the exchange rate between the UK and its main trading partners, and the average interest rate for credits of UK firms; the public or government sector tracks state income and expenditure. Finally, the electricity supply sector includes a detailed representation of the electricity production capacity and determines annual energy produced in the UK. The power supply sector is differentiated by 12 electricity production technologies, including biomass, hydro, marine, onshore wind, offshore wind, solar, other thermal and other renewable energies as renewable technologies, nuclear and CCS gas as other low-carbon technologies and finally coal and gas as brown technologies.[277] [278]



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[277] Hafner, S. et al. (2021). Modelling the Macroeconomics of a 'Closing the Green Finance Gap' Scenario for an Energy Transition. Environmental Innovation and Societal Transitions, 40: 536-568.

[278] Hafner, S. et al. (2021). Economic Impacts of Achieving a Net-Zero Emissions Target in the Power Sector. Journal of Cleaner Production, 312: 127610.

Description of the GIBM complexity features

The following provides a list of complexity features captured by the GIBM in line with the Risk-Opportunity Analysis framework:[279] [280]

- Complexity & multiple equilibria/non-equilibrium: In GIBM, the different economic sectors are also interconnected, as well as the economy with the energy sectors. Also, due to the complexity, agents cannot take 'rational' decisions and a long-term equilibrium outcome is not given.
- Deep uncertainty: SD modelling acknowledges uncertainty at the level of model construction; system complexity means that future system behaviours are not predictable based on past system structure and behaviours.
- Non-linearity: The consumption sector includes changes in the parameter of elasticities once certain consumption levels are reached.
- Feedback-loops, path-dependency and lock-in: The power sector includes cost-decreases of renewable technologies due to learning-by-doing and the economic sector includes the Keynesian GDP-multiplier effects.
- Actor behaviour and decision making: SD aims to represent how model agents take decisions, considering both relevant economic and socio-psychological factors (e.g. agents' values or preferences). In GIBM, the decisions of financial investors are mimicked by using the results of a qualitative study[281] (which includes interviews with these investors) to also include 'soft parameters' about which there is currently no quantitative data.

Description of the scenarios and results

We simulate and compare the following policy scenarios (key macroeconomic dynamics, induced by the introduced scenarios are described in detail Hafner et al., 2021a):

- The low-carbon energy transition scenario (LETS) influences variables in the energy sector of the model as it implies that only renewable energy sources are chosen for new installations. In addition, it implies linear decrease of installed brown energy capacity from 2020 onwards, leading to zero emissions by 2050 in the energy sector. The LETS is introduced by assumption and the required policies are not specified. Within LETS no specific policies are directed towards investors which address current perceived barriers in investment (as reported by mainstream investors and institutions) towards green infrastructure and therefore there is a limit on the availability of capital for such projects.
- The finance system's policy scenario (FSPS) influences variables in the finance sector of the model. This policy scenario is assumed to tackle key green investment barriers in an effective and holistic way, drawing on a systems perspective. Importantly, we note that while the details of this systems policy developed are not specified in this study, we assume that the systems policy involves amendments in current regulations, investment advice, risk assessment requirements (e.g. ESG criteria and climate related risks disclosure), metrics reported and tools applied, drawing on empirical evidence stated in Hafner et al. (2020a). The introduction of this systems policy therefore closes the green finance gap (the availability of capital matches the projected requirements under the future scenarios such that all investable projects are able to attract enough capital). This means that green investment flows to renewable energy infrastructure are no longer restricted by the availability of finance as compared to the base-run that represents the current situation of a green finance gap. That is, in GIBM, without the introduction of an adequate policy available, green finance is below the amount of finance required to finance a green energy transition. Furthermore, the introduction of a systems policy reduces the mark-up on interest rates of renewable energy projects in particular, while also reducing the average interest rate in general (see Figure 85).
- Finally, the scenarios introduced above were tested in combination.

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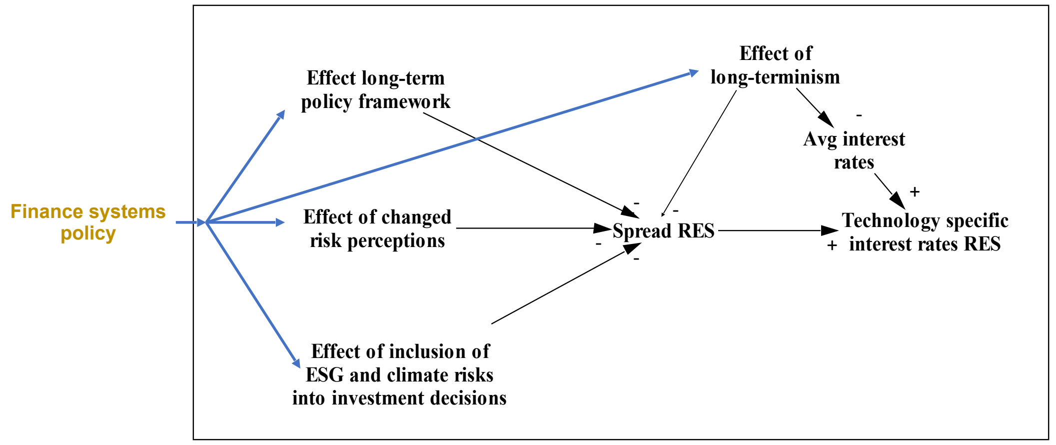
[289] Mercure, J-F. et al. (2021). Risk-Opportunity Analysis for Transformative Policy Design and Appraisal. Global Environmental Change, 70: 102359.

[280] Grubb, M. et al. (2021). The New Economics of Innovation and Transition: Evaluating Opportunities and Risks.

[281] Hafner, S. et al. (2019). A Scoping Review of Barriers to Investment in Climate Change Solutions. Sustainability, 11(11): 3201.

Figure 85: Impacts of a finance system's policy: A finance system's policy tackles key green investment barriers from a system's perspective. It (i) lowers average interest rates, (ii) lowers the interest rate spread on renewable energy technology investment and (iii) closes the green finance gap.[282] [283]



In the following, we present the simulation results for the following key policy indicators:[284]

- Greenhouse gas emissions of the energy supply system
- Unemployed workers plus inactive working-age population
- GDP
- Energy system costs
- Direct generated employment by the energy transition

We choose to define 'unemployed' in this study as the sum of unemployed and inactive workers.[285]

Table 14 shows the results of the simulated energy policy scenarios in terms of the chosen policy indicators as percentages against the base-run simulation results of the same policy indicator (always in accumulated numbers, if not indicated differently). Importantly, although the UK has implemented a CFD scheme, a stylised CFD scenario is not used as a base-run, as the interest lies in understanding the additional costs of different policy scenarios compared with the base-run where no major scheme (but a -price) is introduced.

Table 14: Overview on policy outcomes of the tested scenarios – orange highlights the worst achieved results and blue the best achieved one of all tested low-carbon policy scenarios; impacts on accumulated variables from 2016 to 2050.

	Emissions (%)	GDP (%)	Unemployment (%)	Direct employment (%)	System costs (%)
Finance system's policy (FSPS)	-7.09	3.05	-1.47	15.12	-2.58
Low-carbon energy transition scenario (LETS)	-44.90	0.50	0.20	-6.90	12.44
FSPS and LETS combined	-44.90	3.46	-1.4053	40.15	3.66

Model results demonstrate that the 'closing the green finance gap' policy scenario alongside a low-carbon power scenario leads to the co-benefits of lower power system costs and unemployment, and increases in GDP. Importantly, the results show that focusing on closing the green finance gap alone would not be enough to reach net-zero emissions of low-carbon electricity production by 2050 – policies in the electricity sector itself are needed to complement it.

Conclusion

Given these results, we recommend the implementation of a low-carbon energy transition scenario in combination with policies aiming to close the green finance gap that are based on a systems approach.

Moreover, the simulation results demonstrate that while there exists no clear win-win solution, the implementation of a long-term finance system's policy, designed to contribute to close the green finance gap, brings various co-benefits both introduced in isolation as well as in combination with a low-carbon energy transition:

- When a finance system's policy is introduced in isolation it reduces the average market interest rates and leads to a lower spread on the interest rates of renewable energy technologies. These effects lead further (i) to an increase in GDP due to lower average interest rates and therefore (ii) also a decrease in unemployment, (iii) to an increase in direct employment due to lower financing costs of renewable energy sources and (iv) to lower energy systems costs due to lower market interest rates. The only disadvantage caused by this scenario introduced in isolation are the higher emissions due to the increase in GDP, which implies a higher production and use of energy.
- A finance systems policy combined with a low-carbon energy scenario leads to various co-benefits. That is, the LETS and FSPS introduced in combination lead to higher GDP and direct employment, and at the same time to lower unemployment and energy system costs – and importantly to zero emissions in the energy system costs in the UK by 2050.

The effects from a finance system's policy stem on one hand from its effect on lower interest rates and on the other hand because it closes the green finance gap, which subsequently avoids energy imports from abroad. Given the above, we recommend the implementation of a low-carbon energy transition scenario in combination with a finance system's policy. The key insights, policy implications and conclusions presented are robust under the sensitivity analysis performed.

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[282] Hafner, S. et al. (2021). Modelling the Macroeconomics of a 'Closing the Green Finance Gap' Scenario for an Energy Transition. Environmental Innovation and Societal Transitions, 40: 536-568.

[283] Hafner, S. et al. (2021). Economic Impacts of Achieving a Net-Zero Emissions Target in the Power Sector. Journal of Cleaner Production, 312: 127610.

[284] Results are presented in 'accumulated' terms, which means that the annual amount of each of the chosen policy variables is added up/accumulated over the simulation time horizon from 2016 to 2050.

[285] In GIBM, the number of people outside the labour force is dependent on the percentage of unemployment due to the so-called 'discouraged workers effect'. Therefore, individuals who although would desire to work, may decide to stay outside the labour force due to discouragement and are therefore a part of the inactive labour force. In our study, we decided to consider these otherwise 'hidden' individuals in our policy evaluation.

CASE STUDY:

Exit Options for Renewable Energy Investments in Brazil

ANNA CAROLINA MARTINS (UNICAMP, BRAZIL), MARCELO PEREIRA (UNICAMP, BRAZIL)

Policy question: How might 'exit options' analysis support private financing of renewables projects?

Region: Brazil

Method: Financial modelling

Key finding(s): The uncertainty in the financial evaluation of individual renewable energy projects is a key driver for the application of exit options by creditors and, despite being relatively unknown in the country, this project valuation method is relevant for pushing forward the Brazilian renewables sector.

Engagement: This work has been presented and discussed across a range of meetings and engagement activities in 2021 and 2022, with representatives of the Brazilian National Development Bank (BNDES), the Brazilian Photovoltaic Solar Energy Association (ABSOLAR), the UN Economic Commission for Latin America and the Caribbean (ECLAC), and the Brazilian Energy Research Office (EPE). The work is ongoing and further engagement is planned.

Summary: The authors use a financial modelling approach to consider the feasibility and impacts of an alternative approach – exit options – to private financing of renewable projects. Their modelling suggests this approach has potential and that detailed exploration of implementing and adopting it should be conducted.

Introduction

Despite the consensus that a quick energy transition is needed, the current levels of private funding for green energy are still insufficient[286] [287] [288] and, given the huge investments required, it is unlikely that public investments alone will reach the necessary levels.[289] In Brazil, the situation is no exception. Public banks such as the BNDES and the Bank of Brazil (BB) are the largest funders of renewable energy [290] [291] and another substantial part of investments are made by international development banks such as the European Investment Bank (EIB) and the Agence Française de Développement (AFD). But investments made by the private sector take place in smaller proportions and, according to CEPAL (2020), [292] are reliant on public policies and incentives. So, evaluating alternatives to stimulate the private sector to increase the financial support of renewable energy projects is an important part of the green transition agenda.

Green energy financing

Historically, infrastructural investment in Brazil has relied mainly on public sources of capital (EPGE, 2023).[293] [294] Even if precise figures are not available, anecdotical evidence indicates that the role of private creditors in renewable energy finance is mainly as a mediator of public institutions' programs, like BNDES Fundo Clima or Finem 'indirect support' modality,[295] or BNDES Garantia and FGI credit guarantee instruments.[296] However, such modalities and instruments assume a traditional financial evaluation of projects, where the (direct or indirect) creditor requires financial guarantees for the entire project, without effectively considering the 'added value' of an early exit option. This is particularly critical for very long-term projects, like energy generation, where the uncertainty about energy prices and generation costs, prone to substantial volatility over time, is significant.

The risk aversion of public entities, like BNDES, in requiring substantial credit guarantees from candidate projects may be justified by the Brazilian regulatory framework. But such constraints may not apply to private creditors when supplying their own funds. Understanding under which conditions (real) private finance of renewable energy may change their current behaviour, and increase their support to the green transition, seems to be a key issue for policy analysts and decision makers to address. Supporting a regulatory framework that enables new financing agents and models is crucial for a successful green transition, in particular in developing countries like Brazil, where credit for investment has been historically scarce and expensive.[297]

One major bottleneck on private green energy finance is the scarcity of risk-adjusted renewable energy (RE) investments.[298] The most common project evaluation practice is based on a project's discounted cashflow, also known as net present value (NPV), and considers funds required for both CapEx and OpEx. However, this type of project evaluation and financing does not consider that the parties involved may change their investment strategies as the project develops. This means, once agreed in contract, they must keep their resources dedicated to the project.

Given that green energy projects may require large amounts of financial resources, over long time periods, such rigidity may easily discourage private-sector investment,[299] in particular because of the significant uncertainty about some key assumptions required by the NPV calculation. It can be trivially demonstrated that energy prices demonstrate

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[286] IEA. (2017). Perspectives for the Energy Transition: Investment needs for a low-carbon energy system.

[287] Wüstenhagen, R.A.E.M. (2012). Strategic Choices for Renewable Energy Investment: Conceptual framework and opportunities for further research. Energy Policy.

[288] Bloomberg New Energy Finance. (2010). Global Trends in Sustainable Energy Investment 2010: Analysis of Trends and Issues in the Financing.

[289] Fadly, D. (2019). Low-carbon transition: Private sector investment in renewable energy projects in developing countries. World Development, 122, 552-569.

[290] BNDS. (2022). Fundo Clima – Subprograma Energias Renováveis. Available at <https://www.bndes.gov.br/wps/portal/site/home/financiamento/produto/fundo-clima-energias-renovaveis>. Accessed on December 20, 2022.

[291] Banco do Brasil - BB (2022). Estimulo à Energia Renovável. Available at <https://www.bb.com.br/pbb/pagina-inicial/sobre-nos/sustentabilidade/energias-renovaveis/solucoes-para-voce#/>. Accessed on December 20, 2022.

[292] CEPAL, Energia. (2022). Available at < https://www.cepal.org/pt-br/subtopicos/energia#> . Accessed on December 20 2022.

[293] EPGE. (1999). Investimentos, Fontes de Financiamento e Evolução do Setor de Infra-Estrutura no Brasil: 1950-1996, Available at < https://bibliotecadigital.fgv.br/dspace/bitstream/handle/10438/575/1199.pdf>, Accessed on January 12, 2023.

[294] Albanez, T. and Ribeiro do Valle, M. (2012). High Interest Rates, Capital Sources and Capital Structure: The Debt Of Brazilian Companies In The Period 1997-2006, Available at <https://www.revistas.usp.br/rco/article/download/52667/56551>. Accessed on January 12, 2023.

[295] BNDES Finem. Geração de Energia. Available at < https://www.bndes.gov.br/wps/portal/site/home/financiamento/produto/bndes-finem-energia> . Accessed on January 12, 2023.

[296] BNDES, Guia do Financiamento. Available at < https://www.bndes.gov.br/wps/portal/site/home/financiamento/guia> . Accessed on January 12, 2023.

[297] BNDES, Guia do Financiamento. Available at < https://www.bndes.gov.br/wps/portal/site/home/financiamento/guia> . Accessed on January 12, 2023.

[298] Nelson, D.and Pierpont, B. (2013). The Challenge of Institutional Investment in Renewable Energy. Climate Policy Initiative, San Francisco.

[299] DWIH São Paulo. (2022). 10th German-Brazilian Innovation and Sustainability Congress. Available at < https://www.dwih-saopaulo.org/en/event/10th-german-brazilian-innovation-and-sustainability-congress/> Accessed on September 29 and 30, 2022.

significant volatility in the long run, and in turn, so does the expected project's revenues. Even on the cost side, volatility of essential factors, like wages, (imported) equipment prices and exchange rates, has been historically high, particularly in developing countries. Adding up all this uncertainty leads to creditors requiring high (internal) rates of return for the projects to be financed, discarding in the process many projects that would prove perfectly viable ex post.

Real option analysis

To address this issue, Real Option (RO) analysis has been increasingly used in the evaluation of renewable energy projects in places like California, Norway and Turkey (see Table 15) and has long been used in financial-feasibility studies for power-generation projects in China.[300] Unlike usual financial options, where the underlying assets are liquid assets (easily traded), real options are applied to real assets such as investment projects. The key idea is that the parties involved (i.e. creditor and developer) may change their decisions about the financing and development of a project after it has started, without incurring a breach of contract or litigation.

There are distinct types of Real Options. Gazheli (2018)[301] highlights three:

- Postponement: Option to wait to invest in the project. Thus, the irreversible investment may happen only when more information of future market and production conditions is available.
- Alteration: Flexibility to change the project, through the possibility of altering the form of production, given future market and production conditions.
- Exit: Opportunity to exit the project before the expected term and take back any residual value.

When receiving finance requests, and where the economic environment or the future context is uncertain, the creditor may wish to wait a while to decide on whether or not to invest in a given renewable energy project. In such cases, the postponement option offers the chance to participate in such projects at some point in the future. The alteration option, on the other hand, would enable the agents to switch to technologies or business models that prove to be better over time. Or, if a project offers different ramifications such as wind, solar or hydro, the investing agent can acquire the right to switch between technologies according to the market feasibility.

The exit option, the focus of this work, allows both agents (creditor and developer) the right, but not the obligation, to leave the project before the fixed term. That is, if for any reason the project's financial performance is affected negatively, both the creditor and the developer may (within an agreed period) opt to exit the credit operation, therefore allowing opportunities to change investment decisions.[302] In such cases, the creditor may abstain from the obligation to finance other stages previously established in the contract, as will be detailed below, and both agents must agree on the period(s) in which they can exit. Furthermore, the exit option does not exempt the developer from paying off the amount already borrowed.

Therefore, the exit option provides an alternative instrument to reduce the risk taken by the creditor, and the increase of the project's NPV due to this reduction is indeed a valuation of such option. Put simply, if the traditional valuation (i.e. no exit option) is NPV1 = X, then the valuation considering the exit option value is NPV2 = X + Y. The option value is thus, NPV2 - NPV1 = X + Y - X = Y. Consequently, projects that are not viable under the usual criterion (i.e. have a negative NPV), but presenting a positive-valued exit option, may become feasible.

Exit options for green energy investments in Brazil

Now, we focus on the potential for the application of exit options for renewable energy projects in developing countries like Brazil. The RO approach has been applied in wind, solar and hydro energy projects in various countries (see Table 15). However, we have no information about its application in the case of Brazil, likely due to the absence of this kind of instrument in the standard credit models proposed by BNDES, by far the largest primary source of investment finance for renewable energy [ibid.]. In any case and considering the increased uncertainty in a developing country, it seems that further exploring this alternative can enable financing a group of projects that otherwise would not be viable.

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[300] Kim, K. H. P. A. H. K. (2017). Real Options Analysis for Renewable Energy Investment Decisions in Developing Countries. Renewable and Sustainable Energy Reviews.

[301] Gazheli, A. A. J. V. D. B. (2018). Real Options Analysis of Investment In Solar Vs. Wind Energy: Diversification strategies under uncertain prices and costs. Renewable and Sustainable Energy Reviews.

[302] Kim, K. H. P. A. H. K. (2017). Real Options Analysis for Renewable Energy Investment Decisions in Developing Countries. Renewable and Sustainable Energy Reviews.

There are different methods for estimating the value of an option, as exemplified in Table 15. Here, we apply the RO analysis framework proposed in Kim[303] and briefly discuss the potential of exit options to boost Renewable Electrical Energy (REE) financing. We focus on Brazil, where between 2012 and 2021 almost 7,000 publicly funded infrastructure projects, including renewable energy projects, were suspended (i.e. begun but then paused for some reason, such as insufficient funding or changes in expected outcomes) with a total contract value of BRL 9.32 billion. This highlights the need to review the way projects are evaluated and approved.[304]

Our contribution is to propose a simple model to evaluate projects by considering critical variables that can broadly reflect the economic volatility of an infrastructure project NPV. We focus on two variables – wages and labour productivity – therefore incorporating in the valuation model volatility arising from the labour market. The idea is that higher labour productivity can reduce the costs and make the project NPV (more) positive, but if wages grow faster than labour productivity, the reverse happens. We use wages and labour productivity to exemplify typical sources of project volatility and, from there, define the implicit 'cost' of this volatility through an exit option value. For completeness, we also consider two additional variables, service (energy) tariffs and capital utilisation (service/energy demand) in our model.

We proceed in three steps:

1. Define three future context scenarios for the four test variables, namely, moderate, best, and worst cases;
2. Apply a binomial tree model,[305] [306] which estimates the expected probability (q) of a project becoming more profitable, and calculate the model's single exit option value;
3. Combine the expected NPV with the exit option value to obtain a more realistic project evaluation.

In a demonstration of the concept, we apply the proposed evaluation model to provide a sense of the magnitude of the effects in a real renewable energy project. In future work we will explore it further, by integrating the model as a behavioural rule to be (potentially) adopted by creditors and developers in an agent-based model, like the Dystopian Schumpeter Meeting Keynes model by Lamperti et al.[307] and presented in the case study 'Policy Options for Rapid, Smooth Decarbonisation and Sustainable Growth'. This will allow us to study how ROs in a macro-integrated, RE-financing set-up could affect the energy transition over time in a complexity-informed integrated assessment model.

Simulation and preliminary findings

As a demonstration for the analysis, we consider the Itumbiara hydroelectric plant, part of the Furnas System.[308] The total investment of the project (construction) was US$187.5m. Importantly, the first seven years of the project were dedicated to construction and the remaining 40 years to operation (concession period). As such, we calculate the exit option value on the seventh year. In practice, this gives the option holder, the project creditor, the right to exit the project at the end of the first stage (construction) of the project, on year seven.

Based on a range of technical and market parameters relevant to the Itumbiara project, we build the best, moderate and worst-case scenarios, assuming historically consistent maximum and minimum evolution trajectories for the four considered variables: wages, labour productivity, energy tariff and energy demand. The corresponding Binomial Tree is presented in Figure 86.

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[303] Kim, K. H. P. A. H. K. (2017). Real Options Analysis for Renewable Energy Investment Decisions in Developing Countries. Renewable and Sustainable Energy Reviews.

[304] National Confederation of Municipalities-CNM (2022). Estudo técnico- Obras Paradas. Available in < https://www.cnm.org.br/biblioteca/exibe/15354>. Accessed 2022.

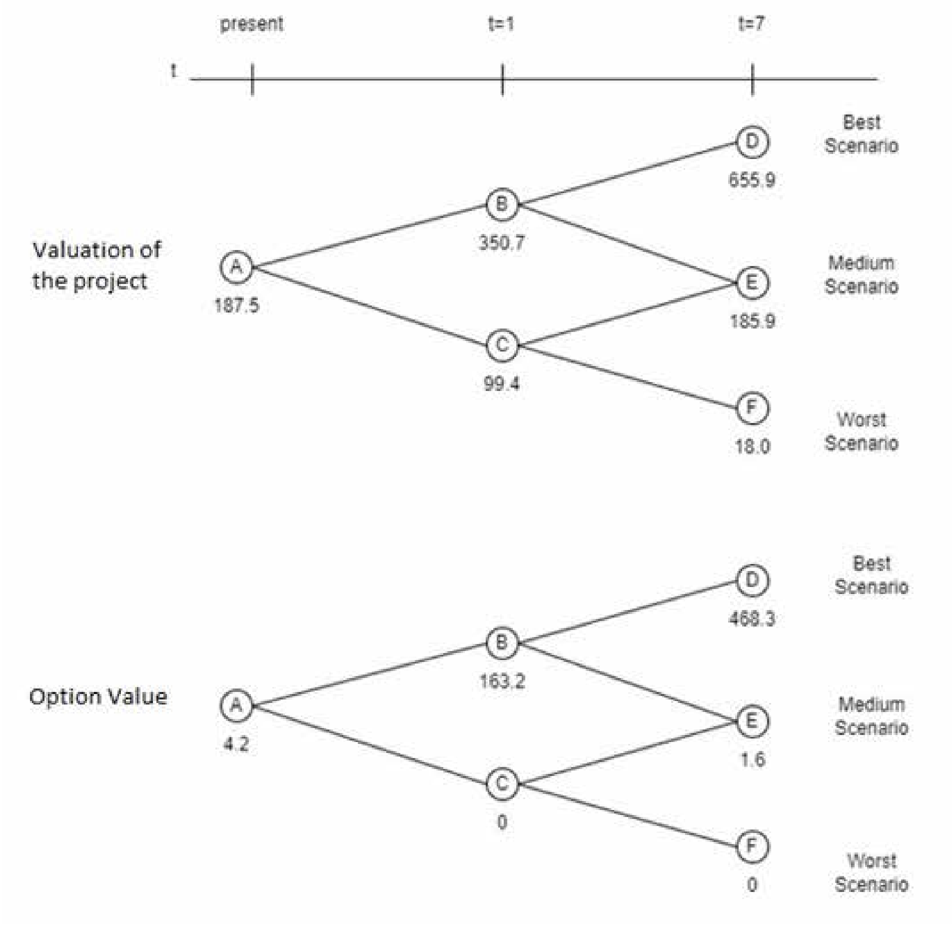
[305] Valuation of the exit option can be computed using different methods: Binomial Tree, Partial Differential Equations, Simulation; Dynamic Programming, Empirical Analysis, Monte Carlo Least Squares Approach, Game Theory, or Probabilistic Model (Extension of the table in Kim, 2014).

[306] Kim, K.t. et al. (2014). Evaluation of R&D Investments in Wind Power in Korea Using Real Option. Renewable and Sustainable Energy Reviews 40: 335-347.

[307] Lamperti, F. et al. (2018). Faraway, So Close: Coupled Climate and Economic Dynamics in an Agent-Based Integrated Assessment Model. Ecological Economics 150: 315-339.

[308] Brazilian hydroelectric power plant systems with facilities in the states of São Paulo, Minas Gerais, Rio de Janeiro, Espírito Santo, Paraná, Goiás, Mato Grosso, Mato Grosso do Sul, Pará, Tocantins, Rondônia, Rio Grande do Sul, Santa Catarina, Ceará, Bahia and the Federal District.

Figure 86: Project and option valuation lattices (in US$ million). Note: Nodes D,E,F represent the project value and the option value at t=7 in the different scenarios. Node A in both trees are the values brought in at t=0. That is, at the present time. The Node A in Option Value tree is the value that should be considered at the time of project evaluation.



As shown in Figure 86, the creditor agent, if considering this mechanism, 'acquires' the right to exit the project at the end of the construction step (after seven years) by increasing the traditional moderate-scenario NPV by US$4.2m. Therefore, the creditor would be no longer required to finance the next project stage (OpEx) if the option is exercised, while preserving the full rights to receive back the outstanding loans (CapEx). Since the NPV without option value for this project was calculated to be approximately US$3.7m, the option value consists of 53 per cent of the new present value. This significant difference means that similar projects with a slight lower NPV may have been refused, while the consideration of the exit option would have proved them as creditworthy as the Itumbiara case.

Starting with the Itumbiara benchmark project, we simulate 100,000 similar potentially viable projects[309] to investigate how the exit option value relates to project variables' volatility. In our model, the difference between the worst and best-case scenarios is given by different assumptions for the wages, energy tariff, capital utilisation and labour productivity, based on the historical volatility. It is worth noting that these variables are fundamentally driven by the respective markets, but how they affect project performance also depends on the developer's skills, another type of uncertainty we seek to deal with in the model. Therefore, the exit option value will reflect both market and project-specific uncertainty.

For the set of simulated projects, Figure 87 shows the modelled total project volatility, the corresponding exit-option value, and the probability q that the project becomes more profitable. Projects with q lower than 0.5 are shown in red, and those with q greater or equal to 0.5, in blue.

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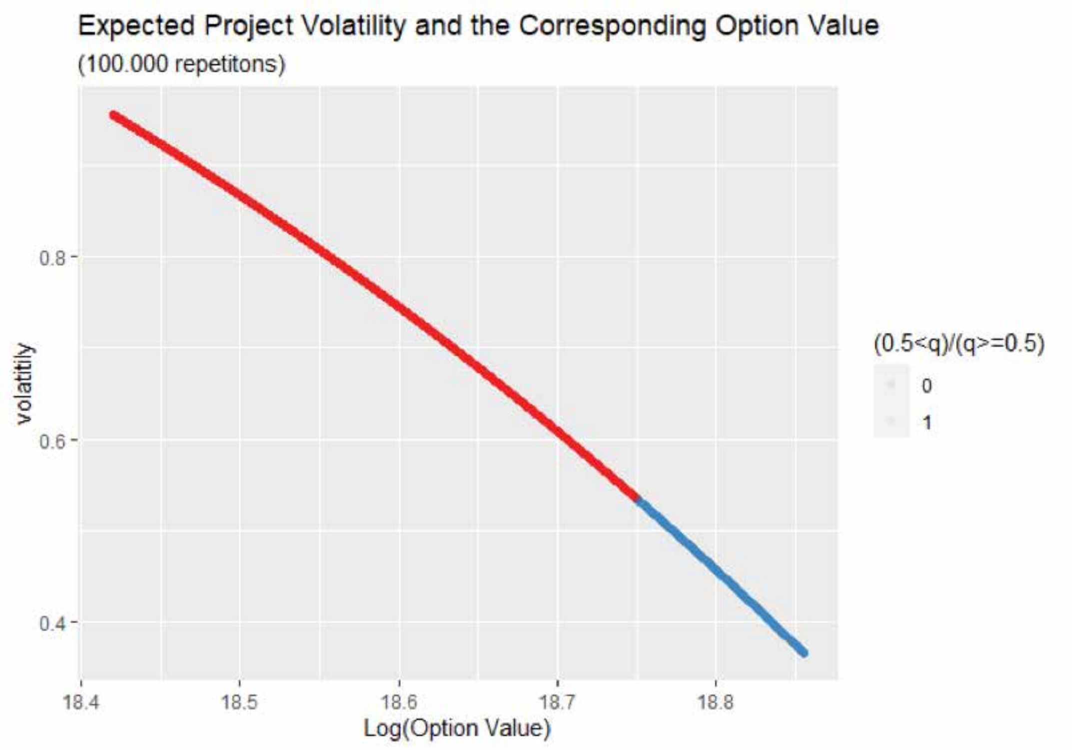
[309] We focus our analysis on financially viable projects – that is, those with a positive net present value.

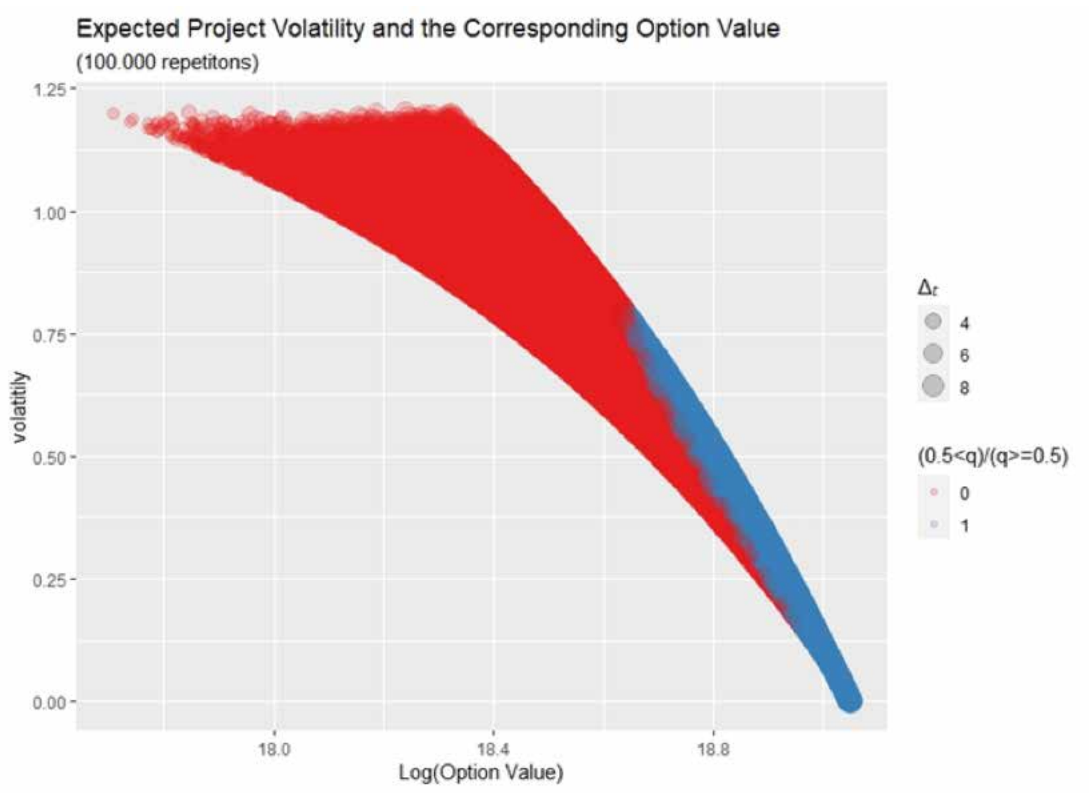
Figure 87: Expected Project Volatility and the Corresponding Option Value with =7 (US$ million/100M repetitions). Source: Elaborated by the author.



Overall, we find that the higher the project volatility, the lower the exit option value. At lower levels of volatility, the share of projects with higher probability of becoming more profitable is higher – and among the projects with very low volatility, all are more likely to increase in value than to devaluate (those in blue). These are low-risk projects and, as such, have the highest exit option value. In turn, higher volatility implies a lower probability of project value appreciation, and lower option value, which can be interpreted as the risk premium incurred by financing the project.

In Figure 88 we present a further exercise, allowing for some flexibility on the time the exit option can be exercised ( ) in each simulated project, from the second until the ninth year. In this case, we can see that there are projects with the same volatility but different option values, and this is because the probability of an undesirable NPV trajectory for some is higher than for others. In this case, adding the exit option to the financial operation would allow creditors to exit the project without incurring unplanned costs (e.g. litigation) as more information about the project performance is realised over time, and so allowing for an increased 'appetite' for risk.

Figure 88: Expected Project Volatility and the Corresponding Option Value, with ranging between 2 and 9 (US$ million/100M repetitions). Source: Elaborated by the author.



Finally, within the ranges of our simulations, most projects have a probability of becoming more profitable lower than 0.5 (areas in red), suggesting that plants like Itumbiara hydro plant, ex ante, have lower probability of being economically viable, even if the main driver for this assessment is exclusively connected to the historical volatility embedded in the main variables. In many cases, perfectly feasible projects, ex post, are discarded because of valuation methodology constraints on dealing with the uncertainty associated with long-term projects.

Conclusion

These experimental results seem consistent with the low levels of private investment in the infrastructure sector in Brazil and many developing countries. The documented higher volatility of domestic markets in these economies, plus the limited ability of the usual valuation methods – developed for advanced countries – to deal with such level of uncertainty, seem to indicate new approaches are required if engagement of private finance is desired.

It is worth emphasising that the simulation above was based on a hydropower plant, so carrying out similar exercises for wind and solar energy projects would be important next steps to better understand the potential of exit options to strengthen private financing for green energy in Brazil. Other than its potential, a better understanding of the reasons for the lower adoption of RO in Brazil, as well understanding the regulatory changes that may be required to make it more viable to financing agents, is the natural direction of our future research.

Table 15: Real Options applications with different valuation methods.

Legend: PDE = Partial Differential Equations; AB = Binomial Tree; SIM = Simulation; PD = Dynamic Programming; AE = Empirical Analysis; AMMQ = Monte Carlo Least Squares Approach; GT = Game Theory; MP = Probabilistic Model

Source: Extension of the table in Kim (2017).[310]

Authors	Country	Type ER	Methodology
HOFF (2003)	California	Photovoltaic	AB
ZHANG X (2005)	Non-Regional	Hydraulics	SIM
KJAERLAND (2007)	Norway	Hydraulics	EDP
KUMBARO⊠LU (2008)	Turkey	Wind	EDP
LEE (2010)	Taiwan	Wind	AB
YANG (2010)	China	Wind	SIM
BATISTA (2011)	Brazil	Hydraulics	SIM
LEE (2011)	Taiwan	Wind	AE
ZAVODOV (2012)	China	Hydraulics	AE
REUTER (2012)	England	Wind	EDP
BOOMSMA (2012)	R. Nordic	Wind	AMMQ
LEE (2013)	Indonesia	Hydraulics	GT + SIM
CESEÑA (2013)	UK	Photovoltaic	SIM
KRONIGER (2014)	England	Wind	EDP + SIM
KIM (2014)	Korea	Wind	AB
ABADIE (2014)	UK	Wind	EDP
WEIBEL (2015)	England	Wind (onshore and offshore)	AMMQ
JEON (2015)	Korea	Photovoltaic	MP
ZHANG (2016)	China	Photovoltaic	EDP
KIM (2017)	Korea	Hydraulics	EDP
AGATON (2018)	Philippines	ER	EDP + AMMQ
GAZHELI, (2018)	Non-Regional	Solar and Wind	EDP

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[310] Kim, K. H. P. A. H. K. (2017). Real Options Analysis for Renewable Energy Investment Decisions in Developing Countries. Renewable and Sustainable Energy Reviews.

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