A Quantitative Assessment Of Investment Environments And Risk Mitigation Strategies For Clean Energy Investments in Emerging Markets and Developing Economies

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Abstract

The risky perception of investment environments in emerging markets and developing economies (EMDEs) constrains the flow of capital for deployment of clean energy technologies at scale. These risks originate from the macroeconomic, political and governance environment in a country alongside the market and policy context. Inducing private and development capital in EMDEs requires that influential macro risks are identified and mitigated using domestic policies and international financial initiatives. The co-presence and interaction of different risks create a non-linear impact on market-wide risk perceptions and financing outcomes. This study adopts a quantitative approach to provide insights into the complexity of macro risks in the investment environment and enables an evidence-based exploration of the impact of risk mitigation instruments and customised strategies in EMDE countries. It identifies the relative importance of different macro risks and explores alternative mitigation strategies to address them in different contexts. A multi-instrument strategy can deliver substantial benefits by targeting their distinct contributors of risk and exploiting the inherent interactions among risk elements. When risk mitigation strategies maximally exploit the non-linear interaction effects among the risk factors, their impact will be greatest.

WORKING PAPER

Introduction

Clean energy infrastructure investments have experienced robust growth over the last decade, surpassing global investment in fossil fuels and enabling an increasing share of renewable power in energy systems. In 2024, over $750 billion was invested in clean energy technologies, with solar PV and wind energy projects attracting a substantial portion of this capital (IEA, 2025b). This expansion has been driven by declining technology costs, improvements in supply chain capacity and broad public policy support. The economic case for deploying clean energy has remained robust even in the face of global political headwinds and concerns about energy security. Clean energy continues to reinforce its role as a critical pathway for meeting both growing energy demands and long-term climate and sustainability goals.

Yet, the large-scale deployment of clean energy technologies remains constrained by limited financial resources, particularly in emerging markets and developing economies (EMDEs) (Nijsse *et al.*, 2023). Despite accounting for two-thirds of global emissions at present and facing significant energy demand growth in the coming decades, these countries face substantial investment challenges. Even after excluding China, EMDEs require annual investments of $1.6 trillion by 2030 - five times current levels - rising to $2.1 trillion by 2035 (Bhattacharya *et al.*, 2024). In a resource-constrained global environment, the capacity of public institutions, both international and domestic, to deliver the necessary climate finance is severely restricted. For clean energy technologies that are now mature, the private sector is expected to play a dominant role in meeting countries' investment needs. However, the macro and sectoral environment in EMDEs, creates a high-risk perception in financial markets that constrains financial flows and increases the cost of capital (Ameli *et al.*, 2021). Projects that are perceived inherently risky therefore struggle to raise sufficient capital or must contend with high costs of capital that may render the project unviable unless large returns are guaranteed to cover these costs. Beyond certain thresholds of risk, projects may become simply uninvestible.

The cost of capital for clean energy projects reflects investors' expectations of the returns on their capital over the project's long-running life under varying financial conditions. In EMDEs capital costs are many times higher than in advanced economies. For instance, in 2021, the nominal cost of capital for a utility-scale solar PV project in Brazil was more than three times that of a similar project in the EU or the United States, while India's was more than double (IEA, 2025a). For clean energy projects, which are capital intensive and have substantial costs loaded upfront during the construction stage, financing costs can thus have a strong impact on the cost of generated electricity and overall project viability. As a result, while financing

costs account for about a quarter of the total levelized cost of a project's energy in advanced economies, they can represent nearly one half in EMDEs.

As technological and project-specific risks have generally declined with increased global installation of commercialised clean energy technologies, inherent uncertainties in the macro context have become the dominant sources of investment risk across countries (Persaud, 2023). These originate from the macroeconomic, political and governance environment in a country as well as the specific market and policy landscape for the renewable energy sector. Macro risks are difficult to transfer, diversify or mitigate completely, at least economically, while creating a substantial impact on project outcomes. The joint perception of these risks in a country may render the investment environment to be conducive or otherwise, affecting the flow of investments in renewable energy. This leads to non-linear behaviour in financial markets – distinct configurations of risk create market-wide alignments through the actions of diverse market participants. Many studies have highlighted the range of factors that may affect the perception of investment environment and create barriers to investment from macroeconomic instability, high inflation and interest rates, foreign exchange risks to unfavourable policies and political risks among others (Hu et al., 2018; Ouedraogo, 2019; Emodi et al., 2022). Inducing private and development capital for investments in profitable renewable energy projects, particularly in EMDEs, requires that influential macro risks are identified and mitigated using domestic policies and international financial initiatives.

International financial institutions, such as multilateral development banks and climate funds, have expanded their use of risk mitigation instruments in EMDEs. These instruments reduce key investment risks by transferring them to the underwriting institution, which assumes long-term risk exposure and indemnifies financial investors against negative outcomes. By lowering perceived risks, they encourage private investment that might otherwise remain on the sidelines. Capitalising on their strengths – strong balance sheets, multi-government backing and diversified global portfolios – international institutions also find a natural partnership with private sector providers of financial and insurance instruments. This enables them to align closer to mainstream capital markets, build investor confidence and crowd-in private investment through co-investments and blended finance investments.

However, there are key economic and capacity considerations involved in underwriting investment risks. From an economic perspective, two questions dominate, firstly, regarding the efficiency in underwriting specific risks – to what

extent does transferring risk from financial investors lower risk premiums and ultimately the cost of capital; and secondly, that of effectiveness – to what extent the mitigation of a particular risk mobilises new capital. And from a capacity perspective, providing mitigation instruments for a wide variety of risks requires substantial capital allocations that are capable of covering payouts and projecting financial resilience during times of economic stress. As a result, institutions typically specialise in underwriting specifc risks, so that they can reach the necessary scale to derive portfolio benefits while possessing the reserves needed to manage large exposures. Currently, a variety of public institutions, both international and domestic, and specialised private market players provide a patchwork of mitigation instruments that leaves substantial gaps in terms of both coverage and costs.

However, an important consideration to underwriting investment risks relates to the combined effect created by the co-presence and interaction of different risks on market-wide risk perceptions and financing outcomes. For instance, multilateral financial institutions have typically focused on providing credit protection instruments to mitigate against the risk of defaults on interest payments and capital repayments. While these instruments certainly reduce risk premiums and alter investment incentives, their effectiveness will be limited in the presence of overarching foreign exchange or political risks. For example, a power-purchase agreement backed by a sovereign guarantee may still fail to attract private lenders if exchange rate volatility jeopardises investment returns. As instruments further increase in their diversity and capacity, there is a need to understand the conditions under which these should be deployed to ensure that they are effective in the diversity of conditions that exist across EMDEs. Similarly public policy efforts need to be able to evaluate whether there are any critical gaps in instrument coverage or affordability, which creates a case for public institutions to deploy targeted instruments while ensuring the efficient use of public resources.

Contemporary approaches to investment risk analysis largely focus on estimating the individual sources of uncertainty and quantifying their potential impact on profitability and investment returns (IEA, 2025a). Efforts are then made to reduce the sources of risk at the project level - through tailored contracts and capital structures - alongside identifying commercial alternatives to mitigate risks. Correspondingly, efforts at the policy level focus on market designs, payment contracts and economic instruments that reduce individual sources of uncertainties or shift risks to domestic institutions to improve investment conditions. Investment decisions however play out in a more complex pattern. Co-occurrence and interaction of uncertainties can lead to adaptive and non-linear investment responses. For instance, high political and sovereign credit risks may signal systemic institutional

weaknesses, deterring capital investments, whereas countries experiencing macroeconomic volatilities due to business cycles, but with strong institutional structures may be viewed more favourably. In reality, EMDEs are often characterised by challenging conditions across varied dimensions, requiring integrated solutions that manage multiple, interacting risks through a combination of instruments. Identifying the relative importance of these risks and the appropriate portfolio of instruments is therefore of fundamental importance to devise policies and establish risk mitigation markets.

This study aggregates the risk environment of individual funded clean energy projects to construct an investment space and identify the frontiers that determine the conduciveness of a macro environment for potential investment. Using a data-driven approach, machine learning algorithms are used to model historical patterns of clean energy investments across countries, to generate quantitative evidence on how different risks affect the probability of attracting investments. The adoption of a quantitative method enables the study to establish key relationships and provide insights into the complexity of macro risks in the investment environment that drives non-linearity in investment behaviour. It provides an understanding of the conditions in which mitigating different risks produces a desired level of response and the combinations of instruments that are most effective for risk mitigation across EMDEs.

Methods and Data

The Investment Space

An Investment Space is defined as the aggregate set of investment environments that can be considered suitable for investments. It thus represents the entire spectrum of investment conditions favoured by investors across financial markets for clean energy investments. An individual investment environment, in turn, is described in terms of the risk factors and decision parameters, whose collective influence leads to positive or negative investment decisions. Risk factors characterise the extent of uncertainty in investment outcomes created through changes in the economic, governance and sectoral conditions on potential investments. Each committed investment in a clean energy project is construed to represent an acceptance of its investment environment. The investment space is then an aggregate of such investment environments where projects across a range of macro risk conditions can be financed. This space can be dense in some regions and sparse in some regions based on the relative preferences of financial markets. This relative preference indicates variations in collective risk perception of different risk configurations. It creates non-linearity within the

investment space whereby investment suitability can show non-marginal behaviour based on different levels of risk elements. The investment space thus captures within it the complexity created by the collective response of the markets to investment risks.

The investment space can be represented mathematically as an n-dimensional hypervolume where the dimensions are the different risk factors that describe an investment environment. It can be constructed as a geometric shape in an n-dimensional Euclidean space whose edges demarcate the frontiers of investment suitability – risk combinations beyond these points will not be considered suitable for investment. Features of this geometrical shape, such as the shape and volume provide a quantitative understanding of the investment space in terms of the distributions of feature values and the interactions among them. It embeds within it localized patterns that indicate the behaviour of investments in different parts of the investment space and across specific ranges of feature values. Further, a probability space can be estimated by defining a multivariate probability distribution function on the hypervolume based on the combination of axes values. This probability dimension provides the contours of relative probability within the investment space indicating the non-linear patterns in investment responses across different feature combinations. It thus adds a probabilistic dimension to the topological shape of the hypervolume to reveal how different mathematical features of the investment space impact investment probabilities.

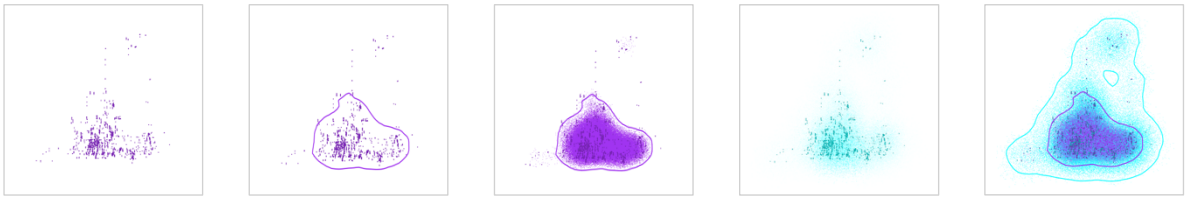


Figure 1: Estimation of the investment space and its probability field illustrated for a two-dimensional or two-risk-factor case. Adapted from Blonder et al. (2018). From left to right: 1. the set of observed data points representing the conditions in which investments have been made, 2. the delineation of a hypervolume shape using the SVM algorithm around the data points, 3. the generation of a random sample of points representing the investment space, 4. the estimation of a probability space around observed datapoints using the KDE algorithm, 5. Overlaying the investment space on the probability field.

Estimation of the Hypervolume and the Probability Space

A continuous n-dimensional hypervolume can be estimated from the discrete points of recorded investment transactions using a one-sided support vector machine (SVM)

algorithm, which learns a classification function that can delineate which combinations across the n-dimensional space are within the hypervolume (Blonder *et al.*, 2014). SVMs are high-performance supervised algorithms that are used for classification tasks, such as dividing the data into different groups or for detecting outliers that do not belong in a particular set. This algorithm constructs a frontier in the hyperspace, defined by the different risk factor axes, that outlines the investment space (Figure 1). The SVM algorithm is calibrated to generate a hypervolume function that provides a tight fit around the observed data. Once this classification algorithm has been learnt using historical investment data and associated risk levels, it can be used to classify regions of the high dimensional space and construct random samples that represent the investment space. An intelligent hyper-elliptical sampling algorithm is used to generate such a random sample, which ensures that the most probable areas for inclusion in the hypervolume are selected in the sample. With a sufficiently large random sample, it is possible to represent the complex dynamics within the investment space in the features of the random sample.

The probability space corresponding to the investment space is estimated by using a Gaussian kernel density estimation (KDE) algorithm that considers the density of observed investment transactions in a specific risk environment (Blonder *et al.*, 2014). This non-parametric method is designed to estimate probability density functions for random variables from finite observations. The KDE algorithm places a Gaussian kernel function on observed data points and assigns probabilities to points in its neighbourhood to generate a padded region around each observed data point. A mixture density of all such kernel functions results in an a hypervolume function that describes the aggregate probability space in terms of the feature space. This function is used to estimate the probabilities for sample points based on their proximity to input data so that points closest to the dense regions of the input data distribution will be assigned high probabilities and the function value would reduce asymptotically to zero with increasing geometric distance.

Overlaying this probability field on the hypervolume shape estimated using the SVM algorithm yields the probability contours of the investment space and describes the relative investment probability across the range of risk configurations (Figure 1). These random points and their estimated point probabilities serve as the building blocks for the estimation of relative cumulative probabilities, which can be used to qualitatively distinguish investment environments into high and low probability regions. The cumulative probability for a point is calculated by partitioning the probability space to include the points that have equal or lower probability than the chosen point, while also including the points that have lower feature values (and thereby lower overall risk) and excluding the points with higher feature values across

all dimensions. The relative cumulative probability is then defined as the total probability contained within the partitioned space divided by the total probability contained within the probability field. This metric serves a key measure of investment likelihood as it indicates the degree to which investment environments will be found suitable for investments by financial markets based on their perception of risk configurations.

Feature Importance and Relationships

A gradient boosting model, XGBoost, is used to model the relationships between empirically derived investment probabilities and the individual risk factors (Chen and Guestrin, 2016). Gradient boosted trees are supervised learning models that learn relationships between features and the predicted variable using an ensemble of simple models, such as decision tress, created by sequentially fitting models on the residual variance of predecessor models. A branching approach enables these algorithms to inherently capture non-linearities and complex variable interactions. They are thus highly suited for tasks where the assumptions related to linear regressions, such as linearity, normality or homoskedasticity are difficult to adhere to and are relatively robust to variable correlation. It is therefore ideal to model the complex relationships between the risk elements in investment environments and their probabilities to obtain investments.

Their effectiveness in modelling variable relationships is tempered by the lack of straight-forward explanations of variable significance. SHAP (SHapley Additive exPlanations) values are used for attributing the investment probabilities to contributions made by risk factors and their interaction terms. These are computed using a game theoretic approach to allocate a predicted value among the constituent variables and interactions based on their average marginal contribution to all potential explanatory models comprising any subset of variables. This provides a quantitative measure of their contribution to investment probability represented as a positive or negative value over a baseline, which can be interpreted as indicating positive, moderate or negative impact on investment probability.

Additionally, scenario analysis is extensively used to compute the investment probability under a range of conditions in order to estimate the effect of mitigation instruments and alternative risk mitigation strategies.

Macro Risk Factors

This study evaluates eight macro risk factors (Table 1) that have been identified across studies to play an important role in investment decision-making for renewable energy projects (Waissbein et al., 2013; Ioannou, Angus and Brennan, 2017; Egli, 2020). These describe different features of the macro investment environment and are used to derive its suitability. As such, while there may be intrinsic correlations, they describe distinct aspects of the system and are used to reveal their interactions and collective impact on investment suitability.

Risk Factor	Description	Indicator
Foreign Exchange Risk	Risk associated with the variability in exchange rates of the domestic currency in which the project revenues are earned against foreign currencies in which investments are made	Annualised value of the standard deviation across a 5-year moving window of the log returns of monthly exchange rates of domestic currencies against the International Monetary Fund's Special Drawing Rights
Interest Rate Risk	Risk originating from the variability in the benchmark short-term interest rates against which loans are typically benchmarked	Annualised value of the standard deviation across a 2-year moving window of monthly changes in annual interest rates
Growth Risk	Risks emanating from cyclical movements in the broader economy of a country where the project is located	Average quarter-on-quarter real GDP growth rate in domestic currency of the previous 4 quarters
Sovereign Risk	Risks associated with the creditworthiness of the country's government where a project is located	A debt service coverage ratio defined as the gross debt position of the government divided by government revenue, which is downscaled by the GDP per capita indicating the revenue raising capacity of the government

Credit Risk	Risks associated with the creditworthiness of the counterparty or the offtaker to whom the power from the project is contractually supplied	The Counterparty Risk score from the RISE indicators produced by the Energy Sector Management Assistance Program and the World Bank
Political Risk	Risks emanating from the stability of the political system in the country where the project is located	The Political Stability and Absence of Violence/Terrorism indicator from Worldwide Governance Indicators compiled by the World Bank
Institutional Risk	Risks created due to shortcomings in the governance, legal and regulatory environment of the project country	Aggregate of four indicators from the Worldwide Governance Indicators compiled by the World Bank: Government Effectiveness, Regulatory Quality, Rule of Law and Control of Corruption
Renewable Energy Policy Risks	Risks originating from the deficiencies and uncertainties in the policy environment for the renewable energy sector	Aggregate Renewable Energy indicator from the RISE indicators produced by the Energy Sector Management Assistance Program and the World Bank

Table 1: Macro risk factors and their indicators

Results

Landscape of Investment Suitability

This study constructs an investment space for global solar investments described in terms of an eight-dimension hypervolume with different risk factor levels as the axes, using investment data spanning 2010-2018[1] (Appendix A).

The investment probabilities across countries globally, based on the corresponding risk levels for 2018, are presented in Figure 2. Highest probabilities are unsurprisingly assigned to advanced economies, boasting high income levels and stable institutions. The inclusion of risk factors pertaining to the energy sector however creates additional differentiation across these countries and provides a

[1] The dataset is currently being expanded to include both solar and wind energy investments for the period of 2010-2024

perspective that differentiates energy sector investments from other infrastructure projects. Among EMDEs, the highest investment probability is estimated for China, which has seen record investments in clean energy technologies over the last decade. Emerging markets for clean energy investments in Southeast Asia, e.g., Vietnam, Thailand and Philippines also record high investment probabilities. However, across South Asia, Sub-Saharan Africa and Latin America the investment probability for most countries is much lower.

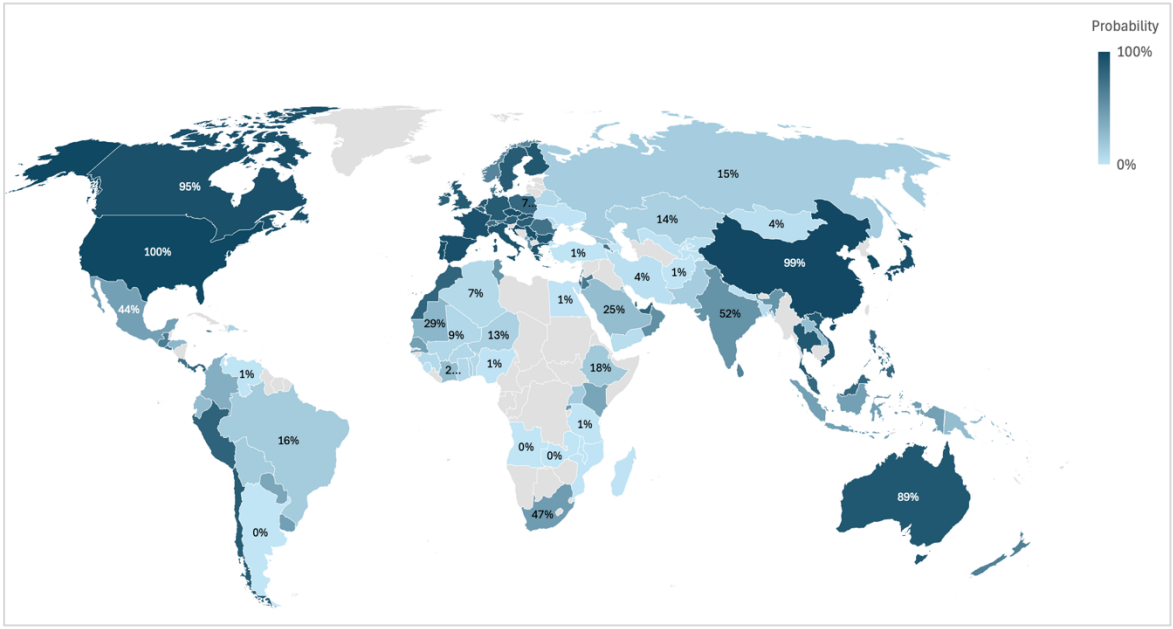


Figure 2: Global Map of Investment Probabilities as of 2018.

Broadly, investment probabilities align with the income levels of countries, with high-income countries estimated as highly suitable and low-income countries the least suitable, as showing in Figure 3. However, within each income class there is diversity of investment suitability, driven by the risk configurations in individual countries.

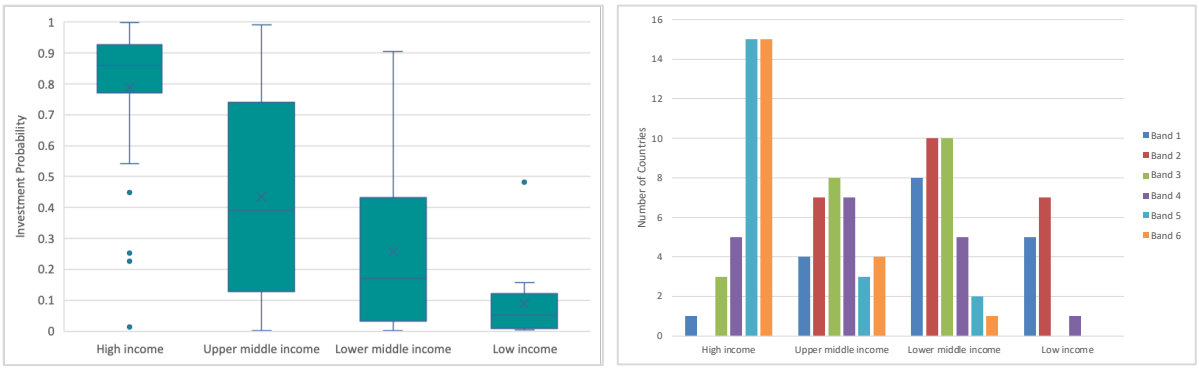


Figure 3: a) Distribution of investment probabilities across income groups of countries. b) Distribution of countries in each income category class across probability bands derived from the distribution of probabilities across the investment space. The bands represent the distance from the mean so that Band 1 has the lowest probability and Band 6 the highest with each band separated by 1σ of probabilities.

This implies that although investments in higher income countries will be considered more suitable in general, there is an opportunity to increase investment suitability through reconfiguration of risks in the investment environment. This is observed through the evolution of probabilities over time for a selection of EMDEs in Figure 4. The investment suitability in India, Indonesia and South Africa has increased considerably during the period from 2010 to 2018, following a rather steady trajectory of improvement. In contrast, Vietnam has seen a marked improvement over a relatively short period that has seen its investment probability soar to very high levels. In the case of Brazil though, the investment suitability has remained low with probabilities increasing only marginally during this time.

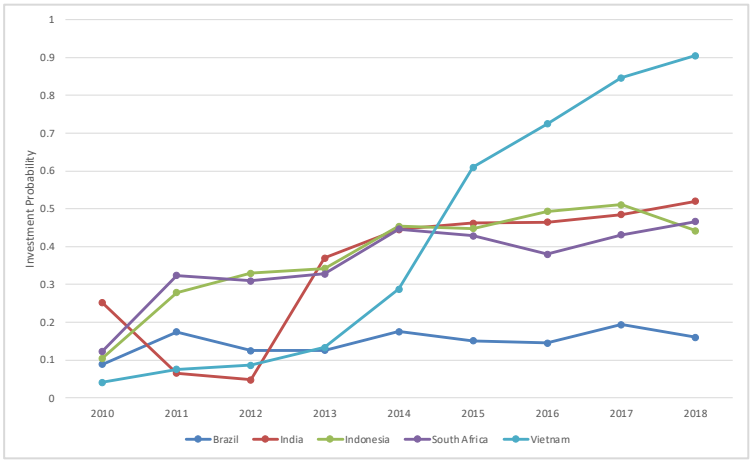


Figure 4: Investment probabilities over time for selected EMDE countries.

Distribution of Risk Levels within the Investment Space

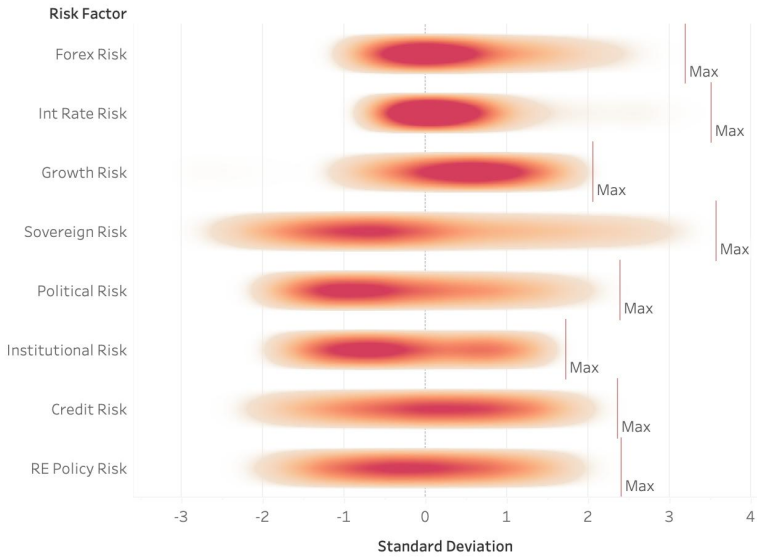


Figure 5: Distribution of different risks in the investment space. Positive values indicate higher risks. Stronger colours indicate a higher level of potential suitability at a particular level of risk based on past investments.

Examining the distribution of different macro risks within the investment space provides insight into their relative acceptability to investors (Figure 5). Different levels of individual risks create non-linear outcomes for investment suitability. This perspective provides information that is beyond a simple description of the risk envelope i.e. a range of acceptable values, by indicating the relative probability of different levels of risk to be considered suitable for investments. Foreign exchange risks, interest rate risks and growth risks are concentrated in the higher risk space (positive values) with a relatively narrow range of highly suitable values (stronger colours) indicating that investment probabilities will decline rapidly as risk levels increase. However, these risks do have long tails that extend towards a high maximum, implying that in certain conditions, higher level of these risks may be acceptable, but with a low probability. Sovereign, political and institutional risks, on the other hand, are centered prominently in the lower risk space, implying that suitable investment environments typically exhibit low levels of these risks. Acceptable levels of sovereign and political risks are spread across a wide range with a greater tolerance for higher risk values, reflecting the environments in some middle- and low-income countries that receive investments to some degree despite high levels of these risks. Growth and institutional risks, meanwhile, have low upper limits indicating limited investor tolerance for low-growth economies and weak governance contexts. Both credit and RE policy risks have wide distributions indicating that investment probabilities decline more gradually with increasing levels of risks. The distributions also indicate that tipping points vary across different risk factors, so that investment probabilities can decline dramatically for some risks even at moderate risk levels.

Risk Interactions

Different risk factors combine to form a risk landscape that determines the investment suitability of macro environments. Investment suitability ultimately depends on how investors respond to collective risk configurations. Risks balance, accentuate, correlate and combine with each other in distinct ways to produce non-linearity in investment outcomes. Tipping points are created through the combined impacts of multiple risk factors. In conditions where a particular risk factor is very high, other risk factors need to balance its impact, but the effectiveness varies across different risks. This is illustrated in Figure 6, for highest risk configurations driven by a single risk factor.

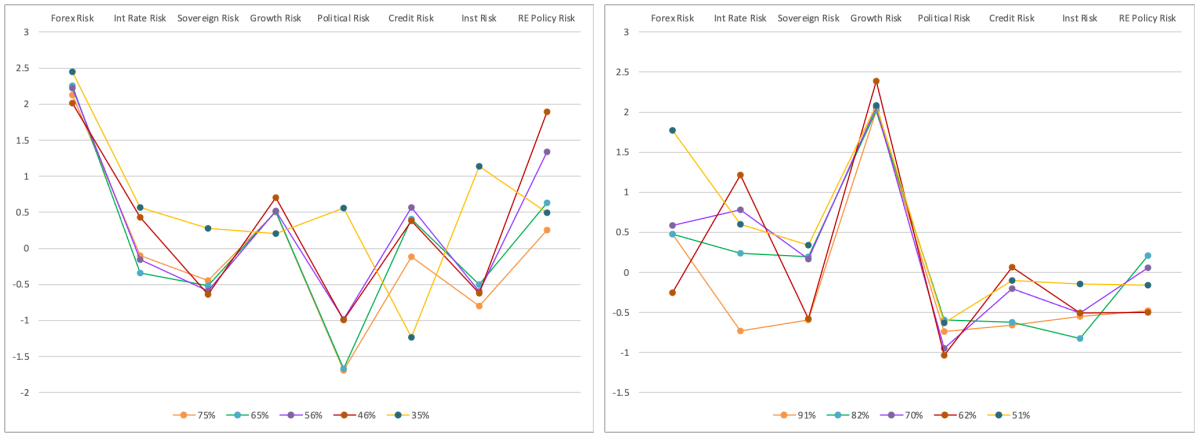


Figure 6: Risk combinations with high levels of a key risk factor but with different investment probabilities due to compensating factors. The chart on the left shows combinations with high foreign exchange risks and the chart on the right shows combinations with high growth risk.

The cumulative effect of risks on investment probability depends ultimately on the levels of individual risk factors and the strength of interactions between them. The general nature of interactions among risk factors is described below.

- Foreign exchange, interest rate and sovereign risks combine to create a higher risk environment for investments producing a strong cumulative effect where investment probabilities decline rapidly as these risks increase in combination.
- A similar interaction is observed between interest rate and credit risks, where the effect appears equally strong. In contrast, a relative smaller effect is observed between sovereign and credit risks, or institutional and RE policy risks where the decline in probabilities is more gradual permitting greater levels of these risks to co-exist at similar levels of investment probability.
- Institutional and political results tend to co-exist – potentially reflecting the environment in EMDEs where elevated levels of these risks, alongside sovereign risk, are widespread across countries.
- Prominent negative correlation is observed between growth risk and sovereign or political risks, indicating that these risks need to balance each other in the investment environment.
- High levels of sovereign credit risk are mitigated by low counterparty credit risk within the energy sector, and a supportive renewable energy policy setup can further improve investment suitability by offsetting the impact of high institutional risk, which typically coexists with high sovereign risk.
- An interesting correlation is also observed between energy sector variables, credit risk and RE policy risks, indicating that they tend to co-exist or are mitigated together through market structures and policies.

Interaction effects vary across different areas of the investment space gaining or losing importance in the context of other risks. Across the investment space, the strongest interactions occur between credit and interest rate risks, foreign exchange and interest rate risks, foreign exchange and sovereign risks, credit and RE policy risks, institutional and credit risks and foreign exchange and credit risks. Identifying these interactions are key for risk mitigation as these combinations can deliver outsized impacts, but their strength and direction can alter. For instance, when foreign exchange risk is high, low interest rate risk produces a strong positive interaction effect for investment probability and moderately positive effects are derived from interaction with low growth and institutional risks. On the other hand, high credit risk produces a strong negative interaction, and high sovereign and political risks also create moderate negative interactions with foreign exchange risk. Similarly in the case of high credit risks, low interest rate risk provides a strong positive interaction effect, with moderate effects coming from lower RE policy and institutional risks, and high foreign exchange risk provides a negative interaction effect.

Risk Factor Importance

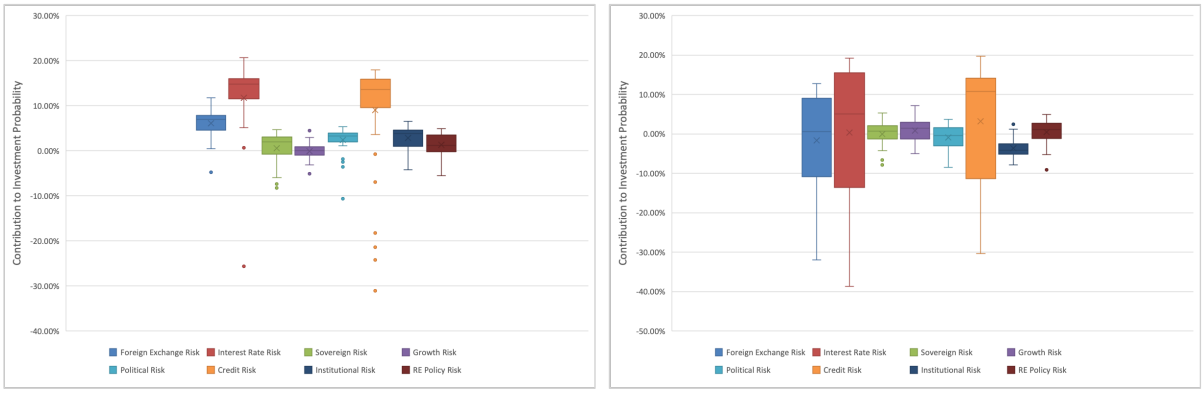
Credit, interest rate and foreign exchange risks make the highest impact on the investment probability of countries, on average. Their distributions are relatively wide, indicating a range of contributions that these make in different contexts given the aggregate levels of other risks, and they display significant interactions with other risk factors. However, their behaviour is influenced by the behaviour of other risk factors as well as the strength of interactions between them across the investment space. The narrow range of growth and institutional risks indicate that investment probability declines rapidly at higher level of these risks thereby creating tipping points. As a result, any reduction in these risks from a higher level creates a greater headroom for other risks and improves investment probabilities non-linearly. As a result of these complex risk interactions, any mitigation instrument employed to reduce specific risks and improve investment probability will create diverse impacts across the investment space. Analysing these impacts reveals the conditions in which reducing specific risks can be the most effective.

The importance of risk factors differs across countries based on their socio-economic context (Figure 7). In high-income countries, the investment probability is driven, on average, by the positive impacts of low risk levels across interest rate, foreign exchange, credit and institutional risks. But countries are differentiated based on their sovereign and RE policy risk levels. As the risk configurations change for countries in the upper-middle-income group, institutional, interest rate and foreign exchange risks, start to create a negative impact, which is counteracted by the

positive contributions of relatively low credit risk, greater economic growth and largely positive renewable energy policy settings. For lower-middle and low-income groups of countries, however, interest rate, sovereign, institutional and political risks create a strong negative contribution to investment probability, while the negative impact of foreign exchange risks reduces. And additionally, in low-income countries the perceptions of the renewable energy sector, both in terms of the credit risk and the policy environment turns strongly negative. The changing configurations of risks across these countries, thus creates different drivers, positive and negative, of investment probability. While it is tempting to attribute the general behaviour of investment probability to individual factors, the role of risk combinations remains paramount – individual factors and their interactions collectively establish investment probability.

a) High-Income Countries

b) Upper-Middle-Income Countries



c) Lower-Middle-Income Countries

d) Low-Income Countries

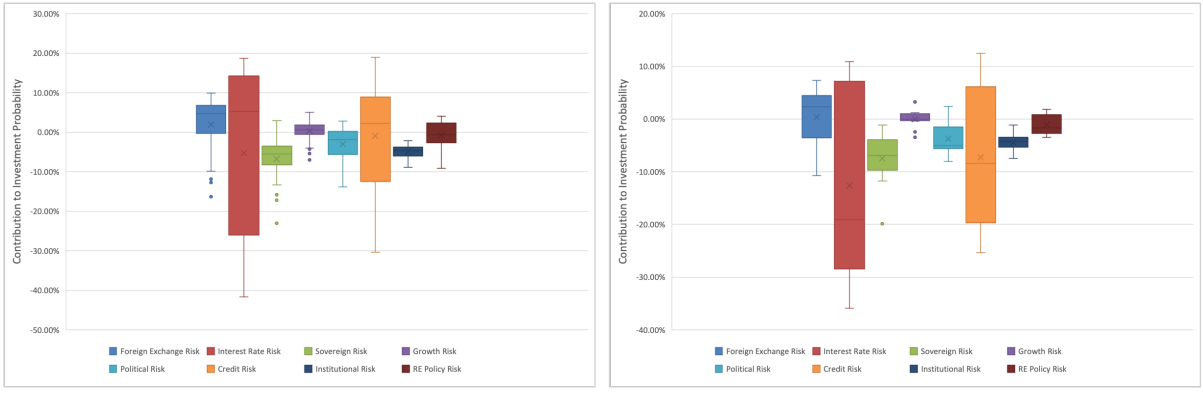


Figure 7: Contribution of risk factors to investment probability across countries. Positive values indicate the positive effect of low risk levels on investment probability and negative values indicate the negative effects. A zero value across risk factors would result in about 46% investment probability, which approximates to a coin-toss impact.

Country Pathways

The nonlinearity created by the compounding and balancing effects between different risks, including higher order effects, provides an opportunity to identify the best path that a country with a given investment environment can take to improve investment probability. This may be achieved by traversing through the investment space to identify the '*closest*' points with the desired investment probability. Doing so should minimise the level of risk mitigation needed across the different risks, which can in turn lower the number of instruments needed and their associated costs. The closest points to a given configuration can be identified by using a distance metric that is computed between the given point and all points within the investment space that meet the desired criteria, for example, to reach benchmark probabilities or to constrain the levels of individual risks.

Consider the case of countries in the sub-Saharan Africa, where despite regional proximity the investment probabilities of countries range from nearly 50% to nearly 0%, as shown in Figure 8. This diversity of investment suitability reflects the individual risk environments in these countries. For instance, high levels of Sovereign, Political, Credit and Institutional risks result in an investment probability of just 9% for Mali. It has very low foreign exchange and interest rate risk owing to its membership of the West African CFA franc currency union, which has a fixed peg to the Euro, and is issued by the Central Bank of West African States (BCEAO) that also sets the policy interest rates for the union. This ensures that currency and interest rate volatility are kept under control. Further, growth and RE policy risks in Mali are also low, but these factors together are unable to balance out the negative effects created by the high levels of other risks.

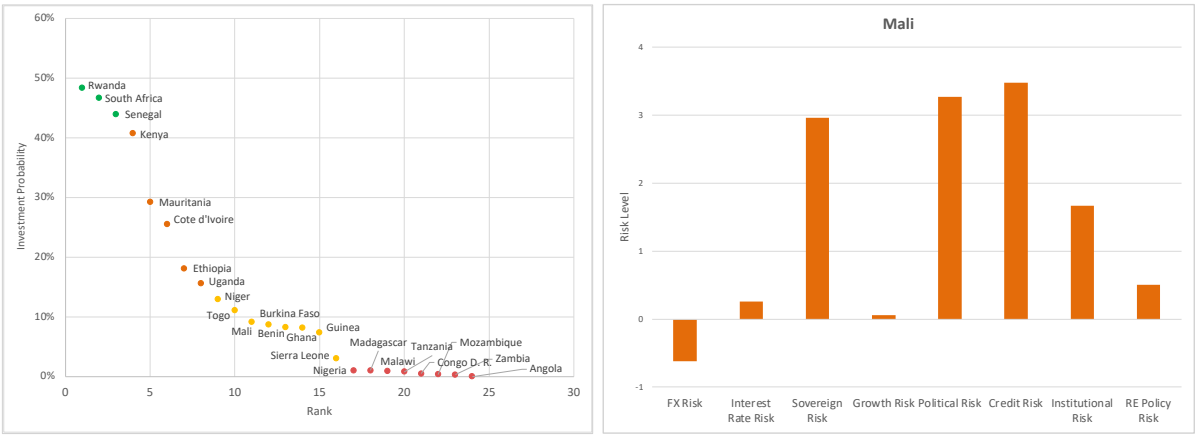


Figure 8: Left: Countries from the sub-Saharan Africa ranked by their investment probability in 2018. Colours indicate the different probability classes within the range of high to low-risk spaces in the complete investment space. Right: The risk levels for Mali across different risk factors.

Therefore, it is clear that for Mali to improve its investment suitability some of these high levels of risks need to be mitigated. There are typically monetary and policy costs associated with mitigation instruments, whether economic or financial, or structural constrains that limit the extent of mitigation for some risks. Thus, it might be beneficial to identify potential mitigation paths that deliver improvements in investment probability while minimising the '*amount*' of total risk mitigation across different risks.

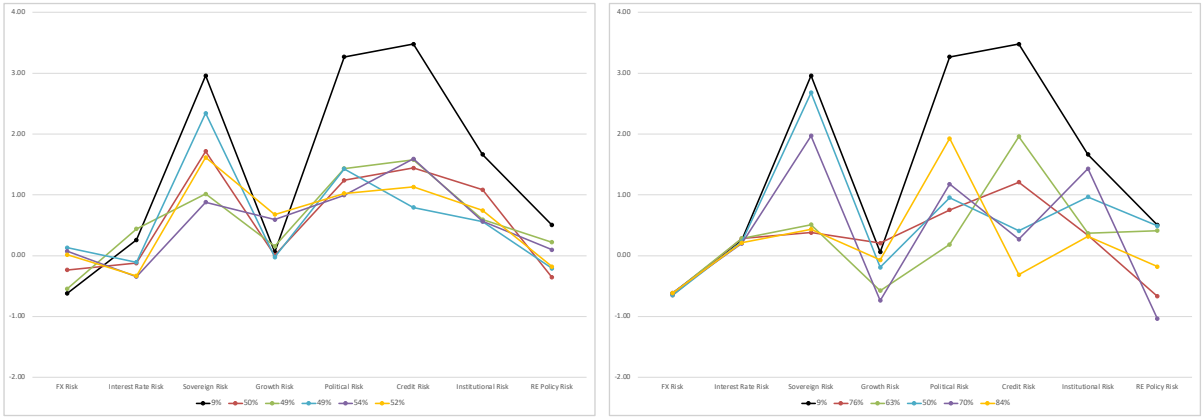


Figure 9: Risk configurations with the desired probability level 49% (matching those of Rwanda) or above, which are in close proximity to Mali's risk configuration (in black) in 2018. Left figure allows FX and interest rate risks to move freely. Right figure constrains their values.

The figures above show the risk configurations from the sampled investment space that are closest to Mali's risk environment in 2018. These have been selected with the aim of achieving an investment probability of at least that of the most suitable country in the region – Rwanda and indicate the potential combinations that can be engineered for investments in Mali to achieve a more favourable investment setting. Alongside low FX and interest rate risk, which is guaranteed due to the currency union, these reveal that reducing political and institutional risks is paramount. These risks alongside sovereign risk are severely inhibitive, and thus only one of these risks can persist at a higher level. However, reducing credit risk is an effective way to balance sovereign risk and similarly the low growth risk compensates for the political and governance conditions, but only to some degree. A supportive RE policy can also be impactful by balancing high institutional risks. This approach thus provides an indication of the potential avenues available for risk mitigation, their interactions and outcomes. Controlling the extent of change needed from the current state, also indicates the extent to which risk mitigation is necessary across different factors. Practically, this translates into identifying the extent of risk mitigation to be achieved using two or three select instruments, considering the feasibility and transaction costs involved.

Risk Mitigation Strategies

Achieving moderate to high levels of investment suitability in EMDE countries is likely to involves the use of multiple economic and financial instruments to address specific risks in their investment environments. However, the mix of mitigation instruments will differ across countries and will correspond with their own unique context. Identifying desirable combinations of instruments and their non-linear impacts on investment probability is crucial for developing a risk mitigation strategy for reducing current and evolving risks. This can be achieved by examining the contributions of individual risks and their interactions on investment probability. Figure 10 shows the macro risks that are driving the investment probability across four countries – Brazil, South Africa, India and Indonesia. Each of these represent an important market for clean energy investments where attaining a conducive investment environment can lead to a rapid growth in clean energy deployment.



Figure 10: Contribution of different risks to the investment probability of four countries: Brazil, South Africa, India and Indonesia across the period of 2010-2018.

These countries present a diversity of conditions where they share some common risk drivers but also have key differences in their investment environment. For both Brazil and South Africa, persistently high FX risk represents a major driver of downward pressures on investment suitability. In most of these markets, on the other

hand, low credit and interest rate risks are positive drivers, with the exception of Brazil where interest rate risk increased in the latter years. And they are all characterised by perceptions of high institutional risks. Beyond this, their investment environments are characterised by different levels of other risks. Low growth risks boost the suitability of India and Indonesia but are relatively higher for the other countries. For Brazil, political risks further impact investment probability negatively, alongside high FX and interest rate risks. For India, sovereign and political risks are key downward drivers. And for the other countries, moderate levels of multiple risks impact investment suitability negatively.

The diversity of risk elements in investment environments across the four countries points to the need for customised strategies involving risk mitigation across multiple fronts. These can be composed of the many instruments that are currently provided for by international and domestic financial institutions for hedging different risks or represent options for policy intervention. For example, for Brazil, a combination of FX and interest rate hedges, which also interact positively with credit risk, and political insurance or guarantees are potential options to consider for improving investment suitability. Of course, an uptick in growth rates or improvement in broad governance quality will have a positive impact on investment probability, but these factors may not be easy to control in the short run. Table 2 below shows the impact of different risk mitigation instrument mixes on the investment probability for Brazil compared to the level in 2018.

Scenario	**Probability**	**Change**
2018 Risk levels	16%	
FX Risk reduced by 1σ	23%	7%
Interest Rate Risk reduced by 1σ	23%	7%
Political Risk reduced by 1σ	19%	2%
Growth Risk reduced by 1σ	17%	1%
FX and Interest Rate Risk reduced by 0.5σ	24%	8%
FX and Interest Rate Risk reduced by 1σ	33%	17%
FX and Interest Rate Risk reduced by 1σ and Political Risk reduced by 1σ	38%	22%
FX and Interest Rate Risk reduced by 1σ and Credit Risk reduced by 1σ	33%	17%
FX and Interest Rate Risk reduced by 1σ and Institutional Risk reduced by 1σ	39%	23%
FX and Interest Rate Risk reduced by 1σ and Growth Risk reduced by 1σ	39%	23%
FX Risk reduced by 2σ and Interest Rate Risk reduced by 1σ	47%	31%
FX Risk reduced by 1σ and Interest Rate Risk reduced by 2σ	43%	27%
FX Risk reduced by 2σ, Interest Rate Risk reduced by 1σ and Political Risk reduced by 1σ	53%	37%
FX Risk reduced by 2σ, Interest Rate Risk reduced by 1σ and Growth Risk reduced by 1σ	57%	41%
FX Risk hedged to 0 i.e. reduced by 3σ	42%	26%
FX Risk reduced by 3σ and Interest Rate Risk reduced by 1σ	60%	44%
FX Risk reduced by 3σ and Interest Rate Risk reduced by 2σ to hedge it to 0	72%	56%

Scenario	Probability	Change
FX Risk reduced by 3σ, Interest Rate Risk reduced by 2σ and Political Risk reduced by 1σ	78%	62%
FX Risk reduced by 3σ, Interest Rate Risk reduced by 2σ and Growth Risk reduced by 1σ	89%	73%

Table 2: The impact of different risk mitigation strategies on the investment probability for Brazil

It highlights the complexity of risk interactions within the investment space that determine the effectiveness of different risk mitigation instruments. In the context of Brazil, reducing FX risk seems like the straightforward mitigation choice but the extent to which it should be mitigated and in what combinations with other risks is a question that requires a nuanced understanding of the potential impact of different alternatives. At its current level of risk perception, reducing FX or interest rate risks by a modest (1σ) level produces a similar outcome in the form of a small improvement in investment probability. However, reducing both together, partially (0.5σ each) or simultaneously (1σ each), produces an outsized improvement in investment probability. FX risk is ultimately the dominant driver so reducing it further from these levels, produces a larger improvement than by reducing interest rate risk. However, the reduction in interest rate risk by 1σ consistently produces a greater benefit alongside FX risk reductions. For instance, when FX risk is reduced by 3σ overall to attain moderate levels of risk, there is a 26% improvement in probability, but with an added 1σ mitigation of interest rate risk, the improvement jumps to 44%. The case is similar for interest rate risk, where a better improvement is recorded in the presence of FX risk mitigation. Reducing both of these to moderate risk levels (±0) produces an overall 56% improvement in investment probability. The case for mitigating other risks such as political, institutional or growth risks is similar. They have a marginal effect until FX and interest rate hedges are in place but provide increasing probability improvements for the same amount of risk mitigation at reduced FX and interest rate risk levels. As mentioned earlier, growth risk is not easily mitigated but needs to be effectively balanced by other risks. However, the table above shows the sizable impact an improved economy can have on the risk perception and effectiveness of FX and interest rate mitigation. For India, Indonesia and South Africa, similarly, a multi-instrument strategy can deliver substantial benefits by targeting their distinct contributors of risk and exploiting the inherent interactions among risk elements.

A portfolio of risk mitigation instruments is therefore needed across a range of developing economies to reduce the specific risks in their investment environment. Considering the low domestic capacity across many of these countries to provide such mitigation options, international public institutions are both increasing capacity of existing facilities and broadening mitigation options by devising new financial instruments. However, given the diversity of risk environments and inherent

interactions there in, it is crucial to identify the key instruments that can have a significant impact across countries. Figure 11 shows the distribution of EMDEs (classified here as countries that are in the middle- and low-income categories) with different levels of risks across risk factors.

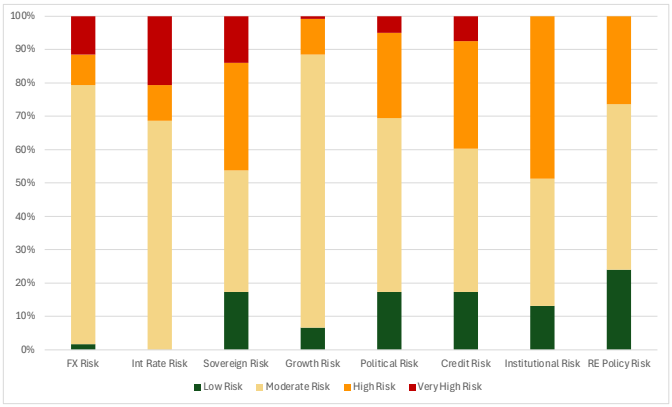


Figure 11: Proportion of EMDE countries with different range of risk levels across the risk factors. The risks are classified into different categories based on the following ranges, Very High Risk: greater than 3σ , High Risk: between 1σ and 3σ, Moderate Risk: between -1σ and 1σ and Low Risk: less than -1σ.

For countries that have one or two risks at a very high level, it is imperative to foremost address these risks otherwise they will continue to dampen the suitability improvements that are delivered by mitigating other risks. Correspondingly, instruments to address these specific risks will need to be at the centre of the risk mitigation strategy deployed in these contexts. Overall though, Sovereign, Institutional, Credit and Interest Rate risks dominate the investment environments in EMDE countries, alongside a few instances of countries with very high FX risk levels. As a result, mitigating any of these risks through a hedging instrument down to a moderate level can be expected to produce improvements in investment probabilities across a range of countries. However, as a result of inherent non-linearities, the biggest gains are observed, on average, in the case of instruments that target interest rate, credit and sovereign risks (Figure 12).

Further, through the effect of positive interactions, a greater gain can be obtained by creating multi-instrument packages, as shown in Figure 13. For instance, when a full interest rate hedging instrument is applied, that reduces the risk levels in every country down to moderate levels of risks (below zero), alongside a partial reduction in FX risk equivalent to 1σ of risk, the highest improvements in investment probability is observed across all EMDEs. And it is substantially larger than the individual impact of fully hedging (to moderate levels) either of these risks. Similarly large improvements are observed when combinations of foreign exchange, interest rate, sovereign, credit and political risk are deployed as part of mitigation strategies across countries (shown in the figure as bars on a colour-scale).

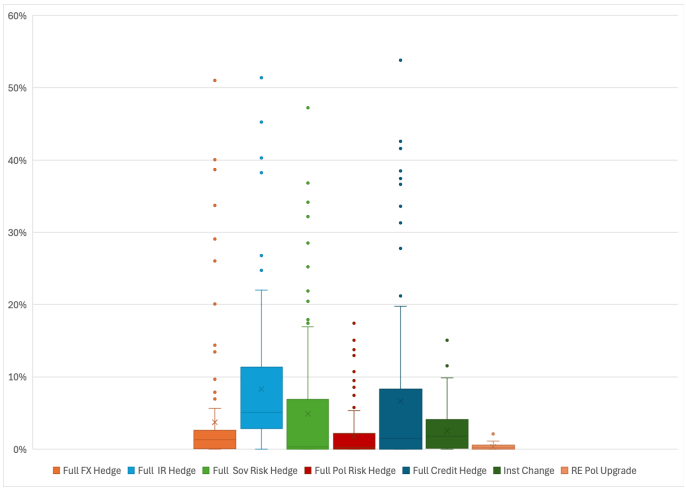


Figure 12: Impact of mitigating individual risks to moderate levels on investment probabilities in EMDEs.

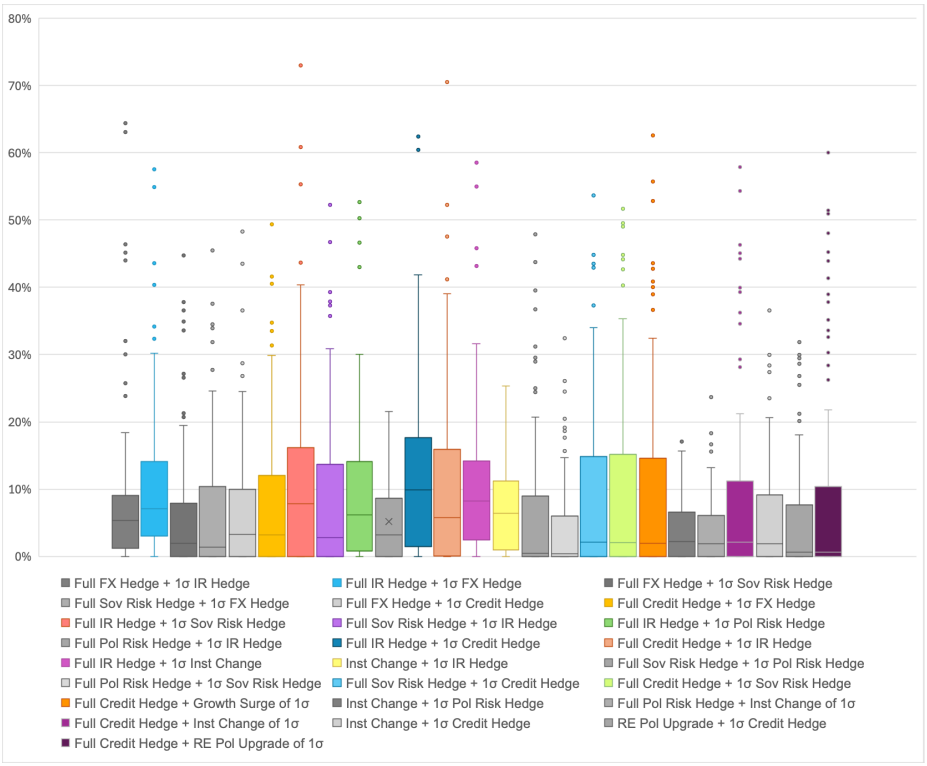


Figure 13: Distribution of improvements in investment probabilities in EMDEs through the deployment of specific risk mitigation strategies. A full risk hedge involves reducing the risk levels of all high risks to zero i.e. moderate levels or applying a 1σ reduction for values at moderately high level (between 0 and 1). A 1σ hedge involves reducing the risk levels by 1 across all values. Strategies with a lower impact on probability (less than 10% at the 75th percentile indicated by the edge of the solid box in the higher direction) have been assigned grey-scale colours.

This figure indicates that there are many possible combinations of instruments to create a strong impact on investment probabilities across different EMDEs. Institutionalising those that are relevant to a large set of countries can ensure that different risk mitigation strategies can be considered at a country-level that provide

substantial benefits to investment suitability based on the given context. However, it is clear that mitigating specific combinations of risks will create a greater impact in most scenarios. Eventually, a customised package will need to be offered to countries with different mixes of mitigation instruments based on the profile of risks in their investment environment. When risk mitigation strategies are able to maximally exploit the non-linear interaction effects among the risk factors, their impact will be greatest.

Conclusion

The measurement of the impact of different macro risks on the suitability of investment environments for clean energy projects is crucial for efforts directed at mitigating investment risks and increasing financial flows, particularly in EMDEs. It can impact the financing strategy of international institutions, domestic policy efforts to improve investment environments, creation of new risk underwriting mechanisms and the structuring of clean energy projects. This study endeavours to understand the significance of different risk factors by adopting an empirical approach, using real-world investment and risk data alongside machine learning models, to establish a functional relationship between macro risk factors and investment probabilities. By adopting a novel conceptualisation of the investment space, as a collective set of conducive investment environments, it uncovers unique insights about suitable risk configurations and the interactions within them that lead to observed investment patterns.

There is a strong relationship between empirically estimated investment probabilities and historical investment flows highlighting the importance of risk perceptions in attracting investments. These investment probabilities are also spread globally according to predictable patterns – high income countries garner the highest probabilities, and these largely decline according to income levels, as weaknesses in country contexts affect investment perceptions. However, there is more nuance to this finding, as different risk factors, particularly related to the energy sector, create differentiation among countries. A brief look at the evolution of investment probabilities also indicates the possibility for reconfiguring investment environments by acting on specific risk factors that improve investment prospects. There is significant non-linearity in the improvements in investment suitability with declining levels of risk alongside the existence of tipping points, which can be capitalised upon to make meaningful improvements to investment suitability.

The construction of a mathematical investment space provides a unique insight into the complexity of market perception, where risks interact to create a collective assessment of an investment environment. Through this quantitative framework, the study identifies the role of varied risk factors in driving investment suitability in different conditions. Broadly, credit, interest rate, foreign exchange and institutional risks create the largest variations in investment probability across a range of conditions. However, the relative importance of different risk factors changes with the context. This is exemplified by the role of different risks across groups of countries defined by their income level. Interest and credit risks retain their position of influence across countries, but investment suitability in low-income countries is driven by the presence of sovereign, political and FX risks, for lower-middle-income countries by sovereign and institutional risks, for upper-middle-income countries by FX risk and for high-income countries by sovereign and RE policy risks. These outcomes reinforce the ideas of non-linearity and localised behaviour of risk factors in the determination of investment probability.

Beyond their individual perceptions, risks combine in complex patterns to shape their aggregate effect on investment suitability. Strong interactions are identified between different risk factors, where they produce non-linear effects either when they are both at high levels or when they balance each other. These include, credit and interest rate risks, foreign exchange and interest rate risks, foreign exchange and sovereign risks, credit and RE policy risks, institutional and credit risks and foreign exchange and credit risks. The intensity of these relationships however gains and loses strength in the context of the overall risk environment. As a result, a localised understanding of risk dynamics can be obtained by examining the behaviour of investment probability in specific sets of conditions. Situations that are most relevant from a risk mitigation standpoint are those when specific risks are high and thereby lead to negative impacts on investment suitability. In these conditions, some risks need to balance the impact of the high-risk factor while others can continue to exist at relatively high levels. A broad risk mitigation strategy targeting the high-risk factor will be most effective when the balancing risks are low or are mitigated alongside the primary risk driver. Correspondingly, the larger gains will be realised through a risk mitigation strategy which reduces a secondary risk that has the strongest interaction with the primary risk driver.

The complex interactions between risk factors imply that a risk reduction strategy will have a varying impact across the entire range of possible investment conditions. However, this inherent non-linearity can be leveraged to effectively alter the investment environment using specific public policy and market instruments in different contexts. Identifying proximal conditions that deliver the desired

investment suitability can help to establish low-effort pathways towards improving investment conditions considering costs and institutional constraints. The diversity of risks in country contexts means that risk mitigation strategies across countries will comprise distinct mixes of mitigation options. Across EMDEs, therefore multiple instruments are needed to mitigate the different risks in their investment environment. A risk mitigation strategy can be devised by identifying the key risks and the strength of interaction dynamics to ensure that a given combination of mitigation instruments are effective in delivering suitability improvements in any given context.

International policy agenda has increasingly focused on using risk mitigation instruments to mobilise finance at scale for clean energy projects in EMDEs. Whether achieved through existing development finance institutions or new multilateral entities, a diverse set of strategies are likely to be more effective in improving the investment suitability across countries. Individual instruments that hedge sovereign, interest rate, credit, foreign exchange and political risks are going to create substantial impacts across EMDEs since these risks are present in high levels. However, mitigating a combination of these risks creates a greater impact on investment suitability across a broader range of countries. Therefore, in terms of mitigation alternatives it is ideal to have mechanisms that can mitigate a diverse set of risks instead of focusing one or two key sources of risk. A country-level mitigation package that accounts for the distinctive characteristics of its risk environment can then be structured as a multi-instrument strategy that maximises the potential for risk mitigation.

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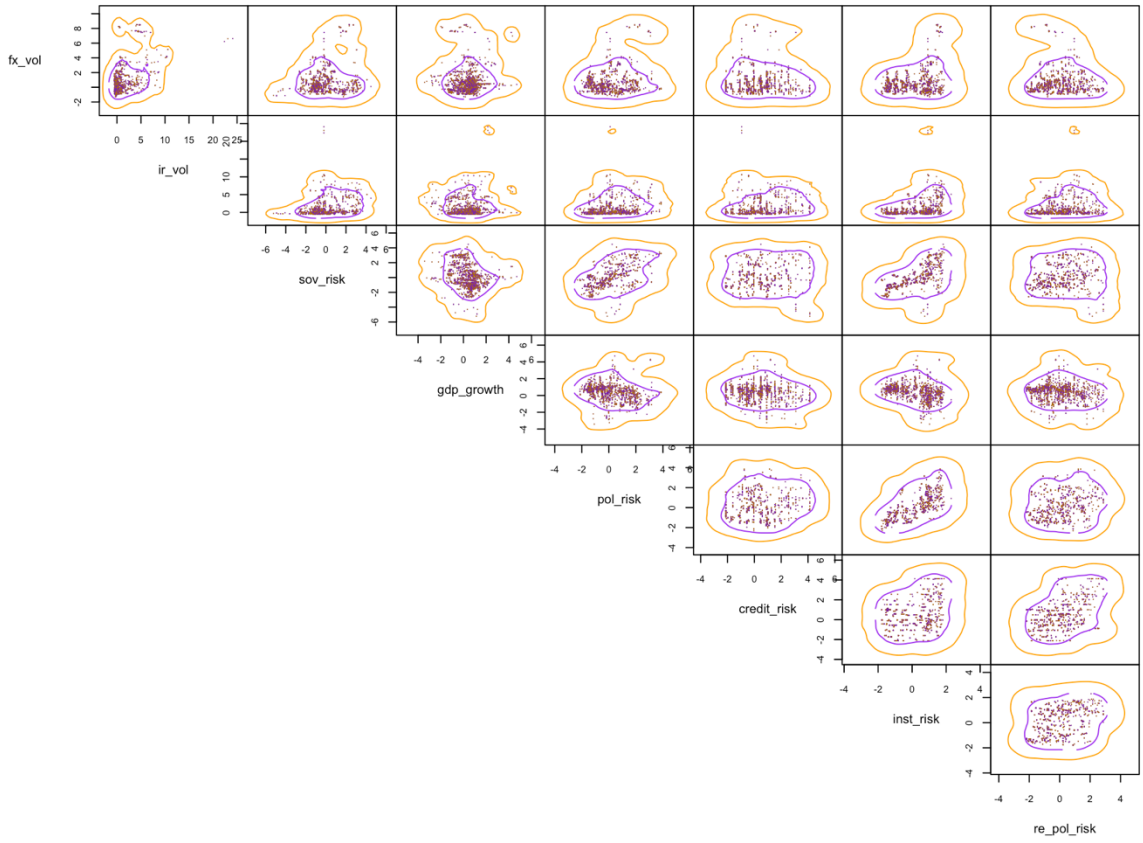
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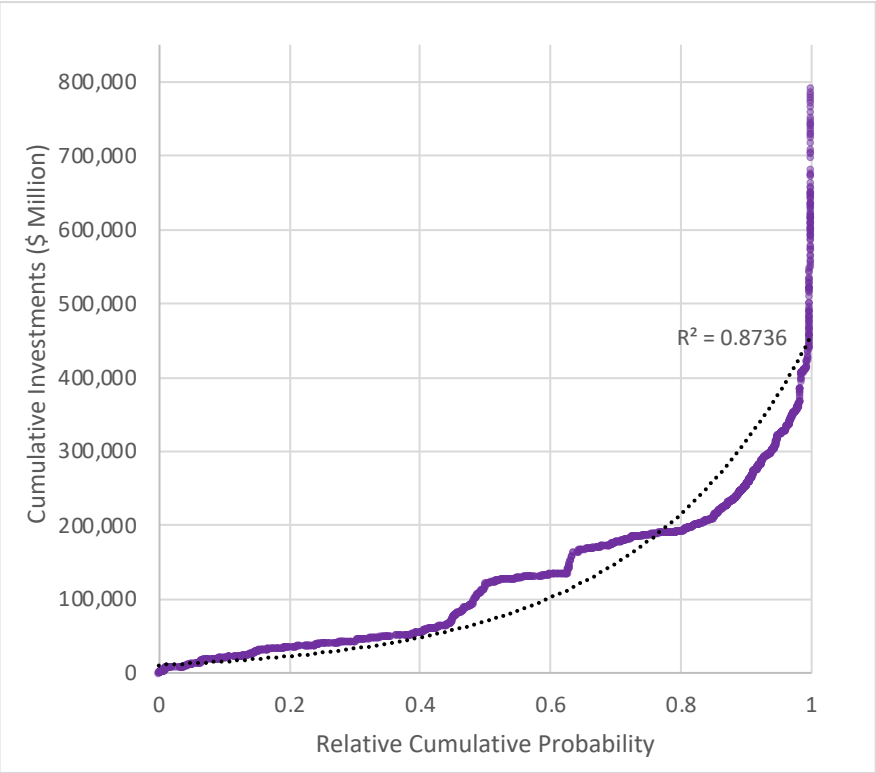
Appendix A

Overlaying SVM-generated Hypervolume and KDE-estimated probability space across all eight risk dimensions:



The purple contour line indicates the hypervolume frontier estimated by the SVM algorithm across each risk dimension. The orange contour line encloses the probability space estimated by the KDE algorithm. Coloured dots represent observed risk levels corresponding to actual investments.

Appendix B


800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Cumulative Investments ($ Million)
R² = 0.8736
0
0.2
0.4
0.6
0.8
1
Relative Cumulative Probability