Exponential Roadmap Initiative

White Paper

A.I. for Clean Energy: Accelerating Project Pipeline Development Globally

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This white paper is a draft proposal to use artificial intelligence tools to support the scale-out of clean energy infrastructure globally. While some digital tools are already being utilised by energy organisations, we believe new tools, for example generative AI, have a genuinely disruptive potential for streamlining regulatory processes such as permitting, assessments and scenario development. The paper aims to explore the potential at a high level and propose an ambitious project to create a platform to use these new tools.

All costs are in USD.

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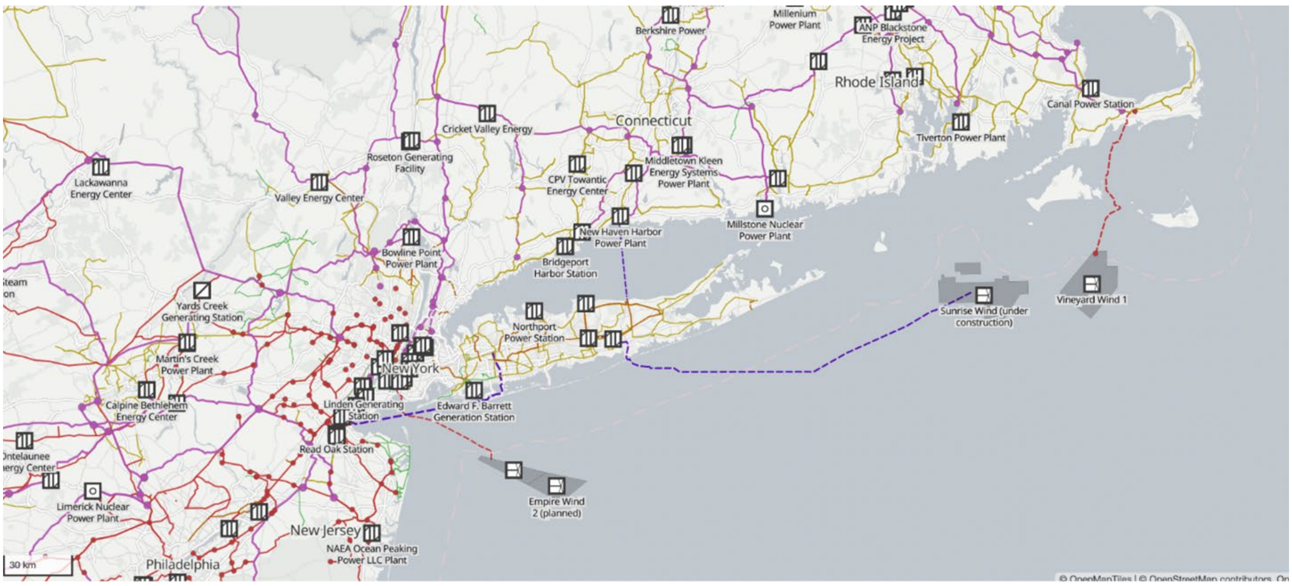


Open Infrastructure map showing New York and New Jersey power generation (existing, in construction and proposed) and transmission infrastructure.

I. Summary

A pipeline of bankable clean energy projects at the scale required to address the climate emergency is still lacking in most countries. The project-development phase for clean energy projects contains many risks for developers and investors. Reducing the time, cost and complexity during the initial project-development phase will contribute to reducing risk and accelerating the scale-out of wind and solar energy.

Project development costs, before construction begins, can account for 2–10% of a project's total budget. With $23 trillion of investment needed in clean energy in the next decade or so, approximately $1.4 trillion will be required just for proposal development. This white paper outlines a proposal for a tool that utilises recent developments in artificial intelligence (AI) to accelerate project proposal development, at the asset level (wind, solar and transmission), at national levels and globally, to reduce time and costs to deployment. Building on existing tools, the goal is to identify assets worth $1 trillion within 12 months and $2 trillion within 24 months, focusing primarily on low- and middle-income economies, based on approximately 30 criteria. We estimate an investment about $3 million is required to develop the tool. We propose a "start-up" mindset and business model to scale this concept.

The climate crisis is moving into dangerous new territory. In the next 24 months, Earth may cross a threshold of 1.5°C warming as El Niño conditions build in the Pacific Ocean. As we write this, meteorologists have announced July as the hottest month on record.[1] While it is likely this extreme will subside with El Niño, there are just six years remaining of a carbon budget aligned with a 1.5°C future.[2] Indeed, the carbon budget is being burned at a rate of 1–2% every month. This means the world is committing to an overshoot scenario where temperatures exceed the highest ambition limit of the Paris Agreement. Given the existential risks of catastrophically destabilising Earth's climate, a priority is the extremely rapid scale-out of wind and solar power.

Annual investment in clean energy must triple by 2030,[3] a point repeated ahead of the COP28 summit by ministers from Austria, Belgium, Canada, Germany, Kenya, Malawi and Vanuatu in the *Financial Times* (12 July 2023). While wind and solar have been scaling rapidly, keeping up the momentum will be a significant challenge. Much of the scale-out is happening in just a few locations: China, Europe and North America. Growth elsewhere is worryingly slow.

The rapid fall in costs of renewable energy in the last decade, ranging between 60% and 80% for wind and solar, coupled with recent political momentum to de-risk clean energy investment for private institutional investors, will help keep up momentum.[4] Indeed, the world is now moving from billions to trillions in investment allocation. However, a known gap is the absence of a pipeline of bankable projects, especially in low- and middle-income economies, to guide equitable scale-out of clean energy. It is a challenge rooted in a combination of factors – technical, political, financial and regulatory. This deficit stems primarily from the absence tof comprehensive planning and policy frameworks to incentivise the development of such projects, a lack of necessary technical expertise and capacity, financial risk perception and high upfront costs associated with clean energy infrastructure development. This makes investment in project proposal development both speculative and costly, potentially 2–10% or more of the total development costs. In addition, the siting of wind and solar infrastructure is largely driven by accessibility and proximity to urban centres, rather than wind and solar availability, land costs or low environmental impacts.[5] There are significant optimisation costs associated with current deployment.

We estimate that the project preparation in the next decade will require $1.4 trillion (*See section III for calculation*). This investment comes at the riskiest part of the project: initiation. Excessive bureaucracy grinds the gears of planning, permitting, land acquisition and transmission roll-out. Unsurprisingly, this deters large-scale investors. Streamlining project preparation – cutting time and cost – is a priority to attract private investors at scale. This is especially important given the gloomy global economic outlook as investors battle with high interest rates affecting the cost of borrowing.

New technologies offer the potential to significantly reduce project preparation time and identify optimised project pipeline scenarios. Recent advances in AI, particularly generative artificial intelligence (GAI), offer powerful new tools to support asset-level project initiation of large-scale wind and solar infrastructure, with the potential to quickly identify a pipeline of bankable projects at a global scale, taking account of environmental and social trade-offs. We believe there is significant potential to couple advancements in AI that improve and accelerate energy scenario development with advancements in large language models (LLMs) such as GPT4 to analyse documents.

Based on earlier analysis,[6] we assess that new technologies (Figure 1) trained on this challenge, coupled with policy improvements (renewable energy zoning, permitting, streamlining environmental assessments) also enhanced by these technologies, could contribute to halving the times in the project development phase of offshore and onshore wind infrastructure and reduce the time by up to 75% for solar deployment. This paper proposes the development of an online tool based on AI architectures to provide a first cut at identifying the asset-level wind, solar and transmission infrastructure needed for a low-overshoot scenario.

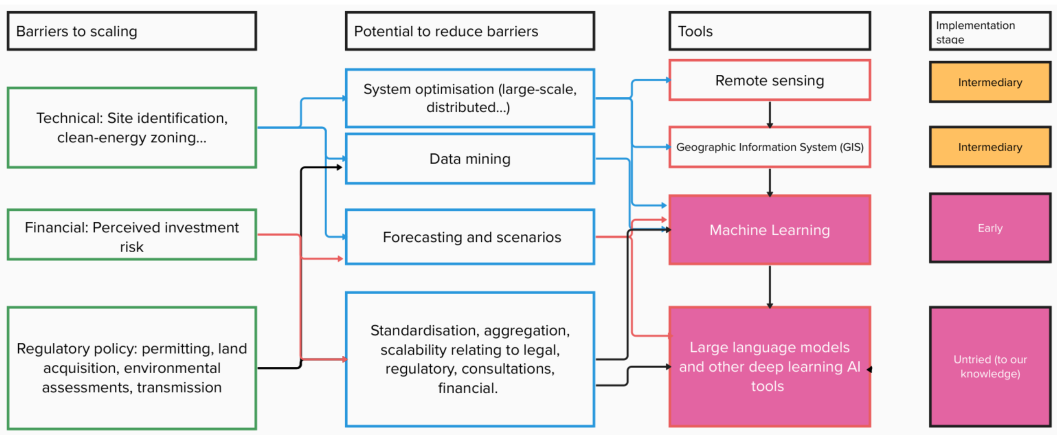


Figure 1. Flowchart summarising some barriers to scaling wind, solar and transmission infrastructure, and the tools to lower barriers.

Building on existing tools, the goal is to identify assets worth $1 trillion within 12 months and $2 trillion within 24 months, focusing primarily on low- and middle-income economies, based on approximately 30 criteria. As AI tools advance, particularly GAI, the tool can expand further to develop systems to support all aspects of project development from proposal drafting and financial assessment to tailored off-the-shelf consultations and auctioning, and from clustering to prediction and scenario proposals. This has the potential to address one of the most important barriers – the cost of capital in emerging markets – by creating more certainty and offering, potentially, a wider menu of financial solutions. Specifically, GAI has the potential to support legal processes including drafting and reviewing proposals, auctions, permitting, assessments and consultations, under expert supervision creating considerable productivity improvements. The proposal could be expanded even further to identify sites for other critical infrastructure for a 1.5–2°C aligned world, for example hydrogen production.[7]

The tool could help identify clean-energy zoning, simplify planning processes and identify clusters of potential projects in regions that could then be reviewed by government and utilities with a landscape-level planning approach. This can help aggregate investment opportunities and create a systems view that could optimise for combinations of mega-infrastructure and distributed energy projects.

The cost of this proposal is estimated at $3 million over two years.

The proposal is neither a panacea for all challenges in the energy transition nor a substitution for the urgent need to de-risk investment, implement stronger policies and rationalise regulations. However, it can contribute to investor confidence, landscape zoning and long-term planning for an energy transformation that is equitable. Through qualitative scenario generation, with “human-in-the-loop” design, it can bridge data and knowledge gaps, with important caveats, and it can help make sense of fragmented, unstructured data to accelerate action. It should be seen as an essential component of a multifaceted response, designed to support other efforts by institutional investors, governments and multilateral development banks to expedite the global clean energy transition. Additionally, the project will build expert capacity at the nexus between AI and energy systems, especially in emerging economies, where interoperability between systems and datasets is challenging and environmental data, for example, may be sparse.

II. Introduction

The world's leading expert on megaprojects is Bent Flyvbjerg, a professor at the universities of Oxford and Copenhagen. He has consulted on over 100 projects costing $1 billion, or more. In his remarkable book *How Big Things Get Done* (Penguin Random House, 2023),[8] he argues that a surprising number of megaprojects, from the Sydney Opera House to high-speed rail to nuclear power stations to Olympic stadiums, come in late and over budget. Shockingly over budget. With shocking regularity. But three megaprojects do not: wind, solar and electricity transmission. They buck the trend. Done well, these projects can scale extremely rapidly and stay within budget. Their simplicity and modular nature are key to exponential scaling.

This is the good news. Wind, solar and transmission technologies need to scale faster – much faster – than they are today. We need to find ways to reduce all friction to scaling. Can other technologies such as machine learning and GAI help? We think there is more good news here.

There is room for more optimism. One of the most significant barriers to progress is the perceived investment risk of wind, solar and transmission mega-infrastructure projects. This perceived risk is especially acute in low- and middle-income countries. In 2023, new political momentum is spurring reform of the international financial system (World Bank, International Monetary Fund, etc) to de-risk investment in climate mitigation. If successful, this has the potential to open the floodgates of investment from billions to trillions of dollars. If and when this materialises, the world must be prepared to scale rapidly.

We need good news. The window of opportunity to secure a liveable future on Earth is closing, according to the 2022 Intergovernmental Panel on Climate Change (IPCC) Working Group 2 report.[9] Without deep emissions cuts immediately, within a generation billions of people will be living in environmental conditions that today we would consider at the edge of habitability (the human climate niche).[10] Recent research indicates that at 1.5°C the world is at risk of crossing multiple high-impact tipping points, including the irreversible collapse of the Greenland Ice Sheet and West Antarctic Ice Sheet.[11] The remaining carbon budget for 1.5°C is approximately 250 billion tonnes of carbon dioxide (2 July 2023).[12] We are exhausting the budget at a rate of about 1–2% every month. Current national legislation coupled with recent credible commitments, that is where there is an independently assessed high confidence of delivering on these commitments, results in a catastrophic 2.4°C of warming by 2100.[13] The stakes could not be higher. This is an emergency situation.

The next decade will need to see the fastest economic transformation in history towards an economy run almost entirely on clean electricity. Wind and solar power, combined with a scaled-out transmission system, are expected to form the backbone of the new energy system. This paper outlines a solution to address one glaring problem: there is no global pipeline of bankable wind and solar projects that takes us close to stabilising global temperature at a "low-overshoot scenario" of, say, 1.6°C–1.7°C.

Recent developments in AI create the potential to identify and map, at an individual asset level, the clean energy infrastructure for a low-overshoot scenario.[14–16] Such a system could support optimisation of infrastructure (wind, solar and transmission) for criteria related to, for example, equity and justice, energy access, investor return or reduced environmental impact. This paper proposes the development of an online tool based on AI architectures to identify the asset-level wind, solar and transmission infrastructure needed for a low-overshoot scenario. The goal is to identify assets worth $1 trillion within 12 months and $2 trillion within 24 months, focusing primarily on emerging markets and least-developed economies. We will highlight the key potential technologies that could be mobilised behind this initiative, an initial sketch of the criteria for identifying sites based on various scenarios for optimising outcomes, and an outline of the requirements needed to deliver a minimum viable product (MVP). The MVP will focus on asset-level site identification, initial site assessment and financial assessment, including return on investment. The proposal will explore the role of GAI to support all aspects of project development, from supporting the project management process to proposal drafting and financial assessment to tailored off-the-shelf consultations and auctioning to streamlined permitting and other legal processes. The proposal could be expanded even further to identify sites for other critical infrastructure for a low-overshoot world, for example transmission or transport. Such a tool will have multiple purposes: reduce time to develop projects at the asset level, accelerate knowledge transfer and increase transparency.

Scaling wind, solar and transmission

Electricity makes up about 20% of the world's total final energy consumption. The electricity sector accounts for about 59% of all the coal used globally, 34% of natural gas and 4% of oil. In total, this is over one-third of all energy-related carbon dioxide emissions.[17] The energy sector has come further than any other sector to address climate change. The share of renewables in electricity generation has now reached 28%. In 2022, some 300 gigawatts (GW) of renewables were added globally, accounting for 83% of new capacity compared with the remaining 17% made up largely of fossil fuel and nuclear additions.[3]

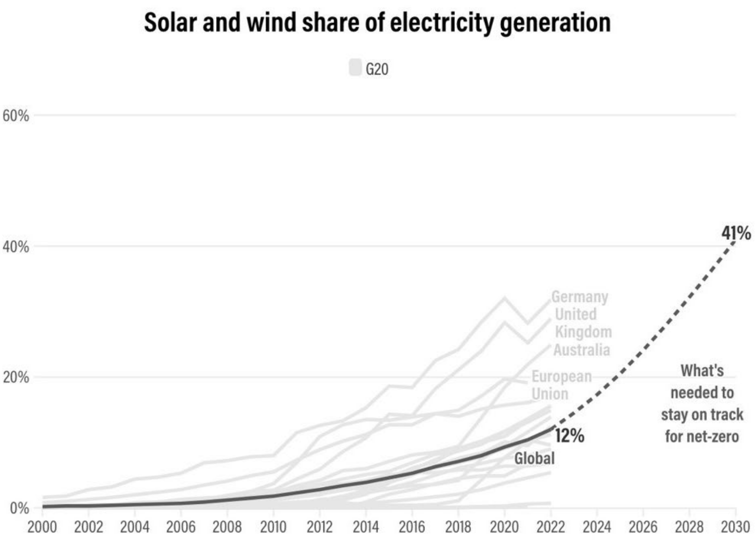
Investment is scaling exponentially. In 2022, investment in renewable energy reached $0.5 trillion in 2022.[18] But this is only around one-third of the average investment needed each year in renewables under the 1.5°C scenario of the International Renewable Energy Agency (IRENA). Furthermore, the global picture masks a surprisingly large divide: 85% of global renewable energy investment benefited less than 50% of the world's population. Investment in renewable energy is concentrated in a handful of regions: China, the United States and Europe. Africa accounted for only 1% of additional capacity in 2022.3 Investments in off-grid renewable energy solutions in 2021 amounted to $0.5 billion – far below the $15 billion needed annually to 2030.[3] Major barriers include the sky-high cost of finance, lack of institutional capacity, perceived risks relating to the planning processes, and geographical bias of developers – "we go where we know". All of this points to the fact that the global clean energy system is not homogenous. Rather, it is a heterogenous mix of different playing fields and different rules.

Strong growth is continuing in 2023. According to the Renewable Energy Market

Update (June 2023) by the International Energy Agency (IEA), global renewable capacity additions are set to hit 107 GW, the largest ever absolute increase, to more than 440 GW by the end of the year. For comparison, this is more than the entire installed power capacity of Germany and Spain combined.[19]

Solar photovoltaic (PV) capacity (utility-scale and small distributed systems) accounts for two-thirds of this year's projected increase. Higher electricity prices and the war in Ukraine's impact on energy security is benefiting solar PV, especially for residential and commercial systems, which can be installed rapidly. Distributed small-scale PV is on track to account for half of this year's overall deployment of solar PV.[19]

Following two consecutive years of decline, onshore wind capacity additions are on course to rebound by 70% in 2023 to 107 GW, an all-time record amount.[19] This is mainly due to the commissioning of delayed projects in China following last year's Covid-19 restrictions. Faster expansion is also expected in Europe and the United States as a result of supply chain challenges in 2022 pushing project commissioning into 2023. But offshore wind growth is not expected to match the record expansion it achieved two years ago, due to the low volume of projects under construction outside China.[19]



Source: Author, based on historical data from Our World in Data, BP and Ember. Global target from IEA.

SYSTEMS CHANGE LAB

Figure 2. Wind and solar energy are scaling rapidly. The challenge is now to reduce friction to keep up the momentum in order for infrastructure to triple by 2030, and continue growing rapidly beyond this date. However, the majority of the scale-out is happening in just three regions. The opportunity is to streamline knowledge exchange from these regions to elsewhere (Data: Systems Change Lab, July 2023).

By 2030, annual deployment of some 1,000 GW of renewable power is needed to stay on a 1.5°C pathway (just over three times the annual installed capacity in 2022). Both the volume of renewables and their share in the energy system need to grow substantially. Breaking this down to the key technologies, compared with 2020, by 2030 the world needs seven times more solar (installed capacity 5,200 GW), four times more onshore wind (3,000 GW) and 11 times more offshore wind (380 GW), according to IRENA's World Energy Transition Outlook 2023.[3] Of course other technologies are needed too (hydro and nuclear), but these are significantly more expensive and do not have the extreme modularity – and thus the scaling potential – of wind and solar. Modularity is key to the dramatic fall in price of these technologies and it is key to rolling them out at the breakneck speed required. Other less mature technologies also offer modularity, for example wave and floating wind power.

Growth in wind and solar is driven by policy support (at the national and supranational level legislating for net-zero-by-2050 and credible policies to achieve it), energy security concerns, improved technological performance and rapid declines in cost compared with fossil fuel alternatives.

III. The pipeline problem

While many countries are legislating to become net-zero by 2050 or thereabouts, success depends on ambitious wind and solar project pipelines aligned with a low-overshoot world. Large-scale installations can take up to 10 years from idea to operation. The world must find ways to shorten this timeline dramatically. Of course, China, Europe and North America have more extensive pipelines of wind and solar projects than many other geographies but even these regions are far from having complete pipelines.

In 2022, the Independent High-Level Expert Group on Climate Finance concluded that "the starting point for a big investment push must be strong country leadership and actions...anchored in sound and convincing long-term strategies" and that "programmes need to be translated into concrete pipelines of projects".[20] But it also said that transaction costs to moving at the necessary scale and speed – especially to crowd in investors – require targeted action to reduce the cost of capital and tackle real and perceived geographical-, technology- and project-specific risks in low- and middle-income economies. The group argues that the key risk in the first phase of any project development is the "lack of funding for project preparation and development".

"Project preparation is a critical part of translating opportunities into realised investments. Limited funding and capacity for project preparation – or difficulty accessing existing project preparation facilities – is a major constraint to scaling private investment in emerging markets and developing countries. Scaling and streamlining existing facilities (such as the Global Infrastructure Facility) and exploring new project preparation tools and funds (e.g. CDPQ's $1.7 billion facility or the philanthropically funded SEACEF initiative for South East Asia [VRI, 2020]) and linking this capital to public sector country platforms will be critical to accelerating the development of a high-quality project pipeline." [20]

The authors say the weakness of the pipeline sends a signal to the private sector that the scale of investable projects is often not sufficient for large investors to commit as this comes with significant upfront costs, which may not be recouped if the pipeline does not materialise.

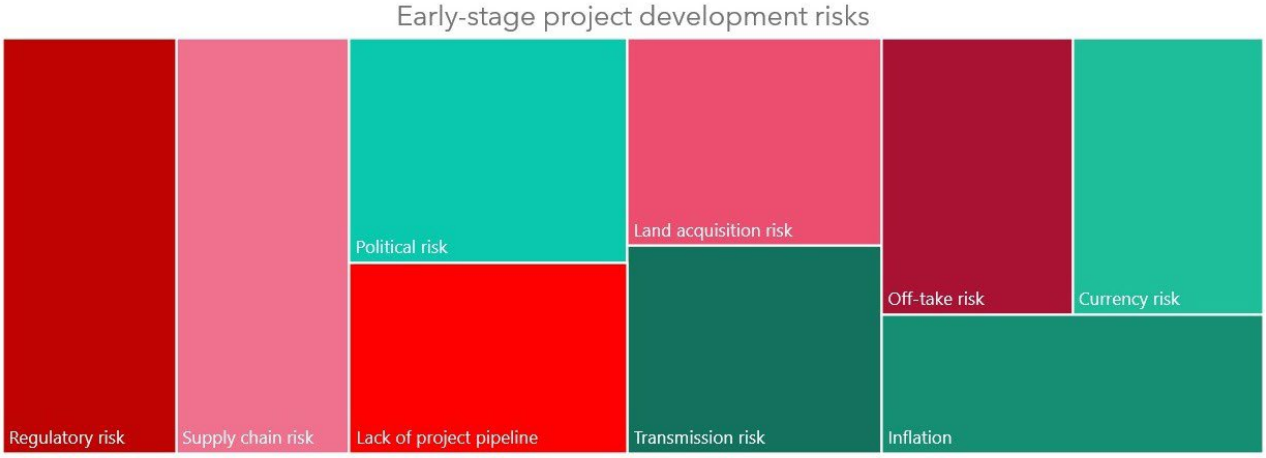


Figure 3. Risks preventing rapid scaling of clean energy (updated and adapted from the International Energy Agency). The risks are interrelated and are more acute in developing economies.

The IPCC's Sixth Assessment Report (Working Group 3) lists barriers to the deployment of commercial finance for sustainable energy: *home bias (developers of infrastructure and investors prefer to invest in geographies and countries they know well)*; country indebtedness levels; *limited institutional capacities*; limited local capital markets; unattractive risk-return profiles, in particular due to missing or weak regulatory environments consistent with ambition levels; limited institutional capacity to ensure safeguards; *standardisation, aggregation, scalability and replicability of investment opportunities and financing models; and, a pipeline ready for commercial investments*. [emphasis provided by the authors].

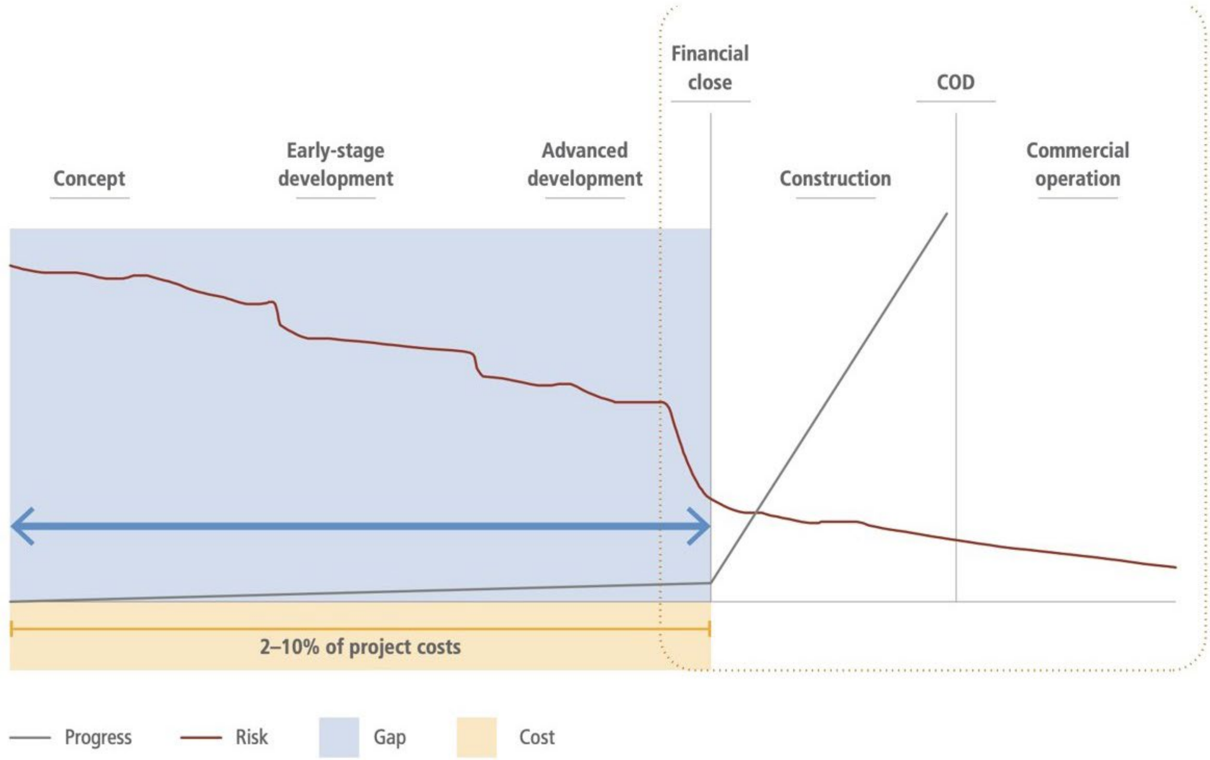


Figure 4. The initial stages of project development account for 2–10% of the total project costs but come at the most high-risk development stage of the project (Intergovernmental Panel on Climate Change Sixth Assessment Report, Working Group 3, p.1064[9]).

The IPCC splits the stages of project development into three parts: project preparation (concept, early-stage development, advanced development), construction and commercial operation. The **IPCC states that the project-preparation phase can consume 2–10% of a project's costs** (see Figure 4). It is unclear how the estimation is derived; however, this is in line with other published estimates. The Global Infrastructure Outlook report, for example, notes that **"Past studies have pegged project preparation costs at between 5–12% of investment needs."**[21] This estimated range relates to all types of sustainable infrastructure projects required to meet climate goals, including, for example, transport. low- and middle-income economies tend to have significantly higher project preparation costs – towards 10% – than developed economies.

The IPCC's Working Group 3 (2022, p.300) states that the investment needs in the electricity sector for a low-overshoot scenario are "on average $2.3 trillion per year over 2023 to 2052" with the bulk of the investment needed in medium- and low-income countries.[9] Taking the global picture and *looking at the next 10 years*, based on IPCC data we can say about **$23 trillion is needed for the renewable energy transition**. How much will be spent on project development? **Taking a midpoint between 2% and 10%, we can say that 6% of $23 trillion, namely $1.4 trillion**, will be required for project development (concept, early-stage development, advanced development) before a spade is put in the ground. This aligns with the [Finding the Pipeline] report published by the New Climate Economy, which estimates that project preparation costs for a clean energy transformation range from $1–2 trillion out to 2030.

Not only is this a significant sum, coming at the initiation stage, it is by far the riskiest part of the entire investment, making it the most difficult to secure. Success in developing rock-solid convincing proposals with healthy returns on investment will unlock the remaining 94% of the budget. Given the importance of this first trillion in unlocking private finance, any efforts to cut time and costs will have a disproportionate impact.

The project pipeline issue was raised by leaders at the Summit for a New Global Financing Pact in June 2023. Notably, the Bridgetown Initiative,[22] spearheaded by Barbados Prime Minister Mia Mottley, emphasised the need for "project preparation support" to strengthen the pipeline of viable climate projects. Beyond Mottley, the International Energy Agency has echoed these concerns, highlighting the "lack of project pipeline" as a significant risk.[23] Similarly, the World Resources Institute (WRI) has published Our Solar Future — Roadmap to Mobilize USD 1 Trillion by 2030, which identifies the absence of bankable project pipelines as a barrier to scaling renewable energy.[24]

Of course, while major infrastructure projects have a greater potential to attract large investors, there is a huge potential for distributed clean energy infrastructure with different ownership models. This has the potential to disrupt the energy sector, and bring with it substantial social benefits, empowering local communities and providing affordable, clean energy to all. But this type of infrastructure can struggle to attract investment at scale. An integrated platform for infrastructure development could allow for optimisation for distributed clean energy, including off-grid, or at least a more balanced approach.

Finally, the project pipeline is not the only challenge at the project development stage (see Figure 3). Other barriers include:

Political barriers

- Lack of political will and cross-party agreements
- Short-term political horizons
- Corruption
- Contradictory political incentives
- Regulatory uncertainty and inefficiencies relating to permitting, environmental assessments, etc

Financial barriers

- High interest rates
- Cost of borrowing in low- and middle-income economies

Developer barriers

- Home bias – developers tend to stick to markets they know well, namely the West and China
- Supply chain challenges
- Connection to grids

Marie Lam-Frendo, CEO of the Global Infrastructure Hub, has described the priorities to reduce friction to scaling as follows: depoliticise clean energy infrastructure by removing it from short-term political cycles, *build project preparation capability in middle and low income countries to help reduce the cost of preparing projects to help de-risk investment and encourage private investors*, and address debt issues [our emphasis added]. In summary, efforts to expand the project pipeline for wind, solar and transmission systems, and reduce time from concept to construction, will accelerate the energy transformation and, crucially, keep a low-overshoot scenario alive.

IV. The moonshot: building a pipeline

In this section we explore the project preparation stages for wind and solar and summarise how technologies can be used to support decision-makers and developers.

Technologies are opening up new possibilities to cut time and costs during the project development stage

Many studies show it is technically feasible and economically viable to achieve a global energy system running primarily on 100% renewable energy, dominated by wind and solar power.[3,25] But progress has often been uneven. Surprisingly, as Dunnett et al. (2020) note, "Despite this widespread interest in solar and wind, policy makers and governments have struggled to maintain robust geospatial information on the rapid expansion of renewable energy technologies." Spatially explicit national data are only available for a few countries and may not always be open access. At the global scale, the IEA, IRENA and others provide data but this is usually *spatially aggregated* and summarised at the national scale. Transparent, spatially explicit, global data of solar and wind installations would be useful for developers, investors, governments and non-governmental organisations to track progress and contribute to accelerating action.[26]

Beyond Geographic Information System (GIS) data, new tools are showing promise for climate mitigation. In 2021, Milojevic-Dupont and Creutzig noted that "The emergence of big data and machine learning methods enables climate solution research to overcome generic recommendations and provide policy solutions at urban, street, building and household scale, adapted to specific contexts, but scalable to global mitigation potentials."[16]

Figure 5. The Global Energy Monitor online tool (snapshot from 7 July 2023) showing solar assets (photovoltaic and solar thermal) in various phases of operation: pre-construction, under construction, in operation, shelved, mothballed, retired or cancelled). The tool also tracks wind, bioenergy, coal, oil, gas, hydropower and thermal assets.

Mapping future infrastructure

Renewable energy site selection is a complex problem that requires considering many factors, including current and future weather patterns, geographical attributes, social impact, ecological impact, proximity to infrastructure, and regulatory constraints. There is now a plethora of online data about existing renewable energy assets. The Global Energy Monitor (GEM) (Figure 5), for example, provides pinned location data of many large installations, and geographic location data on some planned installations. The Open Infrastructure Map (Figure 6) uses the OpenStreetMap platform to display transmission data and asset-level renewables (including assets under construction and planned). And the Global Infrastructure Hub keeps a limited database of infrastructure projects including some in the pipeline. Despite the great availability of public, private and mixed data providers in this space, quality assurance is still a top priority that must be addressed. AI tools can combine diverse data sources and utilise multi-fidelity frameworks to support decision-making.

Figure 6. Open Infrastructure Map on the OpenStreetMap platform providing transmission and asset data (including, for example, offshore wind in construction and planned. Here shown major planned infrastructure around New York).

While GEM and other tools identify existing sites, several new tools explore potential sites for wind and solar assets. One tool of particular interest is the Multi-criteria Analysis for Planning Renewable Energy (MapRE) developed by a team at the University of California in Santa Barbara with the Lawrence Berkeley National Laboratory. The stated aim of the online tool is to “provide a framework for the systematic identification and valuation of areas for renewable energy development—focusing mainly on solar and wind technologies—for developing countries”. The developers hope that "by providing government officials, regulators, utilities, and other stakeholders information about multiple siting criteria for possible renewable energy zones in the form of reproducible planning tools, the MapRE initiative [can] improve the planning of low-carbon, cost-effective, socially and environmentally responsible energy systems. Currently, the emphasis is on utility-scale solar and wind zones, but the spatial models may also be applied to identify off-grid development."

MapRE forms the basis of another tool, the Renewable Energy Zoning (REZoning) tool, developed by the World Bank's Energy Sector Management Assistance Program (ESMAP) with partners. The tool combines spatial analysis and economic calculations to give users insights into the technical and economic potential of renewable energy resources for all countries. It is described by the developers as "an interactive, web-based platform designed to identify, visualise, and rank zones that are most suitable for the development of solar, wind, or offshore wind projects. Custom spatial filters and economic parameters can be applied to meet user needs or to represent a specific country context."

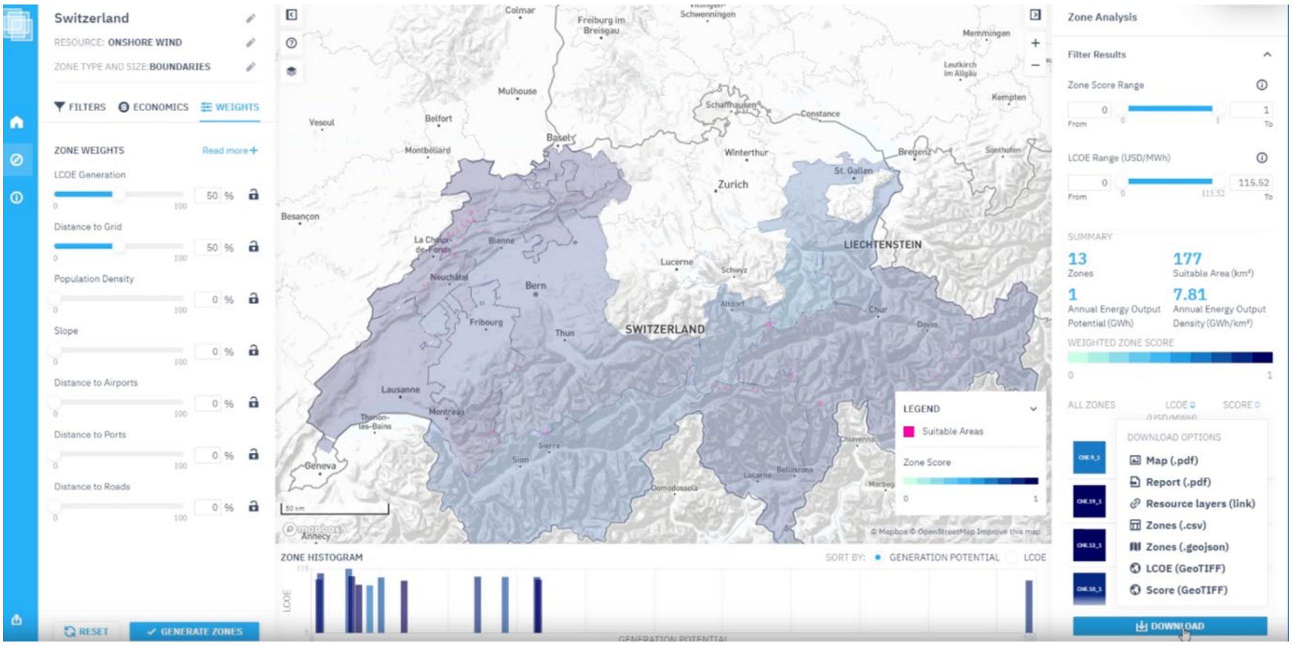


Figure 7. REZoning tool: screenshot of wind potential analysis in Switzerland including suitable locations based on a range of criteria, including the levelised cost of electricity (LCOE).

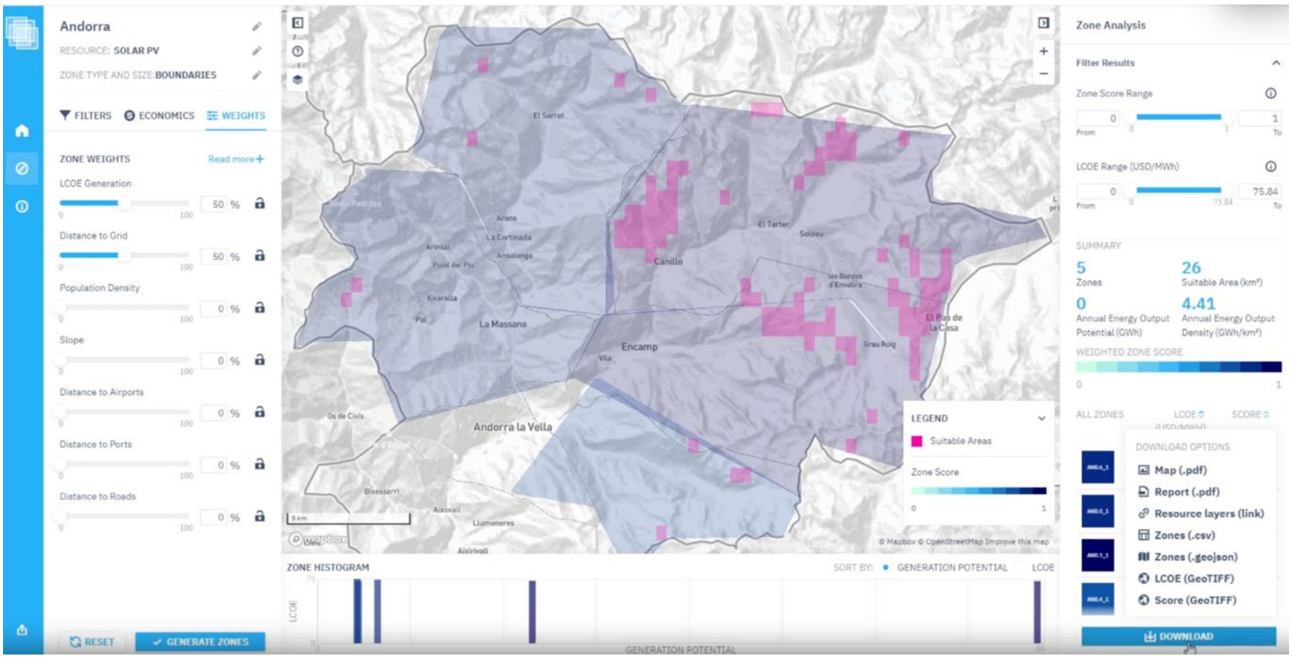


Figure 8. REZoning tool: screenshot of solar potential in Andorra including suitable locations based on a range of criteria, including LCOE.

In India, the Council on Energy, Environment and Water (CEEW), one of South Asia's leading think-tanks, has developed an online map-based, interactive decision support tool to categorise 613 districts in India in relation to their potential for the deployment of solar-powered irrigation systems. The main objective is to help prioritise target regions, identify deployment strategies, and devise policy incentives appropriate to a region's potential and limitations.

The tool will assist policymakers to deploy appropriate processes to ensure the adoption of solar-based irrigation, keeping in mind differing regional challenges. The tool will also support public and private financiers, entrepreneurs and other business professionals to identify and target districts with a high potential for sustainable solar-based irrigation. It will also be a valuable resource for academics and researchers.

If our moonshot is to produce fit-for-purpose project pipelines, spatially disaggregated at an asset level, aligned with a low-overshoot future, then these tools are the Saturn V sitting on the launchpad ready to take off. But this is not the complete picture. We also need to combine this with "low-overshoot" energy scenarios at all scales, from local to global. And this needs to include existing power generation. This exists within GEM and other databases housed by the IEA and IRENA. This is why, combined, these tools give us some confidence that enhanced automation of project proposal development is feasible. For example, three recent analyses used novel technologies to explore clean energy infrastructure (existing and potential) at asset levels.

Three firsts

In 2020, Dunnett *et al*. used OpenStreetMap to publish *the first publicly available, spatially explicit, harmonised dataset describing global solar PV and* *wind turbine installations*. The authors made data available in vector format, either as GeoPackages, shapefiles, or comma-delimited, and describe groupings of wind turbines or solar PV. In follow-up work, Dunnett *et al*. (2022) show that the siting of wind and solar infrastructure is largely driven by accessibility and proximity to urban centres, rather than wind and solar availability, land costs or low environmental impacts.[5]

In 2021, Kruitwagen *et al*. published a global database of 68,661 spatially localised non-residential PV solar energy installation footprints with installation dates, land-cover assessments, estimated generating capacity, and other metadata. The team used machine learning and remote sensing to achieve this goal. The authors concluded that *"This is the first time, to our knowledge, that machine learning and remote sensing has been used to search the entire planet for a specific type of infrastructure asset."*[27]

In 2022, Sachit and colleagues in Malaysia, the United Arab Emirates and Iraq published a paper titled "Global Spatial Suitability Mapping of Wind and Solar Systems Using an Explainable AI-Based Approach". It provides a global assessment of site suitability for wind and solar plants. The researchers used 13 criteria for site selection and data from over 55,000 real-world wind and solar assets worldwide. Criteria included: wind speed, solar radiation, cloud cover, elevation, population density, roads, natural disasters and global energy infrastructure.[28]

The data and criteria were used to train three machine learning (ML) algorithms: random forest (RF), support vector machine (SVM), and multi-layer perceptron (MLP). The output of these ML models was then explained using SHapley Additive exPlanations (SHAP). The output was the identification of suitable sites, based on a limited number of criteria, for the development of onshore wind and solar assets. The authors claim this is *the first to use an explainable AI-based approach for the global mapping of onshore wind and solar power systems*.

Summarising key technologies and how they can be combined

The initiatives summarised above are pioneers at the interface between clean energy development and new technologies, particularly AI. Here we summarise some of the key tools and their potentials.

Geographic Information System (GIS)

GIS is a powerful tool that is already used in energy system analysis to explore spatial data, such as maps and satellite images.

Remote sensing

Tools such as satellite imagery, light detection and ranging (lidar), and radar are already being used to provide critical data about weather patterns, land use and topography, which can be processed using ML algorithms to identify potential renewable energy sites. In recent years, image resolution has increased rapidly. The company Planet operates a constellation of approximately 200 "Dove" satellites[29] that it claims can image the entire land surface of Earth every day at a resolution of less than one metre.[30]

Machine learning (ML)

ML algorithms can be applied to GIS data to identify suitable sites for wind or solar farms. For instance, ML algorithms such as decision trees or random forests can be trained on labelled GIS data (sites labelled as suitable/unsuitable) to predict whether an unlabelled site is a suitable candidate for an asset, based on environmental, economic or social criteria.

Reinforcement learning (RL)

RL is a type of ML algorithm where an agent learns to make decisions by iteratively taking actions in an environment to maximise some notion of cumulative reward. RL algorithms could be used in simulations to identify the most suitable sites for wind farms given complex and interacting constraints.

Decision trees: a decision tree works like a flowchart where each branch represents a decision rule leading to an outcome at leaf nodes.

Random forests: a random forest is a collection of decision trees, hence the term 'forest'. It combines the output of multiple decision trees to arrive at a single result. It handles classification and regression problems. To classify a new object, each tree in the forest gives a classification, and the forest chooses the classification that has the most votes. For regression, it takes the average of the outputs by different trees. This ensemble approach, combining multiple models, helps improve generalisability and robustness over single models.

Support vector machines: SVMs are a type of supervised learning model used for classification and regression analysis. The algorithm categorises new examples when given labelled training data.

Evolutionary algorithms: these are optimisation algorithms inspired by the process of natural selection and can be used to solve complex optimisation problems.

Deep-learning AI

A recent assessment found that AI tools can help enable the accomplishment of the majority of the Sustainable Development Goals (134 of 169 targets across all goals (but they may also inhibit 59 targets)).14 Beyond the AI tools listed above, the following deep-learning tools have the potential to support the energy transition, indeed to create significant disruptions and improve productivity rapidly.

Large language models (LLMs) and generative AI (GAI): LLMs such as Bard or GPT4 could be applied in a variety of ways to support decision-making in renewable energy site selection and management processes. GAI for example can bring together fragmented information to provide a rapid assessment and synthesis of information to gain data and insights from across academic literature and policy reports, across multiple languages, and from unstructured data sources. This could support, for example:

> *Project generation*: generating scenarios, workflows, project plans, financial assessments and first drafts of project proposals based on global best practice and tailoring for the unique requirements of each project and location.

Permitting: drafting and reviewing contracts. LLMs can be trained to understand the language of contracts and generate documents, for example, contracts and drafts based on the specific needs of a project and its social, environmental and cultural contexts. With strong oversight, this could significantly speed up permitting processes, including contract review.

Environmental assessments: environmental assessments are a critical part of the development process. They require detailed analysis of the impacts of infrastructure on wildlife, from the surrounding ecosystem to migratory bird paths, and as such are often highly localised. The process to conduct, review and approve environmental assessments can be long and detailed. The UK's offshore wind project Hornsea 4's environmental assessment ran to 10,209 pages, only slightly longer than the nearby Hornsea 2 project (10,179 pages), both built by Ørsted. There is potential to improve these processes to reduce time and legal costs, while maintaining the highest environmental standards. According to the Energy Transition Commission's report (2023) *Solutions Toolkit: Actions for National/Regional Governments and Policymakers*, "Keeping country-level environmental data banks is the most impactful way to reduce time taken for Environmental Impact Assessments conducted by developers without compromising environmental integrity."

Auctions: helping governments design auctions by creating scenarios that simulate different auction formats and rules to see which ones lead to the most desirable outcomes. This may help energy companies and investors make strategic decisions about how much to bid for contracts.

Consultations: streamline the consultation process, helping to answer common questions and gather important information from stakeholders. This could be particularly useful in the early stages of a project, when there may be many questions from the community about the potential impacts of a wind or solar farm.

Financing: generate predictions about future energy prices, costs of materials, interest rates and other factors that impact the financial viability of renewable energy projects. These predictions can be used in financial models to determine the expected return on investment for different projects, helping to guide decision-making.

Regulatory compliance: parse complex regulatory requirements and generate reports or checklists to ensure compliance with these regulations. This could include monitoring changes in regulations and generating alerts when these changes may impact ongoing or planned projects. Such an open and transparent platform could help regulators streamline their processes and adopt best practices "off the shelf".

Other deep-learning tools can be utilised to model complex relationships between inputs and outputs, such as predicting power output given weather conditions and site characteristics. Convolutional neural networks are good for image recognition, object identification and processing data in a way that takes into account the spatial relationships between nearby locations. For instance, they could be used to process satellite images to identify suitable sites for wind or solar assets.

Together, the tools discussed have significant potential to accelerate the energy system transformation. For example, one might use remote sensing data to gather information about potential sites, GIS to process and analyse that data, ML to predict the potential power output of different sites and transmission requirements, optimisation algorithms to select the best sites given various opportunities and constraints including existing energy systems and future energy demand, and GAI to generalise from local projects to global trends, and relocalise for specific contexts to propose project plans and finance strategies.

Policy and technology efficiencies have the potential to cut project development time by 50% or more

The following table identifies the key elements of grid-scale project preparation in most democratic countries (adapted from: Streamlining planning and permitting to accelerate wind and solar deployment).

Development stage	Technology	Approx time	Time saving	Enabling policy	Enabling technology
Site mapping and selection	Onshore wind	2 years	1 year	Align national, regional and local vision. Create renewable energy zones.	Digitalise and automate process. GIS, RS, ML, GAI; improve mapping tools, optimisation scenarios, modelling, forecasting, auction/tendering support.
	Offshore wind	2 years	1 year		
	Solar PV	4 months	2 months		
Environmental surveys	Onshore wind	3 years	1.5 years	Streamline and automate legal and technical process across multiple authorities. Intelligent digitalisation	GIS, remote sensing, ML, GAI to collect and support analysis of often fragmented and highly localised data on flight paths of birds, biodiversity, pollution, etc.
	Offshore wind	3.5 years	1.5 years		

	Solar PV	1.33 years	1.33 years	(beyond PDFs). Set targets.	Intelligent digitalisation and automation of the process and learn from best practices; supporting developers and authorities to accelerate legal and regulatory processes. Examples: legal research, supporting due diligence and contract analysis, drafting documents, analysing weaknesses and strengths of cases, predicting outcomes.
Stakeholder consultation	Onshore wind	9 months	Not estimated	Build community support. Offer incentives, for example, cheap or free electricity for a period for affected communities.	GAI to tailor process to local needs and support automation of the stakeholder engagement processes.
	Offshore wind	9 months	Not estimated		
	Solar PV	9 months	5 months		
Permit applications and examination	Onshore wind	3 years	2 years	Set streamlining permitting targets. Intelligent digitalisation. Create flexible permit approaches. Assess human capacity and identify bottlenecks to increase resources.	Digitalise and automate the application and review process and build into a one-stop-shop. GAI; supporting developers and authorities to accelerate legal and regulatory processes and optimise general best practice to local needs, e.g. legal research, supporting due diligence and contract analysis, drafting documents, analysing weaknesses and strengths of cases, predicting outcomes.
	Offshore wind	4 years	2.5 years		
	Solar PV	2 years	1.75 years		

Obtaining grid connection	Onshore wind	3 years	2.25 years	Grid connection times could be significantly expedited if grid is built for	Generative AI: supporting developers and authorities to accelerate legal and regulatory processes,
	Offshore wind	4 years	3 years	excess capacity with transparent connection points. Wind and solar connection times can be significantly reduced through policy reform.	e.g. using GAI to support development of a strategic spatial energy plan mapping out the best places for renewables across the country. AI can also support [transmission infrastructure planning]().
	Solar PV	1.66 years	1.5 years		
Legal challenges	Onshore wind	7 years	6 years	Regulatory changes needed.	Increase automation of legal processes using GAI.
	Offshore wind	9 years	7.5 years		
	Solar PV	3.33 years	3 years		

Table 1. Adapted from the report *Streamlining Planning and Permitting to Accelerate Wind and Solar Deployment*.[6] A combination of regulatory reform and technological investment could cut the time to deploy offshore and onshore wind by 50% and solar by 75%. Though precision is difficult to achieve as some processes overlap or occur in parallel, it is reasonable to assume very significant savings are plausible.

Taken together, based on data from *Streamlining Planning and Permitting to Accelerate Wind and Solar Deployment*, a combination of regulatory reform and technological investment could cut the time to deploy offshore and onshore wind by 50% and solar by 75% (acknowledging the caveats mentioned in the caption for Table 1). There is significant scope for very rapid scaling with the right political and technological tools. GAI in particular offers much promise in reducing time and costs spent on legal and regulatory processes, for example via permitting, auctioning and environmental assessments. That said, without major policy reform in many places bottlenecks will remain, especially regarding permitting, despite technological optimisation. Policy reform can go hand in hand with automation and adoption of new technologies, and technology could accelerate policy reform by providing scenarios and options for best practice. Significant human oversight and expertise are crucial to ensure that the AI outputs are reasonable, correct and ethical.

V. Minimum viable product

The goal is to develop a tool that within 12 months can identify assets (wind, solar, transmission) worth $1 trillion, and within 24 months, $2 trillion.

The goal at the minimum viable product (MVP) stage is to train a tool on existing clean energy projects (structured and unstructured data) to generate scenarios at the regional level and asset level everywhere aligned with a low-overshoot scenario and incorporating weighting criteria (population density, access to transmission infrastructure, environmental concerns, financial viability, etc). At the regional level, this can support renewable energy zoning, for example, to streamline regulations for rapid scale out of clean energy. At the asset level this can support project proposal development. Outputs would include optimised scenarios at 1 km^2 resolution or lower, and LLM-generated, first-order approximations of project proposal workflows. To accomplish this we can build on existing platforms, for example REZoning and MapRE (details of existing platforms can be found in Table 2).

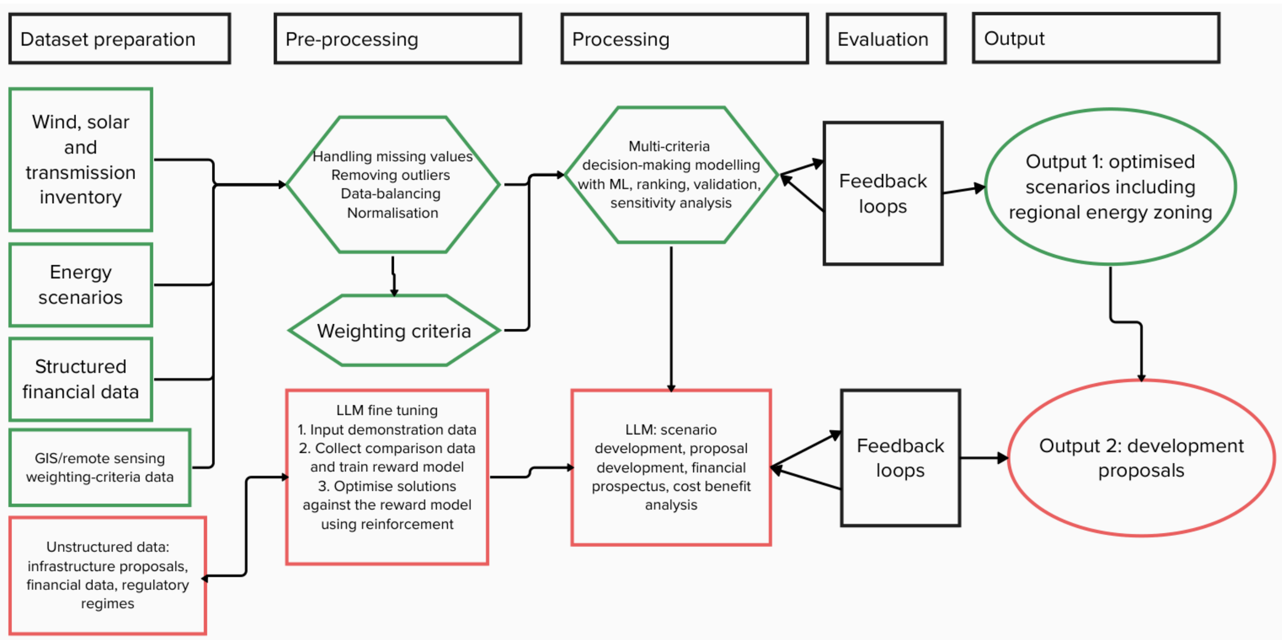


Figure 9. Sketch of a flowchart for a project development tool that utilises several AI systems.

Existing tools

Several efforts already exist to try to remove roadblocks to support the scale-out of clean energy (see Table 2).

Database			
Global datasets and maps	**Data**	**Description**	**Strengths and limitations**
REZoning – renewable energy zoning tool	Source code	Interactive, web-based platform designed to identify, visualise and rank zones that are most suitable for the development of solar, wind or offshore wind projects. Custom spatial filters and economic parameters can be applied to meet user needs or to represent a specific country context.	*Strengths:* Combines GIS and financial data. Multiparameter optimised searches are enabled.
Multi-criteria Analysis for Planning Renewable Energy (MapRE)		Aims to provide a framework for the systematic identification and valuation of areas for renewable energy development – focusing mainly on solar and wind technologies – for low- and middle-income economies. By providing government officials, regulators, utilities and other stakeholders with information about multiple siting criteria for possible renewable energy zones in the form of reproducible planning tools, the MapRE initiative seeks to improve the planning of low-carbon, cost-effective, socially and environmentally responsible energy systems. Currently, the emphasis is on utility-scale solar and wind zones, but the spatial models may also be applied to identify off-grid development.	*Strengths:* The set of GIS script tools for renewable energy zoning enables stakeholders to customise the zoning analysis by changing parameters and input files to meet the specific needs of each stakeholder or to best represent the country context. *Limitations:* Published projects appear limited to Southern Africa, South-Eastern Africa renewable energy zones, and India renewable energy zones.
Global Electrification Platform		Tool to explore least-cost electrification strategies around the world, interacting with country contextual data and different investment scenarios.	
Global Energy Monitor	Solar, wind, coal, oil, gas, hydro and thermal	Global Energy Monitor (GEM) studies the evolving international energy landscape, creating databases, reports and interactive tools. It is a free web-based platform. GEM is developing a comprehensive set of tools that allows users to zoom out for summaries and	*Strengths:* Open access, high levels of accountability and transparency.

		analysis at the regional or global scale, or zoom in for background and details on any element of the system – coal mine, nuclear power plant, wind farm, oil extraction field, fossil gas pipeline or oil tanker.	*Limitations:* Does not include mapping of sites for energy development potential.
Global transmission infrasHellotructure with renewable energy sites	Source code	Map of available electricity transmission infrastructure.	Given transmission is one of the largest barriers to scaling particularly in the US, this is a useful dataset. But it is not connected to other data.
IRENA Global Atlas for Renewable Energy	Solar, wind, geothermal, bioenergy, hydropower and marine.	A free web-based platform that provides users with data and tools to assess their renewable energy potential. The initiative, coordinated by IRENA, is aimed at closing the gap between countries that have access to the necessary data and expertise to evaluate the potential for renewable energy deployment in their countries and those that lack these elements.	*Strengths:* Good partners. The initiative has brought together more than 50 highly skilled international research institutions to share over 2,000 renewable energy maps on this single and consistent platform covering solar, wind, bioenergy, geothermal and marine energy. *Limitations:* Multiparameter optimised searches are not enabled. The tool requires users to search for the sites with the highest potential as per "Suitability index" for a given renewable energy technology. Data transparency.
Global Wind Atlas and Global Solar Atlas	Wind and solar data (topography, bathometry, meteor ological)	The Global Wind Atlas is a free, web-based application developed to provide reliable introductory-level data to help policymakers, researchers and commercial solar companies make better decisions. The Global Wind Atlas facilitates online	*Strengths:* For the Global Wind Atlas: data transparency.

		queries and provides freely downloadable datasets based on the latest input data and modelling methodologies. Users can additionally download high-resolution maps of the wind resource potential, for use in GIS tools, at the global, country and first-administrative unit (state/ province/etc) level on the website. The World Bank has provided the Global Solar Atlas to support the scale-up of solar power in their client countries. The primary aim of the Global Solar Atlas is to provide quick and easy access to solar resource and PV power potential data globally, at a click of a mouse. GIS layers and poster maps showing global, regional and country resource potential can be found on the website.	For the Global Solar Atlas: data transparency. Limitations: For the Global Wind Atlas: multiparameter optimised searches are not enabled. For the Global Solar Atlas: multiparameter optimised searches are not enabled.
Pipelines			
GI Hub's Global Infrastructure Pipeline	Directory of major infrastructure project pipelines.	Aggregator of policy plans related to infrastructure in multiple sectors.	
Roadmaps			
100% Clean and Renewable Wind, Water, and Sunlight All-Sector Energy Roadmaps for 139 Countries of the World (Jacobson et al., 2017)	Aggregated data at national levels.	Roadmaps identifying how 139 countries can be powered using 100% wind-water-solar in all energy sectors.	
WRI: Our Solar Future — Roadmap to Mobilize USD 1 Trillion by 2030		The Roadmap identifies both near-term actions and broader collaborative efforts to overcome barriers to scaling solar.	
Stakeholder tools			
GI Hub InfraCompass		"A tool for infrastructure policymakers, it objectively quantifies the strength of the infrastructure enabling environment by aggregating data for 81 countries, collectively representing 93% of global GDP and 86% of the world population."	

IRENA's Energy Transition Accelerator Financing Platform (ETAF)	Investment pledges	Objective: "Facilitate and build a geographic and technologically diversified pipeline of bankable renewable energy projects in developing countries."	
ClimateView	Broad energy related datasets and policy mapping	Tool for cities to identify data-driven strategies to reduce emissions.	

Table 2. Mapping existing related tools and products.

The operating system

We believe this requires an agile approach and disruptive mindset with the nimble flexibility to pivot and take advantage of new information and opportunities as they arise. With this in mind, the project could be built by a team of technologists, engineers and architects situated outside large intergovernmental organisations and multilateral development banks, but working closely with these important partners. A partnership of technology companies, architects and engineers could allow rapid prototyping and fluid knowledge exchange in cutting-edge fields. It must, however, have a deep commitment to openness and transparency.

The project must build knowledge exchange into its DNA. There is a huge opportunity for low- and middle-income economies to leapfrog high-income economies. This will require a project that has knowledge transfer and best-practice transfer at its core.

MVP stage deliverables

The MVP stage of the tool will focus on asset-level site identification, site assessment, transmission assessment, financial assessment (potentially expanded to assess credit ratings), regulatory assessment, risk management assessment, and proposal generation. The process will employ optimisation approaches, AI tools and financial algorithms in the processing phase.

Key features of the platform will involve integrating about 30 criteria (see the criteria section below) at a range of resolutions, a constantly updated global energy system inventory at the asset level, current and projected energy demands at national, regional and local levels, as well as regulatory documentation and financial scenarios. The platform will undergo rigorous testing and validation using train-test-validate approaches and human-in-the-loop evaluation loops to ensure accuracy and reliability.

The system will be designed to identify sites with flexibility to optimise in multiple ways across a wide variety of criteria and to provide initial estimates of cost and investment solutions. It is important to, for example, allow optimisation for both large-scale infrastructure and distributed energy projects, and the flexibility to explore project aggregation within and across national borders, bringing greater economies of scale.

The front-end and back-end architectures will need to offer considerable flexibility to cope with the rapid evolution of ML and AI technologies, and the need for rapid iteration and overhaul as new tools and use cases become available.

The tool will incorporate a comprehensive and flexible weighting scheme to ensure the equitable and efficient evaluation of potential projects. It will aim for radical transparency, providing stakeholders with information on financial assessment, investment costs, profitability in different scenarios, and rates of return. The tool will provide a preliminary assessment of regulatory environments and mechanisms to navigate challenges. Ideally, the MVP will include first efforts for optimisation and aggregation, for example in the following areas:

Investment: optimisation through analysis of historical data, market trends and cost curves to propose estimates of risk profiles, revenue streams, return on investment and financial viability of different project scenarios.

Equity and social justice: leverage demographic data and socio-economic indicators to help identify where energy access is limited or disadvantaged communities exist, proposing projects that prioritise such regions, promoting social inclusion and reducing energy poverty, with a particular emphasis on distributed energy solutions.

Rapid scaling: provide insights into grid integration, transmission infrastructure requirements and regulatory frameworks, facilitating the scalability of renewable energy projects.

Environmental risks: evaluation of the potential ecological impact of projects, taking into account factors such as biodiversity, land use and water availability. Eventually, by optimising project parameters such as turbine placement, solar panel orientation and land utilisation, the tool can propose plans that minimise environmental footprints and promote sustainable development.

Criteria, optimisation and weighting

The tool will leverage GIS, remote sensing, ML and AI architectures and look to integrate approximately 30 criteria (listed below). It will consider environmental factors such as solar irradiance, wind speed, cloud cover, land availability, slope, elevation and biodiversity. Social factors such as population density, proximity to urban areas, justice and equity, and historical/cultural aspects will also be included. Additionally, economic factors such as energy access, energy prices, existing infrastructure, supply chain access, and regulatory and political factors will be considered. Significant additional work is needed on criteria identification.

Any decision to develop energy infrastructure will include trade-offs. A tool/platform will need a comprehensive weighting scheme and will be tuned to learn from the past. Kruitwagen et al., for example, find that, globally, PV solar energy installations are most often sited on land dominated by croplands, probably as a result of proximity to urban areas. However, China, the United States, India, Spain, France, South Africa, Mexico and Chile also show considerable deployment of PV solar energy on arid lands, which, having uniquely vulnerable ecosystems, bring other complex trade-offs.[27] The following is an inexhaustive list of potential criteria. The tool will need to be designed to adapt weighting to different needs.

Environmental factors

1. Solar irradiance
2. Wind speed
3. Cloud cover
4. Land availability/type
5. Slope and elevation
6. Land use constraints and trade-offs
7. Biodiversity and ecosystem vulnerability (taking account of ecosystem structure, composition and function)
8. Climate change impacts
9. Geographical constraints
10. Water availability
11. Natural hazards

Social factors

12. Population density and proximity to urban areas
13. Health and safety factors related to construction and maintenance
14. Historical/cultural factors
15. Project prioritisation given historical inequities focused on public health outcomes
16. Indigenous people and tenure rights
17. Visual and noise impact

Economic factors

18. Equity and justice considerations, for example, energy access
19. Opportunities to support just transition, for example in areas where coal mining will be phased out
20. Price of energy
21. Existing energy infrastructure and lifespan
22. Transmission access
23. Road access
24. Economic trade-offs
25. Supply chain access
26. Cost of borrowing

Regulatory and political factors

27. Regulatory environment
28. Local community support
29. Corruption levels
30. Political stability
31. Financial stability of the country/region
32. Sensitive geographical areas from a national security perspective, for example geothermal sites in contested regions, or offshore wind in disputed waters

Other factors to be considered may include:

- Co-location – opportunities to co-locate the renewable energy infrastructure with car parks, roads, with agriculture and ranching
- Community ownership – opportunities to finance projects for community ownership

Project pipeline tool

The tool will be designed to support, at a global scale, and at an asset level:

- Site identification (MVP stage)
- Site assessment
- Financial assessment (MVP stage), potentially expanded to assess credit rating
- Regulatory assessment
- Risk management assessment
- Proposal initiation

Platform features in detail:

Data preparation

- Approximately 30 criteria (as listed above) at, say, 1 km^2 resolution
- Global energy system inventory at asset level
- Current national, regional and local energy demand
- Low-overshoot scenario of energy demand at national, regional and local levels
- Transmission assets and estimates of ease of development of transmission infrastructure
- Local, regional and national regulatory documentation
- Local and regional equity and justice documentation
- Financial scenarios

Pre-processing

- Handling missing variables and removing outliers
- Optimisation approaches
- Finance algorithms
- Train, test, validate

Processing tools (examples)

- ML tools
- AI tools
- Financial algorithms

The platform could be expanded beyond project identification and proposal generation to eventually include contract support, auction support, consultation support and regulatory navigation. This could significantly accelerate project development.

Synergistic effects

Building on, and expanding, existing tools to generate optimised asset-level site proposals aligned with ambitious climate targets could be an important solution to reduce other barriers for the following reasons:

> *Political dimension*: it can help foster political will and provide policy stability, thereby building confidence among investors about commitment to a clean energy transition. Further, the tool will help to clarify the important co-benefits of these projects relative to resilience, just transition, affordable clean energy and public health.
>
> *Financial dimension*: such a pipeline could also be instrumental in mobilising climate finance towards countries and regions with the greatest need. A global pipeline plan also opens up the possibility of project aggregation across borders benefiting from economies of scale.
>
> *Regulatory dimension*: a robust scenario for a project pipeline, highlighting global best practice, could drive regulatory reform to cut red tape to streamline permitting processes, fair grid access rules,

and standardised power purchase agreements.

Time dimension: a detailed, granular, project pipeline can reduce the time and cost of project development and deployment.

Technical dimension: a strong project pipeline can help identify and address key technical challenges such as intermittency, storage and infrastructure needs. By aggregating demand for such technologies, it can spur innovation and drive down costs.

Planning dimension: the tool could help identify clusters of potential projects in regions that could then be reviewed by government and utilities with landscape-level planning. A coherent, ambitious plan for a pipeline of clean energy projects will help facilitate capacity building (skills, training needs, staffing) and early identification of environmental, social or economic trade-offs.

Benefits for governments and utilities:

- A practical, project-scale electricity roadmap to help reach net-zero targets faster.
- Reduced project risk in low- and middle-income economies, thereby reducing the cost of hedging and cost of finance.
- Efficiency. The tool could help identify clusters of potential projects in regions that could then be reviewed by government and utilities with landscape-level planning. Instead of evaluating renewable energy proposals case by case, government agencies can study entire landscapes to map out which places should be protected and which are most suitable for energy development.
- Standardised processes and documents enable rapid tendering and financial closure, eliminating delays associated with project development.
- Effective knowledge transfer.
- Transparency and trust.
- Aggregation. The tool can provide the ability to aggregate projects to attract larger investors.

Benefits for project developers and investors:

- Market creation: unlocking nascent or non-existent solar and wind opportunities in regions such as Asia, Africa and South America, providing new markets for qualified developers.
- Reduced development time and costs: from site identification to tendering and auction processes, we can remove friction and stress.
- Level playing field: a transparent view of all opportunities and trade-offs.
- Build effective project coalitions among stakeholders considering justice and equity-related issues built into the tool.

Benefits for international donors and development partners:

- Nimble, rapidly expanding platform.
- Transparency and trust.
- Goal to cut engagement-to-power timeframe to a minimum, say two years.

VI. Call to action

The lack of a robust pipeline of renewable energy project proposals, particularly in emerging economies, is a significant barrier to achieving climate goals. It is a challenge rooted in a combination of factors – technical, political, financial and regulatory. This deficit stems primarily from the absence of comprehensive planning and policy frameworks to incentivise the development of such projects, a lack of necessary technical expertise and capacity, financial risk perception and high upfront costs associated with clean energy infrastructure development. This makes investment in project proposal development both speculative and costly, potentially 2–10% or more of the total development costs.

Be it wind or solar, each technology faces its own particular set of difficulties that creates friction. Projects can take a decade from idea to operation, slowing down the scaling-up of clean energy. This explains why project pipelines are not as long as they need to be. However, new tools can reduce friction to help get proposals off the ground faster, increase investor confidence and facilitate the development of more extensive clean energy pipelines. These tools can also offer support to deal with trade-offs and explore a broad range of financial solutions.

In 2022 and 2023, major international efforts, spearheaded by the Barbados Prime Minister Mia Mottley's Bridgetown Initiative,[22] have created new momentum to de-risk finance through reform of multilateral organisations such as the World Bank and International Monetary Fund to attract private sector investment at the scale of trillions of dollars. At the same time, the cost of clean energy continues to fall, making it increasingly more attractive to investors. The price of wind and solar dropped 60–80% in the last decade.

But a second shift is technological. New AI technologies have entered the market and are reaching a level of maturity that indicates they could provide powerful tools to support the project pipeline by creating, continuously updating and optimising potential projects in real time.

To conclude, with time running out, the world must do everything to accelerate the energy transformation. This proposal provides one tool to support the scaling of ambitious project pipelines for clean energy. It is not a panacea. More work is needed to de-risk financing of clean energy infrastructure, particularly in low- and middle-income economies. This work is under way within the International Monetary Fund, World Bank and other multilateral development banks but also within the United Nations and Group of 20 (G20) large economies. However, as investment flows turn from billions to trillions of dollars, will the world be prepared to scale rapidly? Will investment be opportunistic or strategic? Will those in most need be prioritised? The tool proposed here creates a new level of transparency and can empower actors with information to make informed decisions regarding priorities. In addition, we believe such a pipeline tool can contribute to de-risking investments and reduce the time between project concept and operation. Furthermore, we believe the tool has potential for significant expansion, offering additional support at all stages of project development for wind and solar, and, indeed, beyond these technologies to support transformation across multiple sectors of the economy, including transport and industry.

Development will take support and partnerships with governments, investors, academia, technology companies and international donors. But we need to create a tool now and we believe the world will benefit from a nimble start-up mentality to sprint to an MVP. That is at the heart of this proposal.

VII. Annex 1: Budget, staffing, etc

Here we make an initial estimate of the expertise and budget required to realise this proposal.

Expertise

Based on the technological requirements of this project, this is an inexhaustive list of the expertise needed and their respective qualifications:

1. Energy systems expertise:

- Advanced knowledge of energy systems and renewable energy technologies
- Understanding of power grids, transmission, storage and distribution systems
- Experience in energy demand forecasting and scenario analysis
- Strong understanding of energy policy and regulations

Qualifications: advanced degree in energy engineering, power systems or a related field.

2. Geographic Information Systems (GIS) expertise:

- In-depth knowledge of GIS principles and tools
- Proficiency in spatial data analysis and geospatial modelling
- Familiarity with GIS software and platforms (e.g. ArcGIS, QGIS)
- Experience in data integration and geodatabase management
- Machine learning experience

Qualifications: degree in geography, geomatics, energy systems or a related field with specialisation in GIS.

3. Remote sensing expertise:

- Proficiency in remote sensing technologies and image processing techniques
- Knowledge of satellite imagery acquisition, processing and analysis
- Familiarity with remote sensing software (e.g. ENVI)
- Experience in land cover classification and change detection
- Energy system experience
- Machine learning knowledge

Qualifications: degree in remote sensing, geoinformatics or a related field with specialisation in remote sensing.

4. Machine learning expertise:

- Proficiency in ML algorithms and techniques
- Experience in data preprocessing, feature engineering and model training
- Knowledge of supervised and unsupervised learning approaches
- Expertise in model evaluation, validation and optimisation

Qualifications: advanced degree in computer science, data science or a related field with specialisation in ML, and expertise in energy systems.

5. Artificial intelligence expertise:

- In-depth understanding of AI algorithms, including deep learning and neural networks
- Experience in developing AI models and systems
- Familiarity with AI frameworks and

libraries (e.g. TensorFlow, PyTorch)

- Knowledge of natural language processing and computer vision

Qualifications: advanced degree in computer science, AI or a related field with specialisation in AI.

6. Generative artificial intelligence expertise:

- Expertise in GAI models, such as generative adversarial networks (GANs)
- Experience in training and fine-tuning generative models
- Knowledge of image synthesis and data generation techniques
- Familiarity with GAI frameworks (e.g. StyleGAN, GPT)

Qualifications: advanced degree in ML, AI or a related field with specialisation in GAI.

7. Large language models expertise:

- Proficiency in working with LLMs, such as GPT-3
- Experience in fine-tuning and utilising pre-trained language models
- Knowledge of natural language understanding and generation
- Familiarity with text data preprocessing and text mining techniques

Qualifications: advanced degree in natural language processing, computational linguistics or a related field with specialisation in LLMs.

8. Financial analysts:

- Expertise in financial analysis and investment evaluation related to clean energy investment, particularly regarding potential solutions and overcoming barriers in the Global South
- Knowledge of public-private partnerships, sustainability-linked bonds and other financial tools
- Familiarity with financial modelling and valuation techniques
- Experience in analysing investment feasibility, credit ratings and returns

Qualifications: degree in finance, economics or a related field with specialisation in financial analysis.

9. Governance and policy experts:

- Understanding of energy governance frameworks and policies
- Knowledge of regulatory environments and legal considerations globally for renewable energy
- Experience in assessing political stability and corruption levels
- •Familiarity with energy market dynamics and policy instruments

10. Social and environmental sustainability experts:

- Expertise in sustainable design and development, sustainability analysis and evaluation related to social and environmental sustainability goals
- Knowledge of sustainable systems design and tools, especially relating to biodiversity and climate
- Familiarity with systems mapping and life cycle assessment
- Experience in sustainable infrastructure and third-party certifications such as the Institute for Sustainable Infrastructure's ENVISION system

Qualifications: degree in sustainability or specialisation in sustainability within engineering and or architecture.

Organisational structure

Organisational structure for MVP development:

1. Core team:

- CEO: oversees the overall development and execution of the MVP.
- CTO: guides the technical aspects of the project, coordinating with different teams and ensuring the integration of various components.
- Energy systems expert: provides expertise in energy systems analysis, demand forecasting and policy alignment.
- ML/AI specialist: leads the development of AI models, data preprocessing and optimisation.
- GIS and remote sensing expert: manages geospatial data acquisition, analysis and integration.
- Software developers: develop the online platform, implement ML algorithms and create user-friendly interfaces.
- Financial analysts: conduct financial assessments, evaluate investment feasibility and provide economic insights.
- Social and environmental sustainability expert: provides expertise in social and environmental sustainability, conducts sustainability assessments and evaluates project tool co-optimisations to support goals.
- Engagement and partnerships executive: build and maintain partnerships with key organisations.

2. Partner organisations:

- Engineers, architects and technology companies: collaboration with companies in these sectors will provide cutting-edge expertise, access to novel tools and security that deliverables are robust and add value to these stakeholders.
- International energy organisations: collaborate with established international energy organisations such as the International Renewable Energy Agency (IRENA) and the International Energy Agency (IEA). This partnership can bring domain expertise, access to global energy data and guidance on best practices.
- Academic institutions: form partnerships with academic institutions specialising in energy, ML, GIS and AI. Collaborate with researchers, professors and students to leverage their expertise, access research resources and validate methodologies.

3. Supporting roles:

- Data scientists: process and analyse large datasets, implement ML algorithms and optimise model performance.
- User experience/user interface designers: create intuitive and user-friendly interfaces for the online platform.
- Project coordinators: assist in project management, coordinate with partners and ensure project milestones are met.
- Quality assurance specialists: conduct rigorous testing and validation of the platform to ensure accuracy and reliability.

- Communications and outreach specialists: manage communication strategies.
- Legal and regulatory experts: ensure compliance with legal and regulatory frameworks, intellectual property protection and risk management.

The number of staff and their expertise will depend on the scale and complexity of the project. The MVP team might consist of 10 full-time staff for two years scaling to 15–20 members depending on funding, partnerships and potential to evolve beyond the MVP stage.

Partner organisations and academia will contribute through collaborative agreements, providing subject matter expertise, data access, research support and guidance. Engaging with 2–3 key international energy organisations and partnering with 2–3 academic institutions would provide a solid foundation for the project.

Regular meetings, workshops and knowledge-sharing sessions should be scheduled to foster collaboration and ensure the alignment of goals and objectives among team members and partners.

Budget

General breakdown of cost considerations:

Core team:

- Project manager: $200,000 (assuming a full-time engagement over two years, with an average annual salary of $100,000).
- Technical lead: $240,000 (assuming a full-time engagement over two years, with an average annual salary of $120,000).
- Energy systems expert: $180,000 (assuming a full-time engagement over two years, with an average annual salary of $90,000).
- Machine learning expert: $200,000 (assuming a full-time engagement over two years, with an average annual salary of $100,000).
- 2 x AI specialist: $400,000 (assuming a full-time engagement over two years, with an average annual salary of $100,000 each).
- GIS and remote sensing expert: $180,000 (assuming a full-time engagement over two years, with an average annual salary of $90,000).
- Software developers: $360,000 (assuming a team of three developers engaged full-time over two years, with an average annual salary of $60,000 each).
- Financial analysts: $360,000 (assuming a team of two analysts engaged full-time over two years, with an average annual salary of $90,000 each).
- Social and environmental sustainability expert: $180,000 (assuming a full-time engagement over two years, with an average annual salary of $90,000).
- Engagement and partnerships executive: $160,000 (assuming a full-time role with an average annual salary of $80,000).

Partner organisations and academic collaborations:

Costs associated with partner organisations and academic collaborations will vary based on the nature and extent of engagement. Collaborative agreements may involve financial contributions, data-sharing agreements or in-kind support. It is important to discuss specific arrangements and associated costs with the respective organisations during the partnership negotiations.

Supporting roles:

Data scientists, user experience/user interface designers, project coordinators, quality assurance specialists, communications and outreach specialists, and legal and regulatory experts: assuming a team of six members with an average annual salary of around $80,000 each, the total cost would be approximately $960,000 over two years.

Other considerations:

- Infrastructure and technology: hardware, software licences, cloud infrastructure and other technological requirements.
- Overhead costs: office space, utilities, administrative support and project-related expenses.
- External services: costs of specialised consulting services, legal counsel and potential third-party software integrations.

Based on the above estimates, the core team and supporting roles would amount to approximately $3.4 million in annual salaries over the two-year period. A more detailed cost estimate is required.

VIII. Annex 2: Responses to review process

Here is a summary of some of the most significant queries that arose during the review process of our proposal.

How does this proposal address the needs of emerging markets?

The proposal is primarily focused on emerging markets. Reviewers were keen to point out that de-risking finance and rationalising policy are both essential to make progress in emerging markets. We try to be clear throughout that we are not offering a panacea.

This is not a techno fix in place of good policy. Technology will not be able to fix poor policy, and alone it will not de-risk investment. But the platform can provide policymakers with tools: optimised site locations, processes tailored to local needs, “off the shelf” toolkits for auctions, permitting, assessments. And the platform can work as a catalyst to accelerate policy ambition. Plus, through greater transparency of the opportunities, it can empower other actors to put pressure on policymakers by making opportunities, risks and processes far more transparent than today. Taken together this, we hope, can contribute to de-risking investment. In addition the platform can function as a knowledge exchange and capacity-building tool.

Do we underplay the importance of environmental assessments?

The revised text of our proposal puts greater emphasis on the importance of environmental assessments. Through the review process we realised that in fact the platform could not only reduce time taken to perform environmental assessments and processes, but it could also provide a tool to bring together fragmented, unstructured data relating to disparate environmental challenges. The text has been updated to reflect this.

Do we cover all the state of the art AI tools that hold potential?

One query suggested that some of the machine learning tools we propose are actually quite basic and that other tools could be more powerful. The tools mentioned have all been used in recent (published after 2019) peer-reviewed analyses that have broken new ground. But technology is evolving very rapidly. This platform will help build capacity to implement new tools as they emerge – and provide emerging markets with access to these new technologies.

IX. Acknowledgements

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