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The Green Energy Paradox:

How Non-Technical Losses and Non-Revenue Water May Undermine Climate Mitigation Investment

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ABSTRACT

Global climate investment reached a record USD 2.2 trillion in 2025. Solar capacity is being added faster than at any point in history. Renewable energy now accounts for one-third of global electricity generation. And yet, in the emerging markets where climate action is most urgently needed, emissions may not be falling at the pace those headline figures imply. One contributing factor is structural and often goes unaddressed.

Non-technical losses (NTL) in electricity distribution are commonly estimated at 15 to 30% of distributed energy across sub-Saharan Africa, South Asia, and Latin America. Non-revenue water (NRW) is commonly estimated at 30 to 50% of distributed water across the same geographies. These are more than operational inefficiencies. They can reduce the value of green energy investment before it reaches a paying customer, weaken the finances of utilities that need to take part in the energy transition, add uncertainty to the carbon accounting on which NDC commitments depend, and leave distribution infrastructure underfunded relative to generation.

This paper sets out why NTL and NRW deserve more attention from climate finance. Drawing on IEA, World Bank, and published data, it describes seven pathways through which loss cycles may weaken climate mitigation, and discusses the case for treating loss measurement as an enabler of effective climate investment in high-loss markets.

Prepared for: **Distribution to investment partners, DFIs, and climate finance networks**

Executive Summary

The global energy transition is the largest coordinated capital deployment in history. USD 2.2 trillion flowed into clean energy in 2025 alone. Solar panels are being installed at record pace across emerging markets. Renewable capacity is growing in Africa, South Asia, and Southeast Asia faster than ever before. On the surface, the green energy story looks good.

Underneath it, a measurement problem may be reducing the impact. In many emerging markets, a share of the electricity distributed is never billed, which can weaken the revenue base of utilities and limit their ability to honour power purchase agreements. Where the baseline data behind carbon credits relies on metered consumption, losses can make the reported benefit less certain. And climate adaptation funding for water infrastructure may be absorbed by systems that lose a third to a half of the water produced before it reaches a billed customer.

The common thread is metering and data infrastructure that cannot always tell legitimate consumption from unmetered use, leakage or billing error. Non-technical losses in electricity and non-revenue water losses in the water sector are not simply symptoms of underdevelopment that resolve themselves as investment flows in. They can persist and reduce the value of that investment wherever electricity or water is distributed without accurate measurement.

As an illustration, a solar farm feeding a grid with 25% non-technical loss may deliver only about 75% of the climate benefit attributed to it, because the remainder is distributed but never billed, whether through unmetered use, billing error or other causes.

The table below summarises seven pathways through which NTL and NRW may weaken green energy and climate mitigation investment. Each is developed in the sections that follow. They are presented as hypotheses supported by published data, not as findings about any particular utility.

Pathway	How NTL / NRW May Weaken It	Nature of Effect
Renewable energy output lost at distribution	Clean kWh injected into a high-NTL grid may go unbilled at the same rate as fossil kWh, which proportionally reduces the climate benefit reflected in billed consumption.	Direct
Utility finances limit the transition	Over half of surveyed sub-Saharan African utilities have limited short-term liquidity. Unrecovered losses are widely cited as a contributing factor. A financially weak utility may find it harder to sign PPAs, service project debt or connect new renewable capacity.	Systemic
Climate finance weighted to generation	USD 1 trillion flows annually to generation assets versus USD 400 billion to grids. Loss measurement and recovery, which influence whether generation investment delivers its climate value, receive a small share.	Structural
Carbon accounting uncertainty	NDC baselines and carbon credit methodologies often assume distribution losses are stable and known. In high-NTL markets that may not hold, so renewable capacity additions may overstate emissions displacement.	Market
NRW	Climate adaptation funding for water security and drought	Direct

Pathway	How NTL / NRW May Weaken It	Nature of Effect
reduces water adaptation value	resilience may be absorbed by systems that lose 35 to 50% of treated water before billing, which proportionally reduces the adaptation benefit.	
Renewable integration needs data	Time-of-use tariffs, demand response and grid balancing for intermittent renewables benefit from time-stamped metering data. Analogue grids find these harder to support.	Enabling
The water-energy feedback loop	Water utilities are among the largest electricity consumers on many city grids. NTL can raise their operating costs and NRW wastes pumping energy, so the two loss cycles can reinforce each other.	Compounding

The Investment Paradox: Record Capital, Insufficient Impact

USD 2.2T Clean energy investment in 2025	USD 1T Annual generation investment	USD 400B Annual grid investment	15% Share reaching emerging markets
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In 2025, the world invested a record USD 3.3 trillion in energy, of which USD 2.2 trillion was directed toward clean energy, renewables, grids, and efficiency. Solar investment alone reached USD 450 billion, making it the single largest category of global capital deployment. Africa’s clean energy investment in 2024 was nearly double the level of 2020. On every metric that the climate finance community uses to track progress, 2024 to 2025 represents a period of exceptional momentum.

And yet, the International Energy Agency has issued a stark warning alongside these record figures: grid investment is not keeping pace with generation investment, and the gap is most acute in exactly the markets receiving the most renewable capacity additions. The IEA estimates that annual grid spending of USD 400 billion needs to double to USD 800 billion by 2030. For emerging market and developing economies, the annual grid investment gap alone is approximately USD 33 billion. This is the investment that helps renewable generation reach customers: the transmission and distribution infrastructure, the metering and data systems, and the loss recovery programmes that determine how much of the generated electricity actually reaches a paying customer.

But there is a further question that the IEA’s grid investment analysis does not directly address. Before any renewable kWh can be delivered to a customer and credited against an emissions target, it must pass through a distribution system where, in many emerging markets, between 15% and 40% of electricity sent out may never produce revenue, according to published estimates. That loss is not only a matter of grid underinvestment. It also reflects metering, billing and data limitations, and generation investment alone does not resolve it.

Emerging markets received only 15% of global clean energy spending in 2024, despite being home to 40% of the world’s population. Of that 15%, a disproportionate share is flowing to generation assets in markets where the distribution infrastructure cannot monetise what is generated.

The result may be a paradox. Climate capital is flowing at a record pace into markets where loss cycles can reduce its value before it reaches an end user. The solar panel is installed and the clean electricity is generated, but a meaningful share of it may be lost to unmetered use, bypass, billing failures and technical loss that generation investment cannot address.

Renewable Energy and Distribution Losses

The generation asset and the distribution system are often treated as separate problems, but they are connected. A solar farm, wind installation or hydro plant delivers its full climate and commercial value only to the extent that the electricity it generates is accurately measured, billed and collected. In a grid with 25% non-technical loss, a quarter of the electricity distributed does not produce billed revenue, and the commercial case for the renewable asset is weakened accordingly.

The literature on non-technical loss indicates that the causes, which include meter inaccuracy, unmetered connections, billing errors and, in some cases, deliberate interference, affect whatever electricity flows through a network, regardless of the generation source. A solar farm and a diesel generator feeding the same grid face the same distribution losses. The electrons are fungible; the loss mechanism does not distinguish between them.

Illustrating the Climate Benefit at Risk

As an illustration only, consider a 100 MW solar installation in an emerging market distribution network with a 25% non-technical loss rate. At a capacity factor of 20%, the plant generates approximately 175 GWh annually. At a grid carbon intensity of 0.60 kg CO₂ per kWh, the full theoretical avoided emissions are approximately 105,000 tonnes of CO₂ per year.

With 25% NTL, about 43,750 MWh of that output would be distributed but not billed. Under these assumptions, the output delivered to billed customers is approximately 131,250 MWh, corresponding to 78,750 tonnes of CO₂ avoided, and the remaining 26,250 tonnes of the theoretical benefit are not reflected in billed consumption. These figures depend entirely on the assumptions stated.

Applied across a distribution network of 500,000 meters where 22% of distributed electricity is non-technical loss, the annual gap between the climate benefit attributed to renewable generation and the benefit reflected in billed consumption could run to tens of thousands of tonnes of CO₂. The actual figure depends on grid carbon intensity, the volume of renewable generation and how losses are measured.

Every percentage point of NTL in a grid is a percentage point of distributed electricity that does not appear in billed consumption. The industry accounts for this at the generation level; it often overlooks it at the distribution level.

The Power Purchase Agreement Revenue Problem

The commercial consequence of high NTL can be significant for green energy investment. Independent Power Producers and renewable developers rely on Power Purchase Agreements with utilities as the revenue foundation for project financing. A utility with 25% NTL has less revenue to pay the tariffs those agreements require, because a quarter of the electricity it purchases and distributes does not generate a return. World Bank research has found that distribution companies in high-loss markets may default on PPA obligations, require government support to honour them, or struggle to attract renewable developers because counterparty credit risk is high.

India addressed a related problem by introducing creditworthy intermediary entities to bridge the gap between developers and financially weak distribution companies. Distribution company financial stress driven substantially by commercial losses and NTL is common in many emerging markets. Where no such intermediary structure exists, renewable investment may be constrained not by a shortage of solar or wind resources, but by the off-taker's limited ability to pay for what is generated.

Utility Finances: The Counterparty at the Heart of the Transition

Over 50% SSA utilities below current ratio of 1	USD 96Bn Annual global NTL cost to utilities	USD 39 to 141Bn NRW cost estimates, apparent to total	30% Share of Africa's utility hidden costs from T&D losses
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The energy transition asks utilities to do things they have not done before: sign long-term power purchase agreements with renewable developers, invest in grid digitalisation, connect distributed solar at scale, implement time-of-use tariffs and manage bidirectional power flows on networks designed for one-way distribution. All of these activities require a financially viable institutional counterparty. In many emerging markets, utility finances are under severe strain.

The World Bank's UPBEAT survey found that more than half of surveyed sub-Saharan African electricity utilities have a current ratio below one, meaning they have limited short-term liquidity. Low tariffs and high generation costs contribute. Unrecovered distribution losses are widely cited as a further major factor, because they drain the revenue base that would otherwise support debt service, infrastructure investment and commercial creditworthiness.

A utility under this kind of financial strain may find it harder to act as a credible counterparty to a renewable energy PPA, to access the concessional financing through which DFIs support grid modernisation, or to attract the private capital that green bonds, blended finance structures and impact funds are designed to mobilise. It may also struggle to fund the connection of new renewable generation capacity even when that capacity is available and competitively priced.

One of the most useful actions a climate financier can consider in a high-loss market is not only to fund another megawatt of generation, but also to support the measurement and revenue recovery work that helps the utility pay for and integrate the generation it already has.

Better measurement and loss analysis can help here. Programmes that improve metering, data quality and billing, and that prioritise cases for verification, can strengthen a utility's revenue base over time. How such programmes are funded and structured varies by market and is a matter for each utility and its financiers. The result depends on verified findings and on follow-through, and no outcome can be assumed in advance.

The Carbon Accounting Gap: NDCs and Baseline Data Quality

The Paris Agreement's architecture rests on a chain of data: each country submits a Nationally Determined Contribution quantifying its planned emissions reductions; those reductions are tracked against a baseline of current and projected emissions; and the credibility of the global mitigation effort depends on the accuracy of that baseline data. In high-loss markets, the baseline may carry significant uncertainty.

Here is the mechanism. When a utility reports that it generated X terawatt-hours of electricity from renewable sources in a given year, that figure is accurate at the generation level. What it may not reflect is that a share of the electricity subsequently distributed was never billed or accurately measured. The emissions displacement attributed to renewable generation assumes that it substituted for fossil generation at the full level of consumption. In a grid with 22% NTL, the substitution reflected in billed consumption could be around 22% smaller than the level implied.

The Additionality Question

Carbon credit methodologies under Article 6 of the Paris Agreement and the voluntary carbon markets require that credits represent emissions reductions that are additional to the business-as-usual baseline. For renewable energy projects in high-loss markets, baseline data quality is a point to examine. If the pre-project baseline is calculated from metered consumption data that understates actual consumption, because of meter inaccuracy, unmetered connections or billing failures, the project may appear more additional than it is.

The effect may be compounded when the renewable project feeds into a distribution system that continues to lose 20 to 25% of what it distributes. The project earns credits for avoided fossil generation, while a fifth to a quarter of the output is distributed but not billed, so the net climate impact may be lower than the credit issuance suggests.

This is a risk to consider in emerging markets where analogue metering remains the infrastructure standard. Measurement-grade data, such as continuous, time-stamped consumption records from modern metering, can help establish a measured baseline from which NTL reduction and additionality can be assessed and verified.

Countries counting renewable capacity additions toward their Paris commitments without accounting for distribution losses may overstate their mitigation progress. Better consumption data would help to quantify the effect.

A Compounding Effect Across Markets

This accounting question does not affect a single project or a single country. In many emerging markets, published NTL estimates routinely exceed 15% and in some cases exceed 40%. In each of those markets, renewable energy projects, energy efficiency programmes and clean cooking interventions may be reporting emissions reductions against baselines affected by the same measurement limitation. The aggregate effect on reported climate progress could be material.

Accurate, timely metering at distribution level is therefore more than an operational nicety in this context. It is an important input to the integrity of national carbon accounting, and without it a country's NDC rests on data that may not reflect the actual state of its energy system.

NRW and Climate Adaptation Investment

~35% Average NRW in developing nations	3 to 4Bn People facing water stress by 2050 (IPCC)	Significant Share of electricity used for water supply	2.2Bn People without safe water access
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The IPCC projects that water stress will affect 3 to 4 billion people by 2050 under current emissions trajectories. In response, climate adaptation finance for water security has grown substantially. The Green Climate Fund has committed over USD 3.2 billion to water-related climate adaptation and resilience projects. Bilateral DFIs and multilateral development banks are actively deploying capital toward drought resilience, desalination, and water treatment capacity in precisely the geographies where water stress is most acute.

That investment can be undermined by the same measurement limitation that affects electricity revenue. When a water utility loses 35 to 50% of its treated water to NRW, only 50 to 65% of the water produced reaches billed use, so each euro invested in new treatment capacity, drought-resilient supply diversification or distribution rehabilitation may deliver proportionally less adaptation value. The balance is absorbed by a distribution system that cannot always distinguish delivered water from lost water, because it has limited monitoring at the connection point.

The Energy Cost of Lost Water

The climate damage from NRW is not limited to wasted water. The global water sector consumes a significant share of global electricity. Every cubic metre of water abstracted, chemically treated, and pressurised through a distribution network carries the full energy cost of that process. When it exits the network through a burst main, an illegal connection, or an under-registering analogue meter, the energy consumed to produce it is also wasted.

As an illustration, at an energy intensity of 0.55 kWh per cubic metre (an assumed figure for mixed surface and groundwater supply systems) and a grid carbon intensity of 0.60 kg CO₂ per kWh, every million cubic metres of NRW avoided corresponds to about 330 tonnes of CO₂ per year from pumping and treatment energy alone. The same calculation can be made for a specific network using its own volumes and factors. These are illustrative figures that depend on the assumptions stated.

The Adaptation Question

Climate adaptation funding is flowing into water supply expansion in markets where the existing supply system may be losing a third of its output. Without good metering, that loss is hard to detect, locate or reduce. New treatment capacity may be distributed into the same network at the same loss rate, delivering a lower share of its intended benefit.

Smart water metering is not an alternative to water supply investment. It is enabling infrastructure that helps determine what proportion of that investment delivers an adaptation outcome. The Green Climate Fund's own analysis has identified the lack of bankable investment vehicles as a primary deployment barrier for water climate finance.

SECTION 6

The Renewable Integration Barrier: Measurement Supports Decarbonisation

Intermittent renewable sources, solar PV and wind in particular, introduce variability and uncertainty into power systems that analogue-era grid management can struggle to accommodate. This is well understood in developed-country contexts, where the challenge of integrating high proportions of variable renewables has driven substantial investment in smart grid infrastructure, demand response systems, and real-time market mechanisms. It is less frequently acknowledged that the same challenge is structurally more acute in developing-country grids, because those grids lack even the baseline metering data that developed-country integration strategies take for granted.

Time-of-use tariffs, which incentivise consumers to shift demand away from peak periods and align consumption with periods of high renewable generation, are difficult to implement without granular, time-stamped consumption data at the meter level. Demand response programmes, by which utilities or aggregators signal consumers to reduce load during supply shortfalls, are hard to design, target or verify without the same data. Load forecasting, which determines how much renewable generation needs to be backed up by despatchable capacity, is less reliable without accurate consumption measurement at distribution level.

Africa has approximately 60% of the world's best solar potential but accounts for only 1% of global installed solar PV. The constraint is not a shortage of sunshine. It is the absence of the distribution and measurement infrastructure that would allow that solar energy to be reliably integrated, billed, and paid for.

The IEA has stated that investment in electricity networks in developing economies is particularly needed to support the connection of renewable energy and displace polluting diesel generation. Moving from analogue endpoints read quarterly to monitoring points that provide continuous, time-stamped consumption data is one way to build the grid management intelligence that higher renewable penetration requires. Without measurement at distribution level, integrating additional solar capacity is harder and less efficient.

Measurement Is Part of the Answer

Metering and data investments are modest next to the capital deployed in generation, but costs vary widely with technology, geography and scale, and each utility should obtain its own quotations. This paper does not provide or imply prices. The comparison that matters is between the cost of improving measurement and the value that undetected losses may put at risk, which each programme should establish from its own verified data.

Published estimates put global electricity NTL at around USD 96 billion a year and water NRW at tens of billions to over USD 100 billion a year, depending on how losses are defined (see the Priimal Loss Index). Losses of this scale can leave utilities less able to take part in the energy transition and can reduce the climate value of generation investment in markets where analogue metering remains the standard.

Comparing Marginal Climate Returns

The IEA estimates that adding a terawatt-hour of new generation and grid capacity in an emerging market requires USD 30 to 110 million in investment. At a carbon intensity of 0.60 kg CO₂ per kWh, one TWh of clean generation avoids approximately 600,000 tonnes of CO₂ if it is fully distributed and billed. In a grid with 22% NTL, the avoided emissions reflected in billed consumption from that TWh are approximately 468,000 tonnes, leaving a gap of about 132,000 tonnes of theoretical benefit.

Reducing NTL does not require new generation to deliver an emissions benefit: it reduces the generation needed to meet existing demand. For that reason, in markets where NTL is high, loss reduction may compare favourably with additional generation on a marginal climate basis. Any such comparison must use the figures and verified results of a specific programme. This paper makes no estimate of returns, savings or payback for any deployment.

The marginal climate return on loss reduction depends on how much loss is verified and corrected. Where that is substantial, it may be competitive with the marginal return on additional generation, but this should be tested case by case.

Measurement as an Enabler

Beyond the direct comparison, there is an argument for treating loss measurement as an enabler of climate investment in high-loss markets. Generation investment, grid upgrades, climate adaptation funding and carbon credit programmes all depend on a utility that can operate as a financially viable, technically capable counterparty. NTL and NRW are among the factors that can prevent utilities from reaching that condition.

Climate finance that flows into these markets without addressing measurement may deliver less than intended. Each year without better measurement is another year in which utility finances, carbon accounting and renewable generation may fall short of their potential.

A Call to Climate Finance Networks: Consider Measurement as an Enabler

The argument of this paper is that the green energy transition in emerging markets may be weakened by a measurement gap that climate finance does not always fund or require to be addressed. Non-technical electricity losses and non-revenue water losses are not operational footnotes to the climate story. They can reduce the climate value that record levels of investment are meant to deliver.

DFI capital, green bond proceeds and climate fund disbursements are being directed into markets where, by published estimates, up to 40% of the electricity distributed may not be billed, where more than half of surveyed utilities have limited short-term liquidity, where carbon credit baselines may rest on incomplete consumption data, and where adaptation funding for water flows into systems that may lose a third of supply before it reaches a customer. These are important structural issues.

Priimal Technologies welcomes discussion with climate finance networks, DFIs, green bond issuers and NDC architects on three questions:

- Loss measurement as a consideration: climate finance deploying into markets with high NTL or NRW rates could consider whether a credible metering and loss analysis programme is in place or funded alongside generation investment. Generation investment without distribution measurement may deliver only part of its intended climate benefit.
- Baseline data quality in carbon accounting: carbon credit methodologies operating in high-NTL markets could consider measured consumption data, rather than estimated or historically modelled distribution data, as the basis for additionality assessment.
- Recognising loss reduction as climate infrastructure: measurement and loss reduction programmes can deliver benefits that are quantifiable and verifiable, and existing instruments such as DFI guarantees, blended finance and green bond frameworks may be applicable depending on the structure. The industry could give loss reduction more attention as a category of climate infrastructure.

Improving how electricity and water are measured in emerging markets is not a niche technical matter. It is a foundation that can make other climate investments more effective and more accountable.

¹ IEA World Energy Investment 2025. Global clean energy investment reached USD 2.2 trillion in 2025; grid investment approximately USD 400 billion annually versus USD 1 trillion for generation.

² World Bank UPBEAT (Utility Performance and Behavior in Africa Today), 2023. More than half of surveyed sub-Saharan African utilities have a current ratio below one.

³ World Bank. Making Power Affordable for Africa and Viable for its Utilities, 2016. T&D losses account for 30% of hidden costs in Africa outside South Africa.

⁴ IEA Global Energy Review 2025. Fossil fuels accounted for approximately 60% of global power generation in 2024; coal alone contributing 35%.

⁵ World Resources Institute / IEA (2025). Africa holds approximately 60% of world's best solar potential but accounts for only 1% of global installed solar PV.

⁶ IEA Smart Grids analysis. Annual grid investment gap in emerging and developing economies approximately USD 33 billion; grid investment must double to USD 800 billion by 2030 to meet Net Zero trajectory.

⁷ IPCC Sixth Assessment Report (2022), Chapter 4: Water. Projected water stress affecting 3-4 billion people by 2050 under current emissions trajectories.

⁸ Green Climate Fund (2024). Water and Climate Resilience Portfolio. GCF has committed over USD 3.2 billion to water-related climate adaptation; lack of bankable investment vehicles identified as primary deployment barrier.

⁹ Northeast Group / World Bank. Electricity NTL costs utilities globally approximately USD 96 billion per year. Water NRW estimates vary by definition; see the Priimal Loss Index 2026 for sources.

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