Electric Vehicles-to-Minigrids Integration (V2MG): A Way out of the Energy and Financial Poverty trap

Ingrid Rousseau (ingrid@mde.energy), Rob Kleinbaum (rob@mde.energy)

Executive Summary

After a decade of progress, the world is on the verge of an unprecedented surge in clean energy technologies, widespread deployment of renewable energy solutions and of electric transportation. Unfortunately, to date, the environmental and economic rewards of this progress have mostly gone to the privileged, doing little, if anything, for middle and lower-income communities, and bypassing those in poverty entirely. The result: **worsening income inequality** and social polarization, **slower reduction of greenhouse gas emissions** globally, and **increased disengagement**.

Historically, economic growth and rising emissions have gone hand in hand, presenting a dilemma to everyone concerned about both. For the poorer nations, the impact has been stifling due to a growing yet misplaced fear that their development specifically would cause a surge in emissions, when the real threat comes from the rise of the upper-middle-income countries to high-income status.

There is a realistic path to a more egalitarian and prosperous world, with lower carbon; a path that contributes to ending the fundamental predicament behind green growth. It is founded on the integration of e-mobility with the energy system. Electric Vehicles' (EVs) potential for disruption rests on their capability to create load (i.e., drawing electricity from the grid), store energy, and act as mobile generators (i.e., distributed energy resources on wheels). In doing so EVs will change energy economics and shift the locus of control in favor of the vehicle owner.

Discussions on using electric vehicles as distributed energy resources have become ubiquitous, but few have grasped the profound financial benefits that they could bring to the less fortunate.

MDE was founded on the premise that **integrating EVs with the current energy system could revolutionize the accessibility and affordability of electricity while providing transportation conducive to economic development**. We have studied the impact of electric two-wheelers on the economics of minigrids in markets with energy access deficits. Our analysis suggests that the potential value of vehicle-to-minigrid integration (V2MG) is enormous. In emerging markets, integrating electric two-wheelers with minigrids would be life changing:

- Lowering the cost of energy by ~40% over the best-in-class minigrid, bringing it on par with national grid costs, thereby creating access, where there was none before, to affordable electricity,
- Enabling transportation-facilitated economic development by providing affordable (and green) transportation where there is none today, supporting a fleet of 30 million EVs,
- Mutually reinforcing adoption of electric vehicles and minigrids,
- Reducing the investment required to reach full electrification (10%, or $25 billion for 58 countries with energy access deficit),
- Supporting green growth, and
- Speeding the energy transition on a global scale.

While the idea looks good on paper, many "high concept" ideas crash on the rocks of commercial, technical, societal, and cultural realities. Success will hinge on thorough techno-socio-economic planning. This report shows the potential of V2MG but does not substitute for in-market testing.

In this paper, we lay out the foundation behind our thinking and share preliminary findings. Section 1 briefly reviews the key elements that would favor EV and minigrid integration and highlights the importance of V2MG. In Section 2, we discuss the predicament behind emission reduction and economic growth and argue that it is the richer half that will cause the 'carbon tsunami', not the poorer half, whose development should not be stifled. Section 3 introduces our analytical approach to evaluating the impact of V2MG with e-motorcycles in sub-Saharan Africa, its assumptions and limitations. The results are shown in Section 3.3 and the benefits from V2MG discussed. Section 4 gives a brief overview of foreseeable challenges. We conclude in Section 5 with a summary of our findings and outlook.

1. Key elements favoring V2MG adoption

1.1. Lack of energy access

Today, more than **700 million people have no access to energy.** [1] There is limited prospect for real improvement, with this number projected to be 660 million in 2030. [2] For those in rural areas, it is estimated that only 14 million could be served by commercially viable grids; [3] a far cry from the almost 430 million people for which minigrids offer the least-cost path to electrify. [1] In addition, **hundreds of millions more people live in the "undergrid"**, that is within distribution company territory, but with inconsistent, unreliable service and/or low-quality power that does not meet their needs. [4] Those areas, which are dense enough to support commerce yet with sufficient space to allow minigrids, could present early opportunities for V2MG.

Three ways currently exist to improve energy access. They all have drawbacks:

- Extending existing national grids is prohibitively expensive for most areas, hence well beyond the scope of domestic and global aid budgets,
- Using small solar home systems has become widespread for powering cell phones and other very small appliances but cannot provide enough energy for economic development,
- Installing minigrids, the cheapest method for many to reach full electrification, has proven technically viable although not yet economically. They remain too expensive and require ongoing subsidies.

Without the promise of economically viable and self-sustaining grids, too many will be left without access to energy; aid and charity budgets will not come close to fulfilling the need. By simultaneously decreasing investment and operational costs and providing transportation to communities, **V2MG could ensure that minigrids become economically viable, thereby expanding their reach and creating access to electricity where there is none today**.

1.2. Opportunities and Challenges of minigrids

A minigrid is defined by an aggregation of loads (i.e., energy demand) and one or more energy sources (i.e., energy generation) operating as a single system providing electric power and possibly heat isolated from a main power grid. A minigrid may include renewable and fossil fuel-based generation, energy storage, and load control. Minigrids are scalable so that additional generation capacity may be added to meet growing loads without compromising the stable operation of the minigrid system. [5] Typically, they serve multiple customers through community-based power systems ranging between 5 kW to 1 MW with only distribution-level electrical interconnection. While minigrids have been shown to be the least-cost solution to electrify almost 430 million people in 58 countries with electricity access deficit, [1] as introduced above, they have rarely proved profitable and remain contingent on subsidies to exist.

To compare various energy technologies and their lifetime costs of generating electricity, an economic measure referred to as the levelized cost of electricity (LCOE) is often used. LCOE is given as the average cost in currency per energy unit, e.g., $/kWh. It estimates the cost of production of energy and is useful for comparing alternative energy sources and determining affordability. [6]

A typical minigrid levelized cost of energy can reach $0.50/kWh or higher: much too expensive to be affordable for low-income populations and beyond reach for those who have no access. And, while at $0.38/kWh the current best-in-class minigrid [1] is an improvement, it remains out of reach for most at about twice the cost of energy from national grids. These elevated LCOEs stem from the large amounts of wasted solar energy inherent to minigrids' design, typically more than 50%. [7] It is not surprising that there is no profitable minigrid company in sub-Saharan Africa for which profitability depends on electricity demand. [7] Husk Energy Systems estimates that minigrid developers need to achieve a LCOE of less than $0.20/kWh by 2030 to have a viable industry and operate at the required scale.

Other problems faced by the minigrid industry that can be mitigated include poor planning and execution. For example, in India, a recent study by the Rockefeller Foundation revealed that of the 3,300 minigrids installed by the government (out of 4,000 total), only 5% are currently operational due to poor maintenance and stationary batteries failures. [8] In contrast, Bangladesh has had great success with solar home systems, using a much more integrated, bottoms up approach that involved local stakeholders, including entrepreneurs. [9]

In section 3.3 we demonstrate that **V2MG could be the way to achieve LCOEs competitive with national grids energy prices**, in line with Husk Energy Systems' 2030 LCOE estimates to enable self-sufficiency. As with any other technology, success will hinge on thorough techno-socio-economic design and planning.

1.3. The large two-wheeler market and its growing electrification rate

The two-wheeler market is projected to grow at a compound annual rate of almost 9% through 2029. Its current electrification rate is low, at less than 5% in most major markets (See Figure 1), yet poised for change. In countries where they are the main mode of transport, internal combustion engine two-wheelers consume more than 50% of the total gasoline and account for up to 10% of CO_2 emissions, and, therefore, present strong incentives to electrify. McKinsey forecasts that the global two-wheeler electrification rate will rise to 30% globally by 2030. [10]

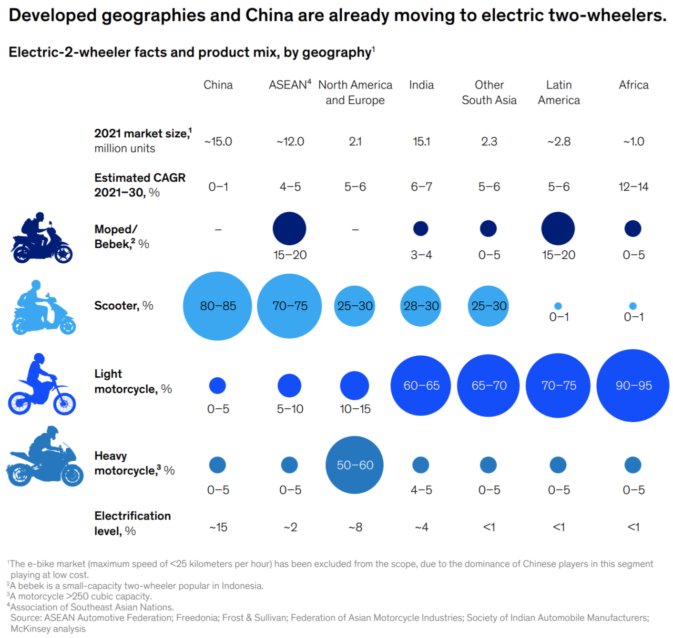


Figure 1. Electric moped and motorcycle market and product mix by geography in 2021. [10]

V2MG and the electrification of small format electric vehicles represent mutually reinforcing opportunities for adoption, just as the adoption of home solar and EVs have worked together in developed markets.

1.4. Early promises from EV and minigrid integration

Although there is limited experience with EVs being supported by minigrids, the Rocky Mountain Institute recently reported on the results of two pilots, one in India, the other in Nigeria. [11] The results were encouraging: small minigrids can power EVs at cost-parity with fossil fuels and offered "**compelling evidence that minigrid-powered EVs can simultaneously support access to clean transportation and electricity**. By tailoring business models to customer needs and boosting vehicle utilization, further pilots can pave the way to a future where electric mobility is the option of first resort."

2. Decarbonization and economic growth: a predicament

2.1. What history tells us

"The trade-off between development and climate change is impossible to avoid"
– The Economist, June 2023

Historically economic development (industrialization and wealth) has grown synonymous of increased GHG emissions. Figure 2 illustrates the fated inevitability that economic growth means more greenhouse gases. On a per capita basis, CO2 increases with income, almost quadrupling from low- to high-income countries.

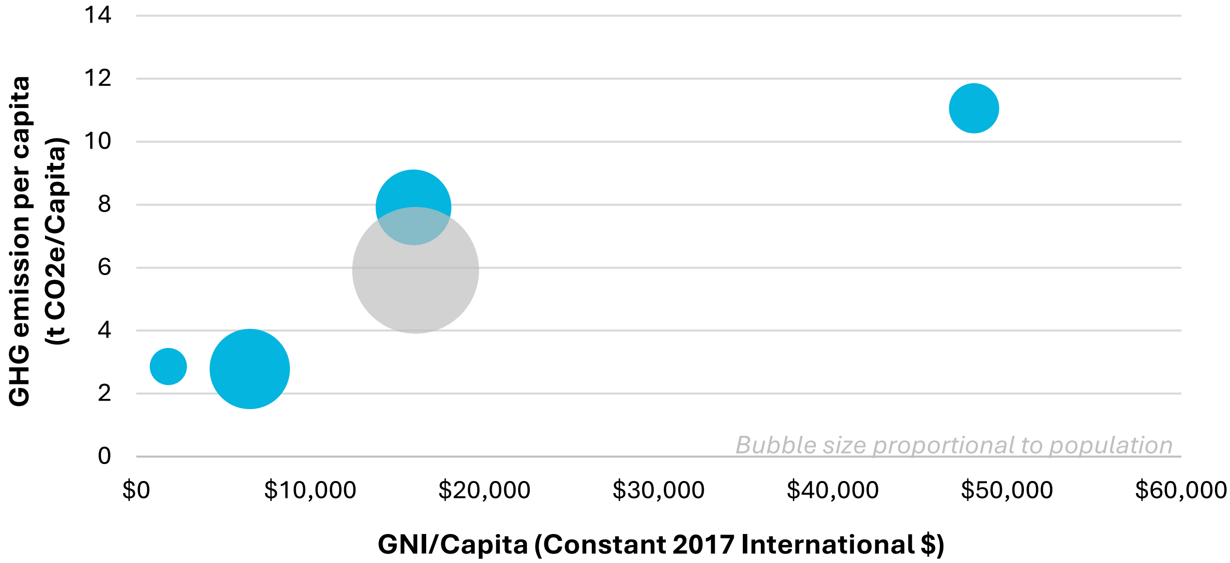


Figure 2. Gross national income (GNI) per capita as a function of greenhouse gas (GHG) emissions per capita for, from left to right, the low-income, lower-middle-income, upper-middle-income, and high-income group, globally (blue) and for the world (grey) as of 2020. [12, 13]

Overall GHG emissions generated by the low-income population are mainly due to agricultural activities (82%) with only a marginal contribution from energy use-based activities (12%) (see Figure 3). Indeed, in addition to sheer financial poverty, the low-income population (far left in Figure 2) also lives in absolute energy poverty with limited prospect for escape: stuck in the energy and financial poverty trap with 59% of the population in low-income countries without access to electricity (see Table 1). This is in stark contrast with higher income groups, where most of the emissions result from energy use activities, a direct consequence of industrialization and economic development, culminating at 86% for high-income countries.

Table 1. Electrification access rate and income of countries classified by income group (2019). [14]

	Units	Low income	Lower-middle income	Upper-middle income	High income
Electricity Access	Millions	265	2,930	2,490	1,210
	%	41%	89%	99%	100%
No electricity Access	Millions	383	360	16	0
	%	59%	11%	1%	0%
GNI per capita	Constant International 2017 $	$1,840	$6,516	$15,915	$48,096
GNI per capita per day	Constant International 2017 $	$5	$18	$44	$132

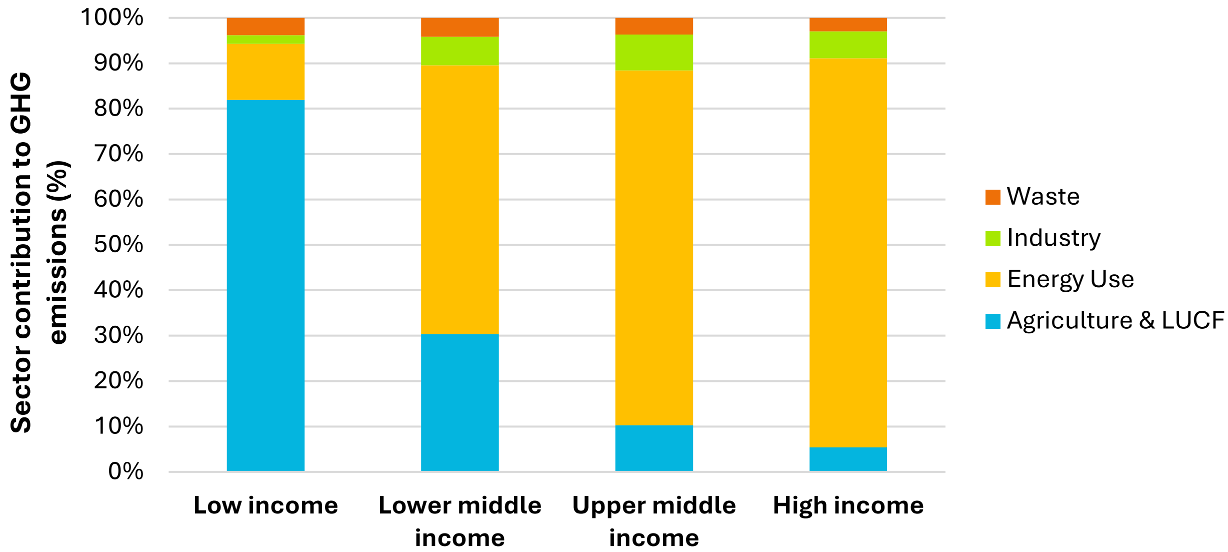


Figure 3. Relative sector contribution to total GHG emissions by income group 2020. [12, 13]

In view of the above, the fear of facing a surge in emission from economic growth appears reasonable. Unfortunately, a great deal of confusion has been brought on by reports from prominent sources as to where the responsibility lies, who point the finger at 'developing' countries. [15, 16, 17] While semantically accurate ('developing' countries being defined by the World Bank as those consisting of the low- and middle-income countries in contrast to the high-income countries characterizing the 'developed' ones), we believe that popular understanding has inadvertently attributed the responsibility to the poor and low-income nations, in turn prompting some resistance to their economic development, in regions of the world that need it the most. Instead, considering nations by income group explicitly can drive clarity and further our understanding of their respective economic development induced contribution to emissions. The contribution can be explained by two factors: the population size of the income groups and their per capita emissions. This is the basis for the evaluation described in section 2.2 below examining the consequences of a hypothetical economic rise of all world's income group by one level.

2.2. What the future may look like

To understand the impact that economic development of the poorer would have on global emissions, we evaluated a hypothetical world created from economically lifting the population of each income group by one level while keeping the GHG emissions per capita for each income group constant. Figure 4 shows the results against today's world emissions. Economic development as hypothesized would increase worldwide emissions by a whopping 54%. However, it is **lifting the advantaged that drives the global increase in emissions**: If all the poor became lower-middle income, GHG would in fact decline (a result from the smaller population size of the low-income population). The lower-middle income rising to upper-middle income would result in a modest emissions increase (+3 Gt CO2e/yr). But the overwhelming growth in emissions would come from **the upper-middle-income countries joining the high-income countries, contributing an additional 31 Gt CO2e/yr.** The surge arises from the very large population in the upper-middle-income countries (2.5 billion) reaching high-income status, currently 1.2 billion.

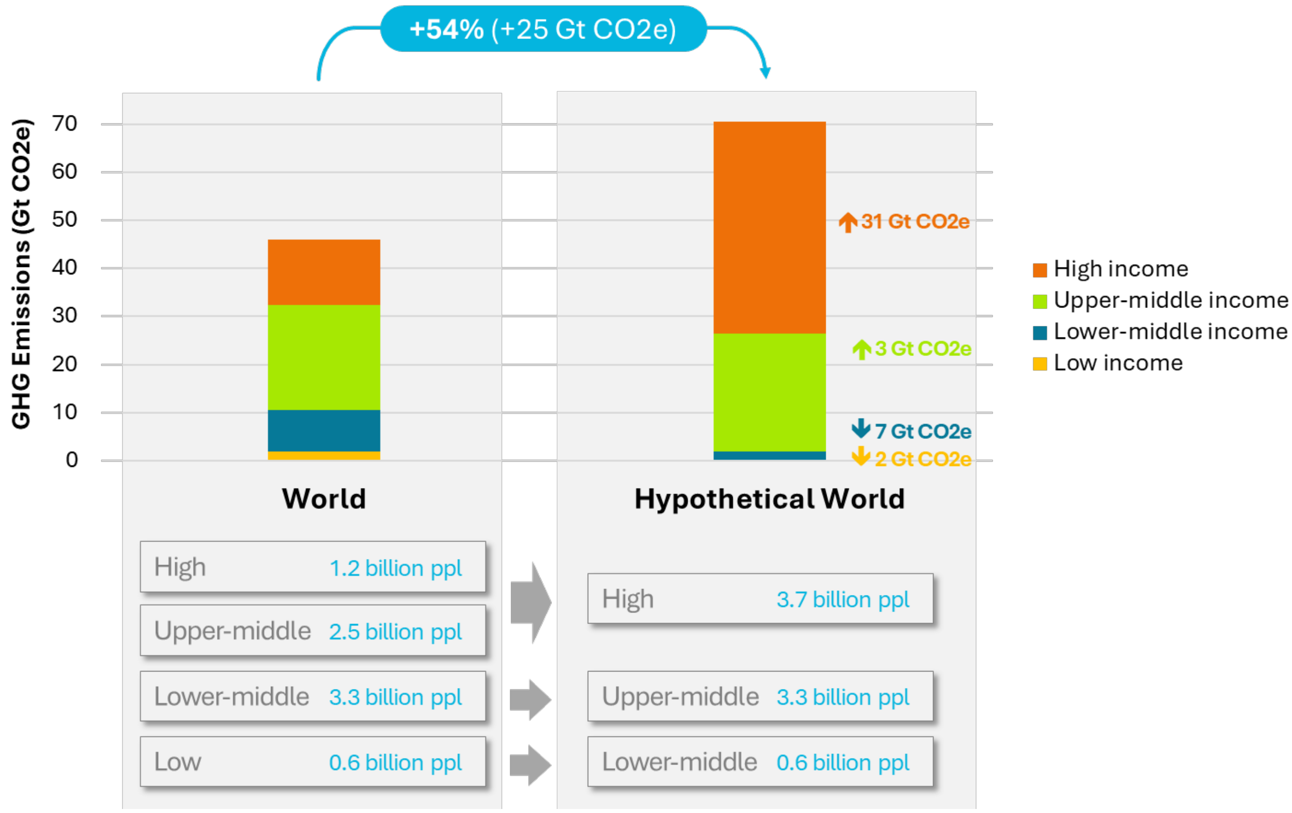


Figure 4. Estimated impact on total greenhouse gas (GHG) emissions in a hypothetical world where economic growth lifted each income group of today's world by one level.

In contrast, the economic benefit for the low- and lower-income nations would be enormous and life changing. Their annual income would quadruple (see Figure 2) and could have a life with real prospects. Escaping the energy and financial poverty trap will be critical to the well-being of the 383 million in low-income countries and 360 million in lower-middle income countries with no energy access (See Table 1) and the similar number who are underserved. To put this another way, we could eliminate low-income status globally (currently affecting 0.6 billion people) and lift every existing lower-middle-income country (3.3 billion people today) to the upper-middle-income status at no GHG cost. This is half the world's population.

We find ourselves at an inflection point and on the verge of an unprecedented surge in clean energy technologies with the promise of widespread deployment of renewable energy solutions and electric transportation. Economic development of the low- and lower-middle-income countries will not be the source of an unprecedented increase in global emissions. They should not be left behind. Technologies and opportunities abound for the poorer half of the world to grow economically without increasing emissions.

"Policymakers and countries shouldn't ever have to choose between reducing poverty and protecting the planet" – French President Emmanuel Macron, Summit for a New Global Financial Pact, Paris, June 2023

We believe that the electrification of transportation will unlock unprecedented opportunities by transforming the energy system and its economics. In addition to providing a mode of transportation conducive to economic growth and creating load, EVs will become mobile generators. **Bidirectional EVs, whether bicycles, motorcycles, cars, or trucks, will be key enablers in ending the trade-off between emissions reduction and economic development.** Their integration with the energy systems will provide the means to a path that decarbonizes, lifts the poor and helps the lower and middle class; a path that accelerates electric vehicle adoption, expands access to (clean and affordable) electricity and shortens our journey to a zero-carbon world.

In the following section, we present our preliminary findings on the benefits of V2MG specific to low-income countries with an energy deficit. We introduce our analytical methodology and model assumptions, then conclude with the results at the minigrid level as well as the broader implications.

3. Mission Driven Energy Preliminary findings: The opportunity in (electric) vehicle-to-microgrid integration (V2MG)

While discussions involving EVs as distributed energy resources have become ubiquitous, few have grasped the profound economic benefits that EVs could bring to marginalized populations across the globe, including those in wealthy nations. Equipped with bidirectionality, EVs can profoundly impact the speed of the energy transition by changing energy economics and moving the locus of control toward vehicle owners.

Technical progress, novel business models and regulatory changes will provide the necessary means to unleash EV's disruptive forces, lifting the poor and turning the traditionally left-behind into key enablers of global decarbonization. Preliminary analytic modelling suggests the potential value of V2MG is enormous for those with unreliable or no access to electricity.

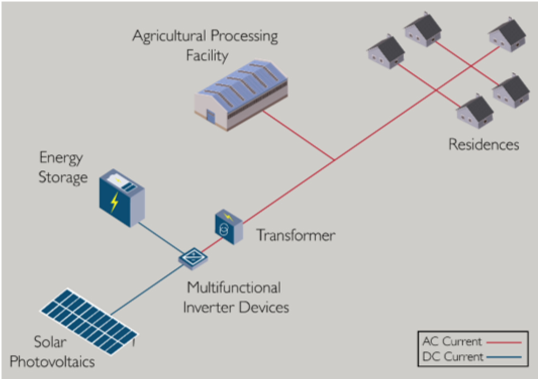
3.1. The analytic model

Microsoft Excel was used to develop a simple and transparent model. Its purpose: to determine the concept's merits and important drivers. We assessed the benefits on the levelized cost of energy, EV adoption, and the global investment cost required to reach full electrification. The modelling philosophy was to be conservative and choose values that would not favor the main idea. At this stage, the analysis omits the impact that changing the system may have on other cost drivers and ultimate sizing. Optimization for a specific project would require more sophisticated simulation tools, such as HOMER.

3.2. The system's characteristics

The minigrid

The analysis focuses on the improvements that integrating EVs would have on the best-in-class minigrid, not the average one. We used the World Bank and ESMAP "Minigrids for Half a Billion People: Market Outlook and Handbook for Decision Makers" report [1] to provide the community and minigrid inputs for our analytical model. Those are shown in Figure 5. Essential elements consist of a solar array, stationary battery energy storage, power electronics and the community it serves. The solar profile selected is that of the yearly average for Wamba, Kenya, a town geographically central to Kenya with solar loads representative of other countries in SSA. [18]



2021 best-in-class mini grid	
kWp (kW)	286
Battery Capacity (kWh)	690
Average daily load, Total (kWh)	758
Load Factor, year period (%)	22%
Number of connections	793
Battery Capex as % of System Capex	15%
LCOE ($/kWh)	0.38

Figure 5. Representation of a sub-Saharan Africa best-in-class minigrid and its main characteristics. [1, 19]

The resulting energy demand/generation/storage profile was evaluated. Figure 6 illustrates the challenging economics of minigrids: a high percentage of solar (free) energy is wasted (43% in this case) resulting in a much higher price of energy than if no energy was wasted. For this best-in-class minigrid, the effective excess solar energy wasted (green bars in Figure 6) is, therefore, at the root of its still too high LCOE of $0.38/kWh.

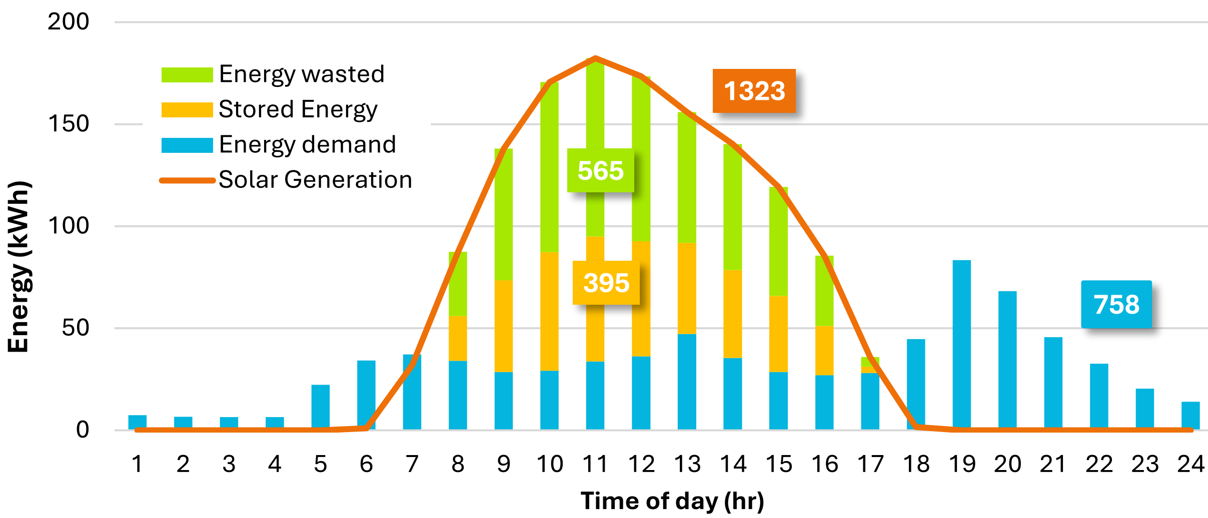


Figure 6. Energy demand, energy generation, stored energy and wasted energy for a best-in-class minigrid in sub-Saharan Africa as modeled following the World Bank's 2021 best-in-class minigrid specifications using Wamba, Kenya, average yearly solar profile. [1, 18]

Creating additional load is a solution to mitigate the amount of wasted energy and has been shown in many studies to significantly lower the cost of energy; however, just increasing load does not tackle the overall minigrid system cost, specifically the cost associated with stationary battery storage – an essential component to fulfilling energy demand that occurs when the sun is not shining and a significant contributor to system cost. In our base case, the capital expenditure (CapEx) associated with the stationary battery represents 15% of the overall system cost, hence a significant portion of the LCOE. By storing energy for future use, EVs can reduce battery CapEx, thereby proportionally lowering the LCOE.

The e-bike (i.e., e-motorcycle)

Publicly available SSA market data was used to derive the typical e-bike characteristics. The values used in the model are listed in Table 2. Bidirectionality is assumed although the impact on the initial e-bike cost was not evaluated. While understanding how, where and who performs the charging and discharging will be crucial in a real-world implementation of a V2MG system, it was not investigated in our preliminary V2MG analysis since the impact is not believed to affect the overall model conclusions.

Table 2. Key sub-Saharan Africa e-bike specifications.

Typical SSA e-bike	
Battery capacity, Nameplate, Dual Battery (kWh)	6.5
Battery capacity, Nominal (% of Nameplate capacity)	88%
Energy efficiency (Wh/km)	47
Battery charger (kW)	0.6

V2MG Model Assumptions

Additional assumptions critical to the model are listed in Table 2. The total number of EVs must support both the customers' productive use needs (i.e., mileage necessary to conduct their work) and the minigrid energy storage requirements. The productive use mileage was informed by a recent study published by Shell in which (unidirectional) e-motorcycles were integrated with minigrids in Nigeria and India. [11] The number of people per EV (30) in the community is assumed at a reasonable level: half way between the national values for Kenya (50) [20] and India (9) today. [21] Although the EV fleet now integrated with the minigrid assumes the energy storage needs, the model maintains 20% of the original stationary battery capacity for reliability purposes.

Table 3. Additional V2MG model assumptions.

V2MG Model Assumptions	
People per EV	30
Productive Use Mileage (km)	50
% Stationary battery capacity removed with V2MG	80%

3.3. Model results

Impact on the Levelized Cost of Energy (LCOE)

Figure 7 shows LCOEs obtained for the best-in-class SSA minigrid with a 22% load factor and after integration of e-bikes. It further compares the LCOE with residential electric grid prices for Kenya, Rwanda, Uganda and Tanzania. **The LCOE decreased from $0.38/kWh to $0.23/kWh (a 40% reduction)**; more importantly, **reaching grid parity with Kenya, Rwanda and Uganda's national electric grids**. Grids like that of Tanzania with heavily subsidized electricity will challenge unsubsidized ways to bring electricity and opportunities to those that have neither. For most communities, however, V2MG will enable the deployment of minigrids that (1) require lower initial investment, (2) provide electricity prices to its users comparable to those from the national electric grids, (3) enable transportation-facilitated economic development. Determining the validity of the concept will rely on a deep understanding of the environment for which it is intended. Careful planning will be paramount to successful implementation.

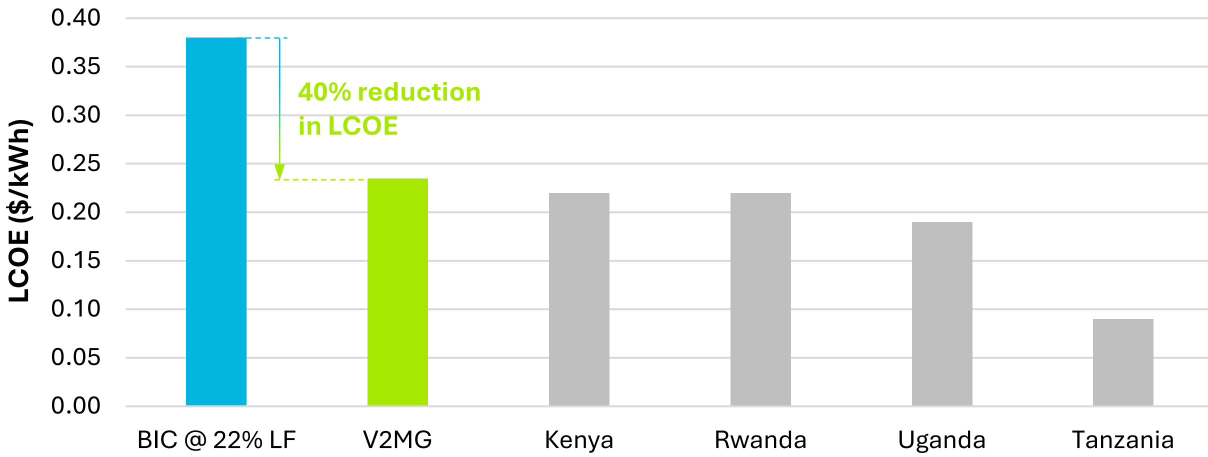


Figure 7. Levelized Cost of Energy (LCOE) comparison for best-in-class (BIC) sub-Saharan Africa minigrid at a 22% load factor (blue), V2MG after e-bikes integration (green), and residential electric grid prices for Kenya, Rwanda, Uganda and Tanzania (grey) as of 2023. Model assumptions are listed in Figure 5, Table 2, and Table 3.

Impact on EV Adoption

Extrapolating our base case model to the almost 430 million people identified by the World Bank [1] that could be served at least-cost by minigrids (~90% in sub-Saharan Africa) projects that the size of the e-bike fleet from by V2MG could reach 30 million vehicles; potentially a very conservative estimate in light of the forecasted 1.2 billion two-wheelers global fleet size in 2030 [21] once V2MG is proven to drive self-reinforcing systems that stimulate organic demand growth, especially considering the forecasted 1.2 billion two-wheelers global fleet size in 2030. [21]

Table 4. Estimated EV fleet size to fulfill V2MG requirements with the minigrid systems that would present the least-cost solution to bring electricity to the 429.5 million people in 58 countries with electricity access deficits.

	Optimal minigrid system size (kW)						
	<20	20-80	80-200	200-500	500-1000	>1000	Total
Population per Settlement	72	294	944	2,264	5,043	13,793	-
# of settlements (thousands)	622	421	104	33	7	4	-
kWp	9	40	121	298	679	4420	-
# of EV per settlement	4	18	56	137	314	2,043	-
# of people per EV*	17	16	17	16	16	7	-
# of EV (Millions)	3	8	6	5	2	7	30

**Although realistic, the number of people per EV tabulated differs from our best case (16 vs. 30, respectively). The difference is due to the distribution by minigrid system size provided by the World Bank and sourced from the ESMAP analysis of Global Electrification Platform results. It infers population per settlement numbers that are about half what the World Bank best in class minigrid settlement population to be (2,264 vs. 3,965, respectively).*

Impact on Global Investment Cost of Reaching Full Electrification by 2030

The World Bank in collaboration with others have developed the Global Electrification Platform (GEP), [22] a tool that optimizes the path to full electrification in 58 countries with known energy access deficits. ESMAP estimates that it would take almost $250 billion to fully electrify using the least-cost method (See Figure 8). Applying a 40% decrease in LCOE as inferred from the V2MG base case assumptions herein would drive a 10% decline in required investment (a $25 billion difference). The impact would be most important for countries that are more conducive to benefiting from minigrid installation than from extending the existing grid.

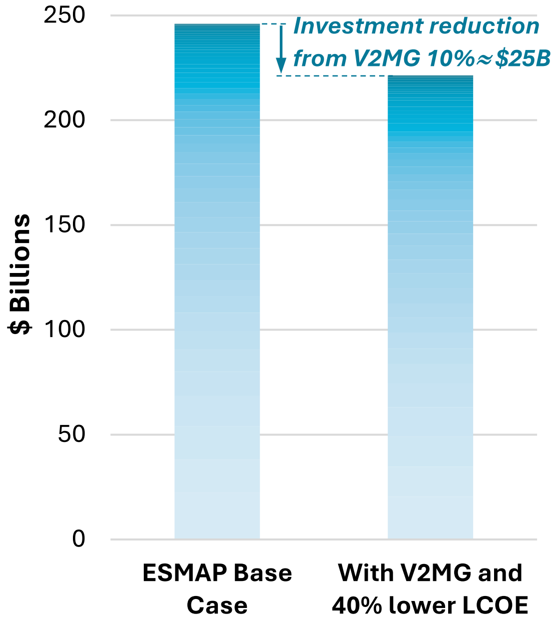


Figure 8. Investment required to reach full electrification in 58 countries with energy access deficits in 2030 as defined by ESMPA Global Electrification Platform [22] results compared with estimated investments in the V2MG base case presented here. V2MG enables a 10% ($25 B) investment reduction.

4. Challenges

While the idea looks good on paper, many "high concept" ideas crash on the rocks of commercial, technical, societal, and cultural realities. Substantial barriers to implementation include:

- Challenges associated with minigrids' maintenance, battery replacement, lack of market acceptance, subpar lifecycle planning and resourcing. These are serious problems affecting the viability of current minigrid deployment.
- Regulatory requirements, protocols, and standards. These are currently in their infancy, in flux, and vary widely across geographies, with sometimes conflicting agendas.
- Lack of cooperation between private, public, and NGO sectors. There may be a need for all three sectors to cooperate at a global, national, and local level.
- Techno-socio-economic design. The optimal technical design and its relationship to market fit and commercial viability needs development.
- Alignment of productive use with grid load curves (an important part of the design). Vehicles need to coordinate when they charge, discharge, and drive with the timing of energy generation and need.
- Financing. Until proven economically viable, initial testing and evaluation may require subsidized investment.

- Although the market potential is high, scalability will hinge on the support of financial and regulatory mechanisms. New mechanisms may need to be developed.

These are serious challenges but not insurmountable obstacles. They must be addressed and will require work and resources. This report shows the potential of V2MG but does not substitute for in-market testing. Critical aspects for successful implementation would require a feasibility study that includes understanding customers and use cases, vehicle characteristics and implications in the context of V2MG, techno-socio-economic design, regulatory and social environments.

5. Conclusions & Outlook

Historically, economic growth and rising emissions have gone hand in hand. Following current trends, a surge in GHG emissions can be expected from the economic development of the more privileged upper-middle-income populations. Fortunately, we find ourselves on the verge of an unprecedented surge in clean energy technologies that offers avenues to grow economically while limiting the impact on emissions. Although the benefits to date have mostly gone to the advantaged, there is a path to profit the low- and lower-middle-income countries who need it the most. Their growth should not be stifled for fear that it would be the one to create a surge in emissions.

A requirement for economic development is access to electricity. Unfortunately, without the promise of economically viable and self-sustaining grids, too many will be left in financial and energy poverty. At the root of minigrids' unfavorable economics is the large amounts of solar energy wasted (≈ 50%) inherent to their design.

With bidirectional EVs, V2MG could provide the means to decrease the amount of wasted energy and to enrich its surrounding communities. V2MG could pave the way to grid parity in many markets and enable profitable, self-sufficient systems. With an electrification rate expected to rise to 30% by 2030, two-wheelers and other small format electric vehicles with V2MG represent mutually reinforcing opportunities for adoption.

Complementary to earlier evidence, our analysis shows that integrating EVs into minigrids can provide the means to a path that lifts the poor, accelerates EV adoption and expands access to (clean and affordable) electricity. Critically important to rich and poor alike: a path that shortens our journey to a zero-carbon world. Integrating EVs into minigrids could:

- Lower the cost of energy by 40%, bringing it near parity with that of national grids,
- Provide affordable green transportation for productive use, enabling green growth,
- Reduce by 10% (or, $25B) the investment required to reach full electrification for 58 countries with energy access deficit, if widely deployed,
- Support a fleet of 30 million EVs, if widely deployed.

We believe the opportunity to design similar solutions that integrates a variety of small format electric vehicles (e.g., e-bicycle, two- and three- wheelers) within the existing grid in targeted communities could yield similar results and prove critical in electrifying transport and developing with reduced carbon cost. As with any other technology, success will hinge on thorough techno-socio-economic design and planning.

References

[1] Energy Sector Management Assistance Program, Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers., Washington, DC: International Bank for Reconstruction and Development / The World Bank, 2022.

[2] International Energy Agency, "World Energy Outlook 2022," IEA, Paris, 2022.

[3] S. Graber, P. Mong and J. sherwood, "Under the Grid: Improving the Economics and Reliability of Rural Electricity Service with Undergrid Minigrids," Rocky Mountain Institute, 2018.

[4] J. Agenbroad, K. Carlin, K. Ernst and S. Doig, "Minigrids in the Money: Six Ways to Reduce Minigrid Costs by 60%," Rocky Mountain Institute , 2018.

[5] I. Baring-Gould, K. Burman, M. Singh, S. Esterly, R. Mutiso and C. McGregor, "Quality Assurance Framework for Mini-Grids," National Renewable Energy Lab. (NREL), Golden, CO, 2016.

[6] Wikipedia Contributors, "Grid parity," Wikipedia, The Free Encyclopedia., [Online]. Available: https://en.wikipedia.org/w/index.php?title=Grid_parity&oldid=1185692001. [Accessed 3 December 2023].

[7] B. Mattson, M. Sinha and W. Brent, "Scaling Solar Hybrid Minigrids: An Industry Roadmap," Husk Power Systems, 2022.

[8] K. Mehrotra, "India joins rush to renewables, but its rural solar systems fall off grid," *The Washington Post,* 2023.

[9] G. Heinemann, R. Dumitrescu, C. Von Hirschhausen, N. Kebir and D. Philipp, "Lessons from Deploying Large-Scale Solar Electrification in Bangladesh: Can the last Mile Become the First?," in *WIT Transactions on Ecology and the Environment, Energy and Sustainability 2019*, vol. 237, WIT Press, 2019, pp. 75-86.

[10] R. Gupta, P. Hertzke, V. Lath and G. Vig, "The real global EV buzz comes on two wheels," McKinsey & Company, 2023.

[11] A. Allee, J. Sherwood and S. John, "Powering Small-Format Electric Vehicles with Minigrids," Rocky Mountain Institute, 2022.

[12] Climate Watch, "Global Historical Greenhouse Gas (GHG) Emissions," Climate Watch.

[13] The World Bank, "World Development Indicators, GNI per capita, PPP (constant 2017 international $)," The World Bank, Washington, 2023.

[14] H. Ritchie, P. Rosado and M. Roser, "Access to Energy," *Our World in Data,* 2019.

[15] S. K. Gallagher, "The Coming Carbon Tsunami," *Foreign Affairs,* 2021.

[16] A. Bhattacharya, J. W. McArthur and H. Kharas, "Developing Countries Are Key To Climate Action," Brookings Institution, 2023.

[17] Accra and Paris, "The choice between a poorer today and a hotter tomorrow," *The Economist,* 2023.

[18] Global Solar Atlas, "Wamba North ward," The World Bank, Washington, 2023.

[19] Meister Consultants Group, Inc., "Practical Guide to the Regulatory Treatment of Mini-Grids," National Association of Regulatory Utility Commissioners, Washington, DC, 2017.

[20] T. Addo-Ashong, "Power Two Wheelers in Africa," Africa Transport Policy Program (SSATP), The World Bank, 2021.

[21] Bloomberg New Energy Finance, "Two- and Three-Wheeler Electrification Outlook 2021," Bloomberg NEF, 2021.

[22] The World Bank, "The Global Electrification Platform (GEP)," The World Bank, 2021.