

Schneider Electric™
Sustainability Research Institute

The unexpected disruption: distributed generation

A new power system is emerging

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Life Is On Schneider Electric

Introducing our Sustainability Research Institute



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Progress on energy and sustainability is at an all-time high. How will that momentum fare in a new decade – and under radical new circumstances?

It is our responsibility, as a large organization, to make a positive impact by reducing our energy consumption and CO_2 emissions, and contributing to societal progress, while being profitable.

At Schneider Electric we have set ambitious targets aligning with the United Nations Sustainable Development Goals through our 2021 – 2025 Schneider Sustainability Impact (SSI) program; our technologies reconcile growth, access to energy for all, and a carbon-free future for our planet. Our climate commitments aim to minimize carbon emissions for our customers and our own company. For Schneider, this means the neutrality of our business ecosystem by 2025, net-zero carbon from our operations by 2030, and net-zero carbon of our end-to-end supply chain by 2050.

With pioneering technology and end-to-end solutions for sustainability, we've been building momentum.

The Schneider Electric™ Sustainability Research Institute examines the issues at hand and considers how the business community can and should act. We seek to make sense of current trends and what must happen to maintain momentum, and preview the changes that we believe are yet to come.

In this white paper, we model the global potential of distributed generation and we find it will significantly increase in the future. As economics become increasingly compelling in the coming decade, distributed generation represents a promising solution to decarbonize the building sector, not to mention its "silver bullet" – it also facilitates electrification. Forecasts on its development have, however, remained very conservative in current scenarios. A few key roadblocks stand in the way of a rapid deployment such as regulations and value chains, but a clear blueprint exists to accelerate this otherwise inevitable transformation.

To achieve the sustainability goals set out by hundreds of global organizations, bold steps are required to reduce emissions and operate more sustainably.

Join us in this series where we explore compelling predictions and conclusions in the areas of energy management, digital innovation, climate action, goalsetting and confidence, and fresh financing mechanisms.

It is time to embrace sustainability as a business imperative, and to capture the momentum now, for the future.

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Executive summary

Distributed generation (customer-sited solar photovoltaic energy in this report) is generally not considered as a major game changer in existing energy transition forecasts.

This study puts the current consensus in check. Through a detailed modeling analysis, it reviews what the true potential of this technology is and how it can contribute to building decarbonization.

The key finding? A massive potential exists, and it will only increase as the economic case continues to improve worldwide. As a consequence, its development is largely inevitable and will – to a large extent – contribute to reshaping the energy system.

Within the next decade, the deployment of distributed generation on new construction will make obvious sense globally, and further penetration on existing assets will also progress. Distributed generation indeed offers a multitude of benefits: it reduces household energy costs, helps fast-forward electrification by mitigating the impact on distribution grids, and reduces overall grid (and system) costs. As these benefits materialize, collateral innovation, notably around technology improvements and building design evolutions, will continue to enhance its potential. It is possibly due to existing scenarios not fully integrating such ripple effects that current forecasts have so far remained conservative on its development.

Our detailed analysis suggests that the current potential of distributed generation stands today at around 7,500TWh (or one third of global electricity demand) and will increase up to 25,000TWh by 2050. By then, the potential of distributed generation could exceed local demand in certain buildings, turning them into energy centers, i.e., energy resources contributing to the overall supply of energy on the grid, and thereby significantly transforming the traditional paradigm of one-way energy flows which has prevailed for decades. More importantly, this potential generally dwarfs the additional electricity demand from heating and mobility electrification, creating a strong case for economically competitive electrification.

Key roadblocks nevertheless remain to its full adoption, mainly stemming around policy frameworks which continue to favor an *ex ante* situation and a highly conservative value chain. Such issues are, however, not insurmountable. Two scenarios of adoption (with or without ambitious policies) project a growth of distributed generation up to 8,000 – 16,000TWh by 2050, in the latter case a forecast twice higher than current estimates.

Distributed generation is only a matter of time. Can we simply envision living, 30 years from now, in buildings that do not provide such access to free (and decarbonized) energy? The clear rationale for consumers makes it largely inevitable; a key innovation to a more decarbonized world, providing benefits to consumers.

It is only a matter of time

In September 2021, BloombergNEF[1] released in partnership with Schneider Electric a detailed and first of its kind analysis of the economics of distributed generation.

The study highlights that a "huge potential exists for more distributed generation on buildings and facility rooftops". It notably mentions that over half of US and German rooftops, two-thirds of UK rooftops, and 80% of Australian rooftops would be eligible for solar development. The report also predicts that, while economic improvements (combined with sustainability and resiliency incentives) have already made the case compelling in several geographies, this would likely be a common pattern within the next decade. More importantly, it also demonstrates that returns on investments are so significant for new constructions that such investments have already become a "no-brainer".

One of the main areas of concern now revolves around the necessary need for storage, a key complement to distributed generation. The BloombergNEF report focuses on economics associated with the introduction of stationary battery storage combined with distributed generation, and highlights what smart policies could do to make the case compelling going forward and reap greater benefit both at consumer and system levels. It also acknowledges that "shiftable loads" or thermal storage solutions (e.g., water tanks) could also contribute significantly and substitute (at least in part) the need for batteries, with much lower upfront costs, making the case even more compelling going forward. After all, heating and cooling needs represent on average 30 – 60% of total energy within building premises[2]. While such needs can also be met with distributed thermal storage solutions, the report does not go as far as qualifying this opportunity in detail, however.

The conclusion that stands out is unequivocal: distributed generation will progressively pervade the market, to an extent and a pace which are likely underrated. While policies will play a critical role in enabling the ramp up of this new innovation, the benefits are also a significant driver, as they translate into decarbonized and free energy access for consumers. Moreover, such positive development also contributes to the decarbonization of heating (by switching to electric heat pumps for instance) and helps mitigate the rising demand for distributed electricity in cities and the associated impact on the grid infrastructure (a smarter grid, where distributed generation partially offsets additional electricity demand stemming from, for example, electric vehicle charging or heat electrification[3]).

While distributed generation appears to be on the verge of significant development, forecasts at a global level continue to be scarce and/or conservative on its role in the global energy transition. This study aims to bridge this gap and provide a new perspective on its true potential. After detailing in the first chapter the methodology of this study, the second chapter offers a detailed global perspective of the potential of distributed generation, with the focus being on buildings only. The third chapter explores how this potential could be turned into a reality and offers a set of two scenarios for its development. The last chapter summarizes key findings and outlines a few recommendations to enable faster scaling up of distributed generation.

80%

of Australian rooftops would be eligible for solar development

30%-60%

of total energy on average is needed for heating and cooling within building premises[2]

(1) BloombergNEF (2021), Realizing the potential of customer-sited solar.
(2) Schneider Electric (2021), Cracking the energy efficiency case in buildings.
(3) Schneider Electric (b)(2021), Back to 2050.

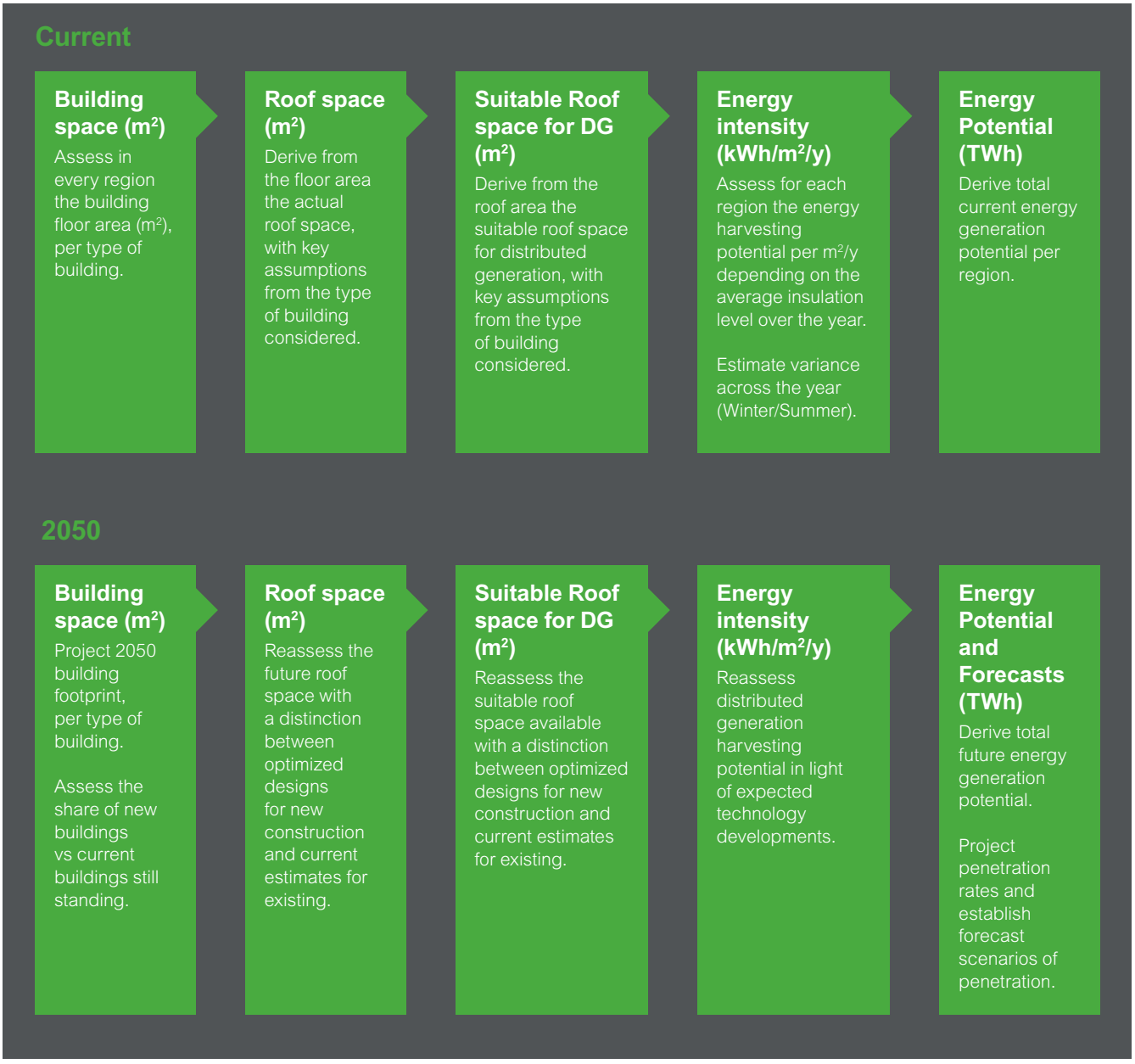
Methodology

Figure 1 summarizes the methodology followed in this review. Four steps are followed:

Step 1: assess the floor area

Although distributed generation is a function of roof area, data on buildings development is typically expressed in floor area, and therefore, this needs to be retrieved first. There are a number of existing studies on current global floor area by region; however, these vary, indicating the complexity in obtaining a precise estimate. The problem becomes even more acute as these forecasts get split further into different building types (or segments). In this study, we have focused on four building segments: individual households, collective residential buildings, and commercial buildings (both "horizontal", e.g., a retail center or warehouse, and "vertical", e.g., a large office building in a city center, archetypes). While this is not off-the-shelf data, creating such a mapping of current building types is essential to accurately forecast the potential of distributed generation as the available space for distributed generation on roofs is naturally dependent on the building configuration.

Figure 1 – Methodology



Step 2: assess roof space suitable for distributed generation

Once the exact building floor area (in square meters) is evaluated per region and building segment, we need to identify the exact roof space suitable for distributed generation. This is developed from two main indicators:

- The Floor-to-Roof ratio, which builds on a particular configuration of building and assesses the surface of the roof from that of the floor area. "Horizontal" commercial buildings (such as a one or two-story retail center or warehouse) will typically have a much higher ratio than large "vertical" buildings (such as a 10-story office building).
- The Suitable Roof Space ratio, which evaluates the percentage of the roof surface which is effectively suitable for distributed generation. Many roofs in city centers are impacted by shaded areas or poor orientation (which make them improper for energy harvesting), and more importantly, equipment is often installed on rooftops (such as chillers in large commercial or collective residential buildings) which limits the surface available for distributed generation provisions.

Combined together, these two ratios provide a suitable roof space surface for distributed generation, in square meters.

Step 3: assess the energy potential of distributed generation

Once the suitable roof space surface is computed, the potential of distributed generation can be assessed. It is defined by the generation capacity of solar photovoltaic panels per square meter over a year (in $kWh/m^2/y$). This comes as the product of both the capacity of solar panels (in W/m^2) and the actual irradiation level, which varies per region (regions from the Northern hemisphere have typically lower irradiation levels than the ones closer to the tropics).

2050 potential differs from current

Not only can the current potential be computed, but a more long-term projection of the potential needs also to be evaluated. It requires us, however, to revisit the assumptions:

- Building floor area: this will evolve upwards as new constructions come online progressively, driven by economic development and population increase. Such projections are also associated with uncertainty, and various scenarios have been explored.
- Suitable roof space area: this will not stay even over time. As the economics of distributed generation become more compelling, **building asset value is likely to increasingly depend on the actual potential of distributed generation** (as free energy available might become a key argument of sale). As building designs evolve accordingly, the actual suitable roof space available for distributed generation will increase (from new building forms, increasing Floor-to-Roof ratios, as well as new roof configurations, increasing Suitable Roof Space ratios).
- A key here will also be to make a clear distinction between existing buildings still standing (which follow old design patterns) and new building constructions, which will adopt new design patterns. This is why it is also critical to discriminate building floor area to 2050 between existing assets and new constructions.
- Finally, technologies will continue to improve, and we can safely posit that the actual power capacity of current solar photovoltaic technologies will continue to increase.

Step 4: forecast to 2050

Once the 2050 potential is evaluated, different scenarios of adoption can then be developed, and corresponding forecasts estimated.

All detailed assumptions are available in the annex and are built on a broad range of sources which are also referenced. Given the limits of data available at the required level of granularity and the discrepancies between existing sources, the results presented below must be taken with certain caution, as with other similar exercises trying to provide a global perspective on this new technology. Ultimately, only granular studies based on precise data at the building level will provide an accurate view of the potential for a given location.

The aim of this report is to establish a global order of magnitude to confirm or infirm the current highly conservative stance over the potential of distributed generation as a solution for global decarbonization, as well as better capture the dynamics of its development. The four steps described above are rigorously followed, and conservative assumptions are taken at every step. The sensitivity analysis (available in the annex) also indicates that – if anything – the forecasts presented below are conservative.



2 The potential for distributed generation is significantly underestimated

This chapter evaluates the global potential for distributed generation, with a view by region and by segment.

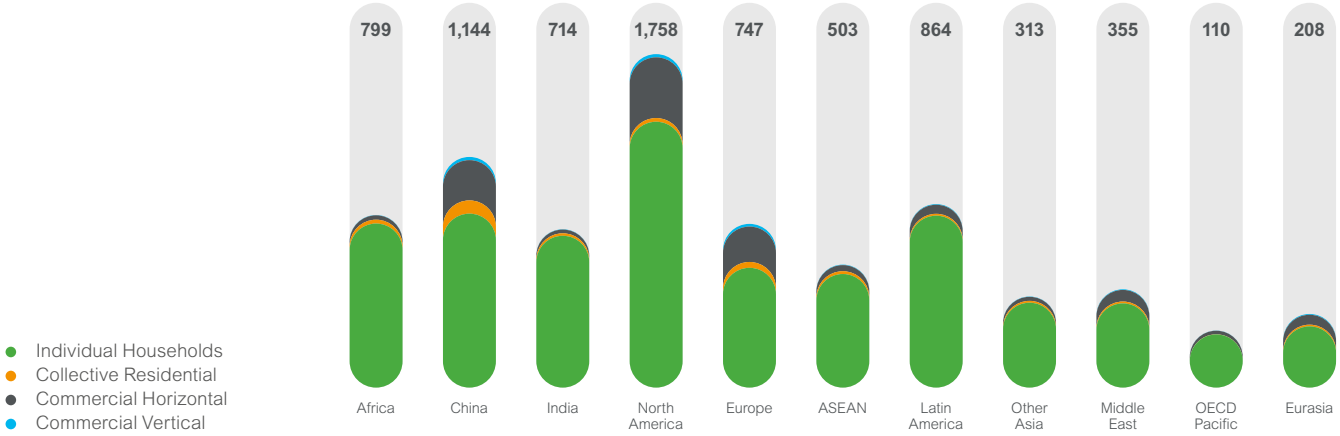


A significant potential today

We estimate the potential of distributed generation today to be around 7,500TWh globally (or one third of worldwide electricity generation, Figure 2). North America represents the largest potential in absolute value, and distributed generation could reach up to 40% of the region's electricity demand. In Europe and China, the potential is lower, both in absolute value and in share of electricity demand (at around 20% of total). Although absolute potentials are smaller in Africa and India, they represent a significant share of electricity demand, above 50% for India and 100% in Africa[1].

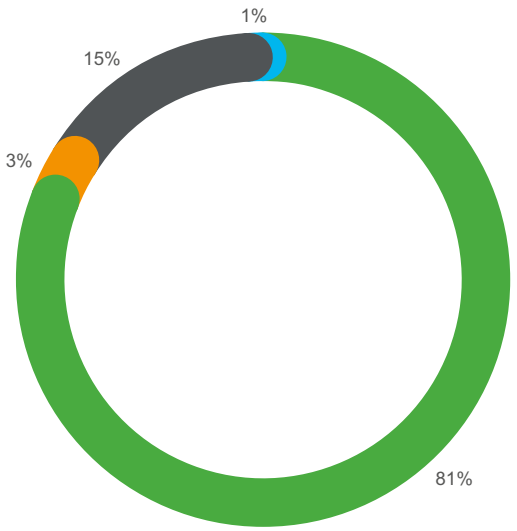
The size of the potential results from the actual floor area in a given region, and the distribution of building segments (e.g., share of individual households).

Figure 2 – Current potential (TWh/y)



80% of the potential, or around 6,000TWh, materializes in individual households, with the second largest opportunity being "horizontal" commercial buildings, at around 1,000TWh (Figure 3). These figures are not only the result of the actual floor area of these building segments, but also relate to the suitable roof space area. This explains why North America represents the primary opportunity today, given its largely distributed residential market and high penetration of retail centers.

Figure 3 – Current potential, per segment (%)



In those sectors where the potential is the most promising, distributed generation could contribute to a significant share of current electricity demand (if not more than current demand in some cases).

- Individual Households
- Collective Residential
- Commercial Horizontal
- Commercial Vertical

(1) © OECD/IEA (2021), World Energy Outlook.

A massive potential tomorrow

Yet, more is to come. **By 2050, we estimate the distributed generation potential to reach 25,000TWh**, or three times current levels (Figure 4). This is due to a combination of factors:

- The building stock increases 85% by 2050.
- Solar technology improves continuously, enabling greater power output by square meter.
- More importantly, building designs (for new constructions) evolve to maximize the potential of distributed generation on rooftops, increasing the suitable roof space area (compared to current assets), a collateral innovation with significant impacts on the total potential (as our sensitivity analysis suggests[1]).

Driven by rapid stock growth and economic development, three regions (Africa, India and Latin America) represent nearly half of the total potential. The potential in mature economies also rises significantly, albeit less rapidly (due to lower construction rates).

Figure 4 – Future potential (TWh/y)

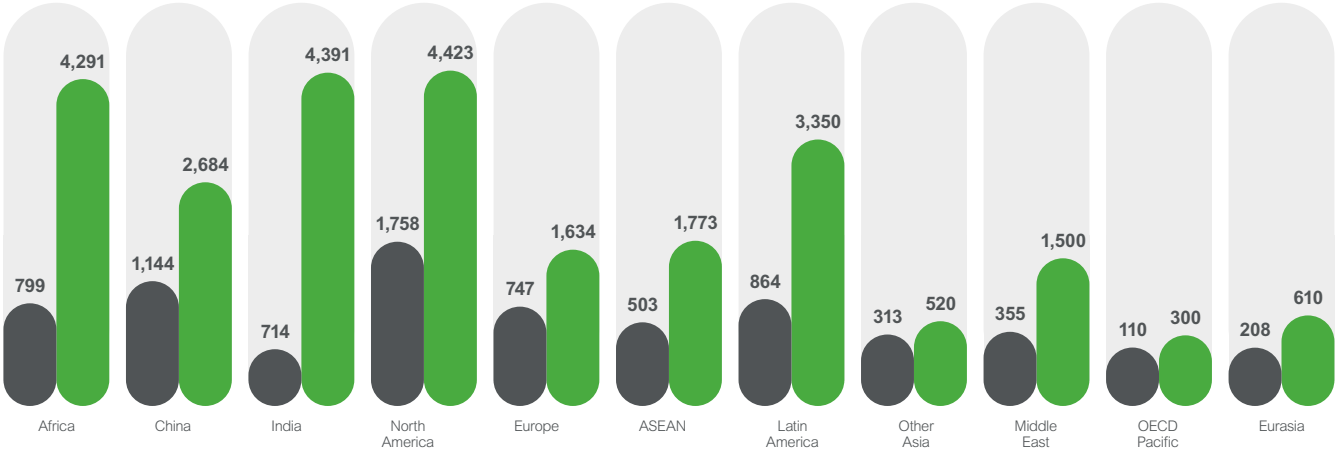
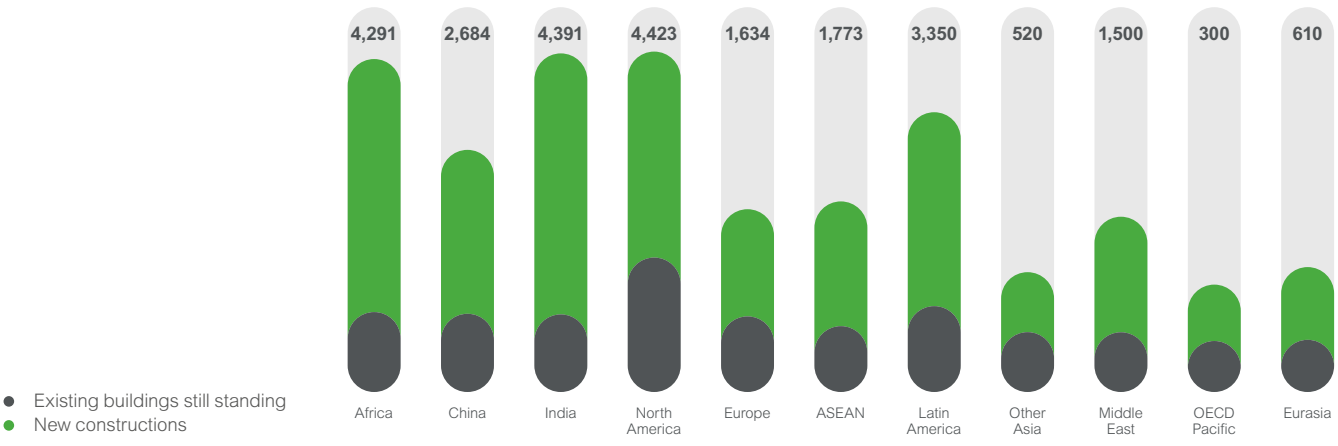


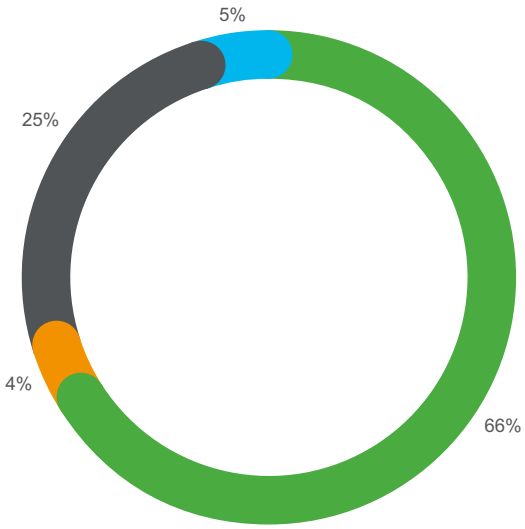
Figure 5 shows the split of the 2050 potential between existing buildings and new constructions. **New build represents nearly 80% of the global opportunity** (in energy terms). This ratio is higher in new economies, where a large majority of the opportunity stems from new construction, and lower in mature economies (between approximately 50% and two-thirds of total) where construction rates are lower. A key finding, however, is that, in energy terms, the potential is higher in new constructions. This is because we assume new building designs will evolve and optimize the suitable roof space area which greatly enhances the overall potential of such buildings, compared to current designs which have not considered distributed generation.

Figure 5 – Future potential, existing assets and new buildings (TWh/y)



(1) See annex for more details.

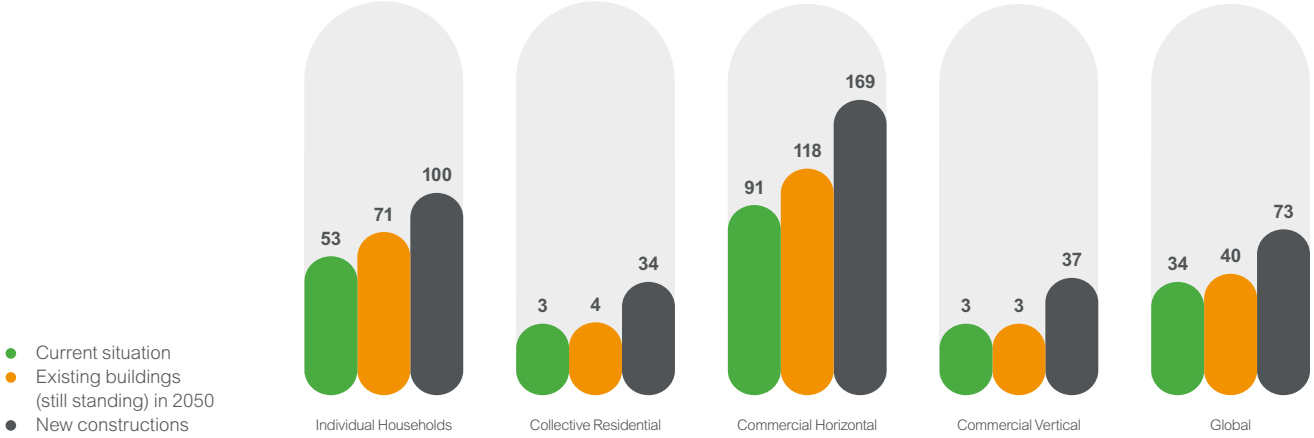
Figure 6 – Future potential, per segment (%)



With enhanced building designs (and technology improvements) also comes a greater potential for collective residential and commercial buildings. **The share of individual households drops to 66% of the total by 2050** (compared to 81% today), with a significant increase for vertical buildings which are traditionally assumed to have limited contributions (Figure 6).

Another interesting way to look at this transformation is to explore the progress in energy harvesting intensity. The potential per square meter (here accounting for square meters of floor area) increases thanks to technology improvements and new building designs, as discussed. While the latter only applies to new constructions, technology improvements benefit all building types. Overall, **global energy intensity doubles by 2050**. This is notably visible in vertical buildings (collective residential, "vertical" commercial). In "horizontal" commercial buildings (e.g., retail centers, warehouses), the potential is fully maximized.

Figure 7 – Future potential, per square meter of floor area (kWh/m²/y)



How this compares to current studies

Existing studies provide interesting insights on the potential of distributed generation[1]. On the global current potential, Deng et al. and the International Energy Agency both come close to our results with around 8,000 – 11,000TWh of potential[2], just slightly higher than our own estimates (the key parameter is that of the actual suitable roof space area, as shown in our sensitivity analysis[3]).

Other studies also show interesting conclusions. The study from Apur and Egis on downtown Paris generally reaches a potential twice lower than our current estimates. However, the specifics of Paris architecture and area density make a global extrapolation of such local patterns unrealistic. This, however, indicates the significant disparities across regions and configurations, and ultimately the need for granularity. Taminiau and Byrne, who focus on New York City, reach, for instance, much higher penetration rates (around 70% of the city's rooftops suitable for distributed generation). Similarly, a 2016 federal study conducted by the National Renewable Energy Laboratory (NREL) has shown that 39% of current US electricity demand could be met by solar panels, a figure broadly consistent with our own findings.

Also, with the exception of Deng et al. who estimate a potential for 2050 at around 26,000TWh, a figure highly consistent with our own findings, most studies essentially focus on the current potential for distributed generation but do not go as far as looking at its long-term potential with increased stock, technology improvements and new building designs.

A key takeaway from this review is that, while the current potential is already large, it is likely to significantly increase going forward. **When forecasts are run over long periods of time, it is critical to embed into them the disruptive potential of new technologies, and more importantly, the collateral innovation effects which inexorably emerge to maximize their potential.**

As a final note, this potential is likely largely underestimated as we do not take stock of the additional potential of energy harvesting over facades, a concept often coined as building integrated photovoltaics. Deng et al. have notably estimated its potential to 2050 at an additional 15,000TWh by 2050 and up to 25,000TWh by 2070[4].

8,000-11,000TWh

of global current potential distributed generation

39%

of current US electricity demand could be met by solar panels

(1) Apur and Egis (2015), Analyse de potentiel solaire. Toitures du Grand Paris. Deng et al. (2015), Quantifying a realistic, worldwide wind and solar electricity supply. Mearian L. (2016), Solar on all U.S. roofs would supply 39% of power. © OECD/IEA (2019), Renewables 2019. Analysis and Forecast to 2024. Taminiau J., Byrne J. (2020), City-scale urban sustainability: Spatiotemporal mapping of distributed solar power for New York City.
(2) The International Energy Agency estimates a potential of 9,000GW of capacity, which we estimate translates into slightly below 11,000TWh of generation potential. © OECD/IEA (2019), Renewables 2019. Analysis and Forecast to 2024.
(3) See annex for more details.
(4) Deng et al. (2015), Quantifying a realistic, worldwide wind and solar electricity supply.



3 The unexpected rise of distributed generation

Although the potential for distributed generation is significant, and growingly economically compelling, this does not mean it will be fully realized within the time frame under review. We explore two possible scenarios of its unfolding.



Distributed generation could reach 8,000TWh to 16,000TWh by 2050

We developed two scenarios in a previous exercise[1]:

- "New Normal": in the current policy context, we explore the natural rate of adoption of new technologies as they progressively reach maturity.
- "Back to 2050": we investigate a forceful policy context to reach a greenhouse gas emissions trajectory consistent with a 1.5-degree global warming by the end of the century, and effectively promoting the development of distributed generation globally.

Assumptions are detailed in the annex.

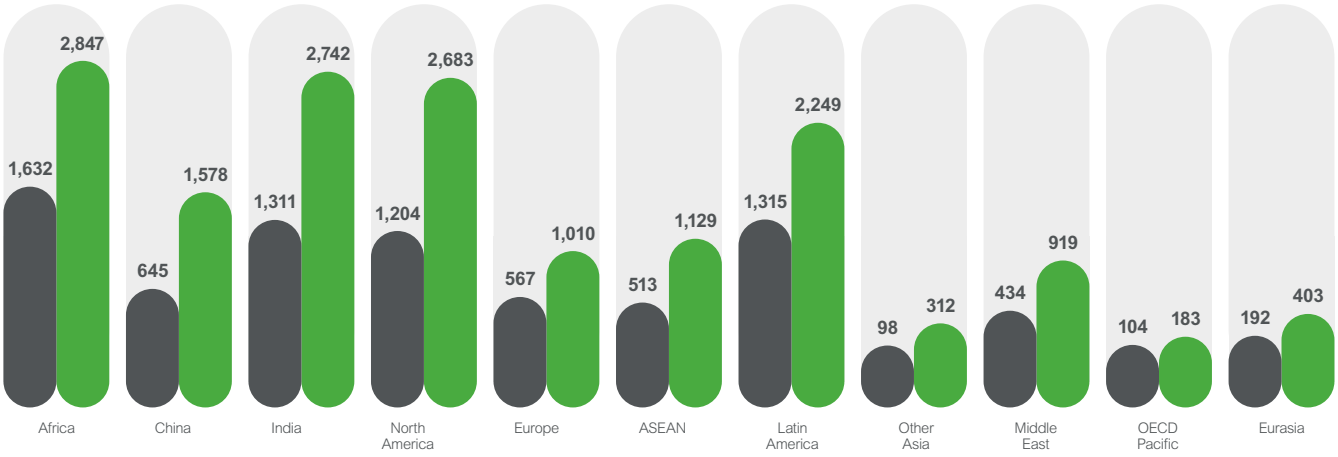
At a high-level, the "New Normal" scenario is marked by the absence of favorable policy frameworks, which still remain heavily geared toward fossil fuels. The result from this is that it takes more time for solutions to reach scale and for the value chain to organize and bring costs down. Rates of penetration differ both between new buildings and existing assets. In new buildings, economics are more compelling sooner and help scale up demand. In retrofits, the market is driven by consumer-led demand, with first markets developing where there is weak infrastructure or high retail prices. Rates of penetration also differ between mature and new economies since drivers of adoption, cost tipping points, and levels of maturity of the value chain differ.

In the "Back to 2050" scenario, a global, coordinated, and supportive policy framework drives the case for new constructions in the decade to 2030, including in new economies. While retrofits are also targeted, they lag slightly on new construction until the economic case becomes also highly compelling (without subsidies) post-2030.

As a consequence of these assumptions, distributed generation reaches around 8,000TWh in the "New Normal" scenario and up to 16,000TWh in the "Back to 2050" scenario (Figure 8).

- The development of distributed generation is generally more significant in new economies across both scenarios, accounting for around two-thirds of the total. This is due essentially to the size of the building market (by 2050), and we expect its development across both scenarios. Indeed,
  - Distributed generation represents a critical alternative to lagging infrastructure development;
  - It provides a more compelling economic case; and
  - The share of new buildings is higher in those geographies.
- In the "Back to 2050" scenario, ambitious policies help accelerate this trend globally, maximizing the potential everywhere, including in economies such as North America, China or Other Asia, which reach penetration levels 2 – 3 times higher than in the "New Normal".

Figure 8 – Distributed generation penetration scenarios (TWh)



- Schneider Electric New Normal scenario
- Schneider Electric Back to 2050 scenario

(1) Schneider Electric (b)(2021), Back to 2050.

An unexpected development

These forecasts can be compared to existing projections available. We use both projections from BloombergNEF and the International Energy Agency[1]. The International Energy Agency reports a 2050 estimate of 7,500TWh, with BloombergNEF well below at around 2,500TWh[2].

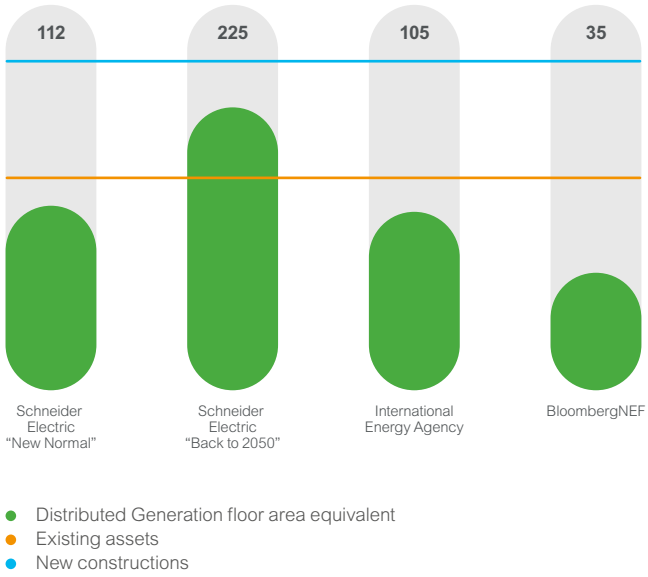
Both forecasts thus stand below the ones above, even though the "New Normal" scenario is close to the "Net Zero Emissions" (NZE) scenario from the International Energy Agency. However, the NZE scenario should really be compared to "Back to 2050" and yet, it estimates half the forecast by 2050.

There is thus significant discrepancy between all three scenarios. Another interesting way to look at these forecasts is in relation to how much of the potential discussed above is effectively harvested by 2050, in other words how much building footprint is actually in use by 2050. Figure 9 shows the equivalent floor area of buildings equipped with distributed generation[3]. Also plotted on this graph is the volume of new construction (272 billion square meters added to the stock by 2050), and that of residual building assets still standing (144 billion square meters).

The "New Normal" scenario and the International Energy Agency NZE scenario both range around 100 billion square meters, or around 25% of total building footprint, by 2050. "Back to 2050" stands at around 225 billion square meters, closer to 50% of total footprint (that is also 80% of new constructions alone, if we discard deployment on existing assets). Even if different, those scenarios tell a similar story, that of a massive acceleration of penetration of distributed generation across the building stock, fueled (ultimately) by consumer-led demand.

BloombergNEF departs, however, from this with an estimated floor area of only 35 billion square meters[4], significantly below all other scenarios. There are few reasons to this. First, BloombergNEF estimates do not include any assumptions of favorable policy frameworks (at least at global level)[5]. Then, the organization also takes stock of key hurdles to a successful development of distributed generation, such as a rather conservative value chain (and broader ecosystem) which currently shows no sign of rapid transformation[6].

Figure 9 – Distributed generation scenarios in floor area equivalent (bn m²)



Scenarios are as good as their assumptions, and their value is to highlight key tipping points and roadblocks. While the potential of distributed generation is considerable, transformative, and highly beneficial (both for consumers and the planet), this short review demonstrates that its development might be slowed down by outdated policy frameworks and an over conservative value chain which fails to adapt to modern technologies and solutions.

In this report, we, however, argue that this potential will inevitably materialize, due to, on the one hand, the obvious economic rationale, and on the other hand, the fact that it represents an alternative to weak and lagging infrastructure development in many regions of the world.

After all, can we reasonably imagine that the homes we will build in 30 years will have no rooftop solar panels (not to say walls and facades with integrated photovoltaic capacities)? And will we thus truly consider living in antiquated buildings without such provisions by then?

(1) BloombergNEF (2021), Realizing the potential of customer-sited solar. © OECD/IEA (b) (2021), Net Zero by 2050.
(2) BloombergNEF estimates a potential of around 2,200GW, which can approximately be translated into 2,500TWh. Schneider Electric Research.
(3) Given the lack of granular data on penetration per type of building available for both the BloombergNEF and the International Energy Agency forecasts, average conversion factors are being used to recompute the equivalent square meters of floor area.
(4) This is still around eight times more capacity deployment than current (2020 data). BloombergNEF (2021), Realizing the potential of customer-sited solar.
(5) See detailed study on a policy blueprint from BloombergNEF (2021) and Schneider Electric. BloombergNEF (2021), Realizing the potential of customer-sited solar.
(6) The construction industry has notably made virtually no productivity gains in the last decades. A positive disruption, enabled by digital technologies, could, however, strongly change the case by 2050. Schneider Electric (b)(2021), Back to 2050.

A new energy system is emerging

The potential for distributed generation, currently ranging around 7,500TWh, could reach 25,000TWh by 2050. Out of this potential, two scenarios for 2050 project 8,000TWh to 16,000TWh of generation, depending on the policy context.

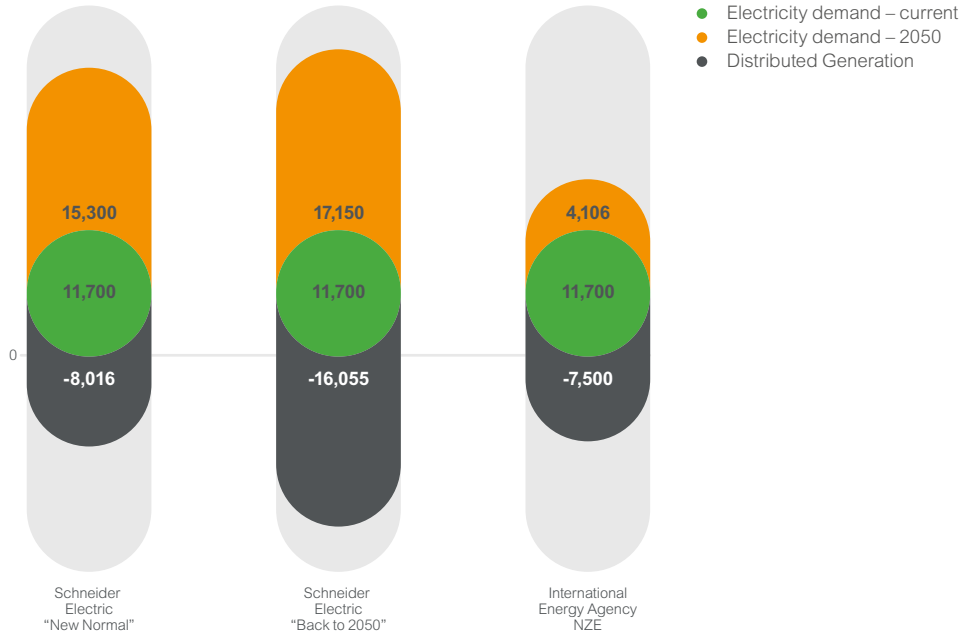
Such figures must be put in perspective of the actual electricity demand in buildings (where those capacities are deployed). Yet, different scenarios also show different electricity demand in buildings. All, however, assume a rather significant electrification of the energy mix in buildings, generally above 70%, with major impact on demand. Forecasts for these scenarios typically range between 16,000TWh and 29,000TWh[1].

Figure 10 maps both the forecast in electricity demand for buildings to 2050, alongside the forecast for distributed generation presented earlier, for the two scenarios of Schneider Electric ("New Normal" and "Back to 2050") and the International Energy Agency NZE scenario.

The share of distributed generation in total electricity mix varies between 30% ("New Normal") and around 50% ("Back to 2050", NZE). In other words, a considerable share of electricity demand is in fact offset by distributed generation, and this goes with significant positive effects on consumer bills.

More importantly, more than the entire increase in electricity demand to 2050 (stemming from electrification) is actually offset by distributed generation in the scenarios "Back to 2050" and NZE[2]. **This also means that a considerable potential exists to mitigate additional infrastructure costs from electrification of the energy system, and that both should in fact advance together.**

Figure 10 – Distributed generation vs building electricity demand (TWh)



(1) For instance, the Stated Energy Policy Scenario (STEPS) shows building electricity demand at around 20,000TWh, while the "Net Zero Emissions" (NZE) scenario ranges around 16,000TWh. The Schneider Electric "Back to 2050" scenario ranges — as a comparison point — at around 29,000TWh. It is important to note that these forecasts do not include additional electricity needs for mobility charging within building premises, estimated at around 6,000TWh globally by then. © OECD/IEA (2021), World Energy Outlook. Schneider Electric (b)(2021), Back to 2050.

(2) This figure is lower in the "New Normal" scenario, yet still at around 50%, a considerable offset to necessary infrastructure upgrades. Also worth noting is that electricity demand projected here does not include the need for mobility charging within buildings, which is estimated in the "Back to 2050" scenario to be around 6,300TWh. Schneider Electric (b)(2021), Back to 2050.

A key takeaway of such a review is that the current prevailing view in relation to electricity supply and grid development is likely to be misconceived. **The unfolding of distributed generation is a true game changer for the building stock, and the supporting grid infrastructure**, with four key outcomes:

Outcome 1: distributed generation can offer a key alternative to expensive (and slow) grid upgrades, helping to fast-forward the electrification of the stock. This is obviously dependent on the ability to harness the energy locally and store it for further use[1].

Outcome 2: a key reality of grid infrastructure is that costs are not even across different uses. The cost of low-power distribution infrastructure is generally higher (per kW) to that of high-power lines. Since the bulk of the potential lies within individual households, maximizing the potential there thus enables optimizing the necessary investment in infrastructure on low-power infrastructure, hence overall grid costs, with positive effects across all ratepayers. This would be particularly relevant in rural areas, and notably constitutes a key alternative to natural grid development in new economies[2].

Outcome 3: in many areas, we are likely to see buildings (or districts) turning into energy centers, i.e., producing more energy than they actually consume over the course of a day (even after including storage provisions for optimized self-consumption). As such a transition materializes, the way distribution grids are designed, and their role, will significantly evolve. The grid of the future is likely to resemble more that of a platform than the traditional distribution delivery system we have known for decades.

Outcome 4: more importantly, such provisions also lead to significant savings on energy expenses for consumers. We have already alluded to this point earlier. As tipping points are reached, and new business models emerge, this evolution is likely to become inevitable, and unstoppable.

(1) See notably the potential of thermal energy storage solutions, which could provide for high levels of storage at competitive costs. Schneider Electric (b)(2021), Back to 2050.
(2) It would also contribute, through greater balancing of demand across different times of the day, to mitigate the recourse to peakers, further reducing costs and accelerating decarbonization.



4 Modern issues will be solved by modern solutions, and require a modern policy framework



Key takeaways

We estimate the current potential of distributed generation at around 7,500TWh, ramping up to 25,000TWh by 2050.

Many technological enhancements and collateral innovations contribute to this increase, besides building footprint natural evolution, and they mainly materialize on new constructions. As a consequence, new constructions represent 80% of the total harvesting potential by 2050.

Individual households naturally represent the segment with the largest potential (66% in 2050), yet all other building types show growing potential, particularly "horizontal" commercial buildings such as retail centers and warehouses.

While a significant share of the potential today lies in North America and China, two-thirds of the future potential to 2050 would materialize in new economies, notably in Africa and India. This is largely because of the strong construction dynamics of these regions. Yet, the deployment of distributed generation is truly global.

Two scenarios of development of this potential to 2050 bring distributed generation at around 8,000-16,000TWh, or 30 – 50% of electricity demand in buildings by then. The most ambitious scenario, which can be compared to the International Energy Agency NZE scenario, shows a forecast twice higher (16,000TWh compared with 7,500TWh for the NZE scenario).

In fact, distributed generation appears to be a major game changer, driven by strong and compelling economics (a sizeable share of energy demand provided at free or near-free marginal cost), and the fact it represents an alternative to traditionally weak infrastructure. Yet, its benefits go beyond this. Distributed generation will also contribute to fast-forward electrification, thus decarbonization, as it can potentially limit the impact on (and cost of) grid infrastructure upgrades. Since it also contributes to optimize low-power (more expensive) distribution connections, it also contributes to lower grid costs overall, another major economic benefit for all ratepayers.

We thus argue in this paper that existing forecasts for distributed generation are likely to be underestimated at global level. We recognize key roadblocks may come along the way, notably the lack of supportive policies for decarbonization[1] and a rather conservative value chain, nevertheless, we consider the rationale for consumer-led demand to be so strong that such development is likely to be inevitable. More importantly, as the potential for accelerated decarbonization and economic benefit becomes obvious to policymakers, we can assume policies to naturally evolve toward a more favorable environment globally.

As a final takeaway, buildings of the future will become energy centers, supplying and sharing energy to their surroundings, a critical transformation of current energy systems, which needs both to be accelerated and prepared for.

A modern policy framework

There is a clear blueprint for fostering the development of distributed generation, building on existing experience from countries having traveled that journey already, as depicted by BloombergNEF[2].

- Kick-off: at low levels of penetration, the conditions need to be created for a positive case to emerge, despite suboptimal value chains and costs.
- Focus on new build: the economic rationale is very strong on new builds with the key roadblock being the value chain and its relative inability to integrate new solutions. Regulations thus play a fundamental role in forcing the shift rapidly, notably through mandates and installation codes. Also, creating a sizeable market for distributed generation will be a powerful enabler for the structuring of the value chain. This could further be enhanced by additional incentives on retrofits.
- Introduce storage: as penetration increases, it becomes much more attractive to integrate storage alongside generation to provide for flexibility. The value of rooftop solar typically goes down as penetration increases since all generation capacities essentially produce at the same time. Incentivizing for storage, however, calls for more fundamental market reforms, including the wide adoption of Time of Use schemes, payments for grid services, the introduction of demand charges, etc.
- Finally, and in addition to the above, other aspects must be carefully reviewed. They include split incentives between building owners and dwellers, misaligned utility incentives, lack of financing support, etc.

The sooner governments engage on such ambitious reforms, while clarifying the long-term commitment, the faster the intrinsic benefits of distributed generation will be realized, among which, decarbonization comes first.

(1) See notably BloombergNEF (2021), Realizing the potential of customer-sited solar.
(2) The paragraph that follows comes from the joint BloombergNEF and Schneider Electric study. BloombergNEF (2021), Realizing the potential of customer-sited solar.

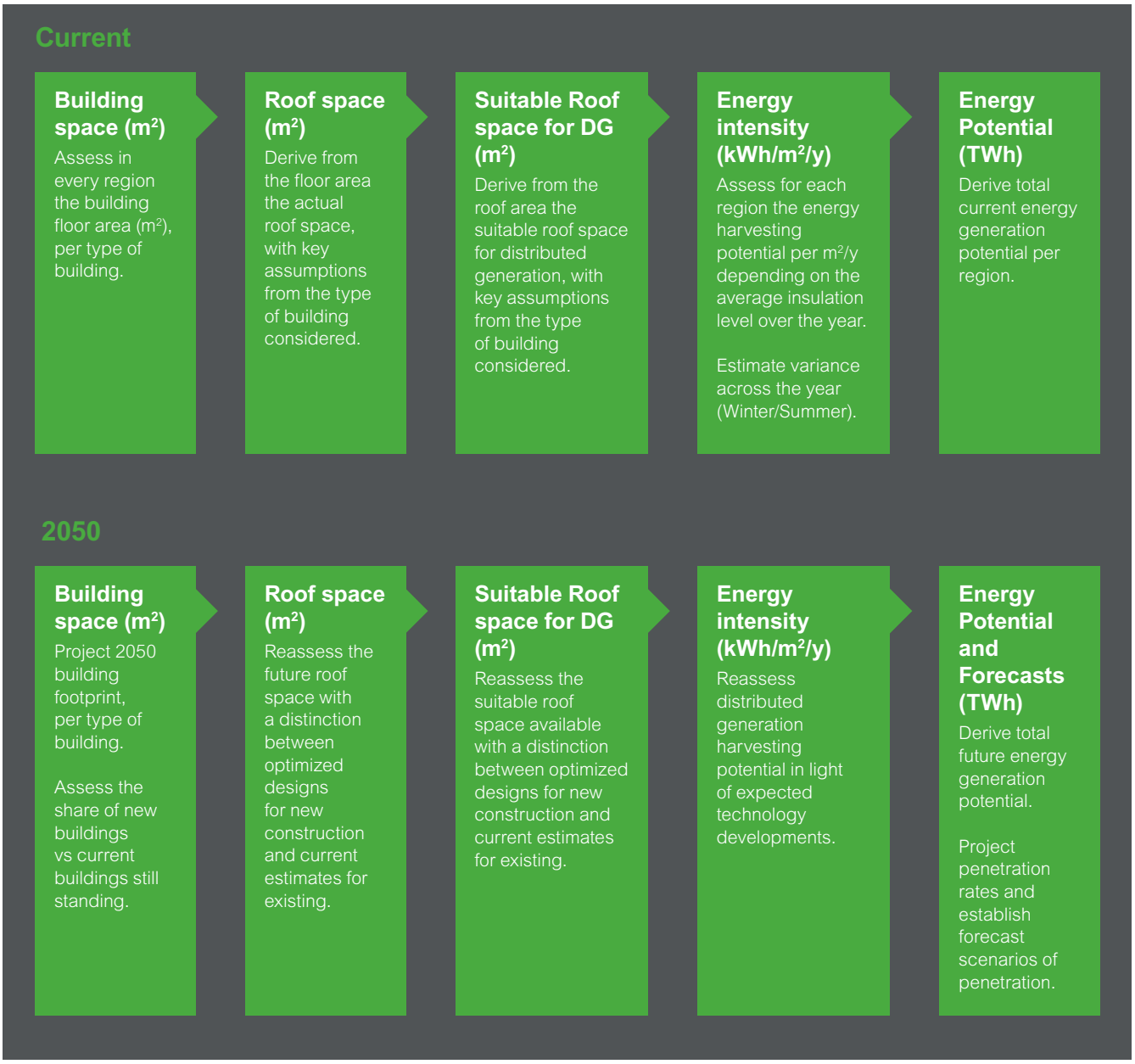


5 Annex



Modeling and assumptions

Figure 1 provides a key overview on the steps followed.



Step 1: assess the building floor area (in square meters) and generate a forecast for 2050

We look at four distinct data sets that we converge into one forecast[1]. There are notable differences between them, both for the current footprint (ranging between 200 – 230 billion square meters) and for the projected one (360 – 430 billion square meters), highlighting key uncertainties. We take a central approach with a growth from 224 billion square meters currently to 415 billion square meters by 2050.

We then need to provide a more granular view on the split per key segment. We have decided to focus on four key segments: individual households, collective residential buildings, "vertical" and "horizontal" commercial buildings. The reason for this is that the potential penetration of distributed generation (the suitable roof surface) considerably varies across these segments, as well as patterns of use. As this data is not readily available, we have to take a number of assumptions:

- The split between commercial and residential areas is available for current floor area[2]. We extrapolate it to 2050 by assuming a convergence of new economies to similar splits as those of mature economies currently, with no change for mature economies.
- The split between individual and collective residential can be retrieved from a variety of sources for current floor area in select geographies[3], and we extend those findings to other regions. We have to, however, make a clear distinction between rural and city development patterns as they vary strongly from one region to another, and we assume collective residential are located only within cities. Urbanization rates (both current and projected) help refine the actual split per region[4].
- The split between "vertical" and "commercial" buildings can also be estimated. We have leveraged data available in key geographies of North America, Europe and India and have extrapolated it for other regions[5] (Figure 11).

Figure 11 – Current building floor area (bn m²)

Current building floor area	Current bn m²	Commercial buildings bn m²	Individual Households bn m²	Collective residential bn m²
Africa	18	1	12	5
China	57	11	20	26
India	16	1	11	4
North America	38	10	23	5
Europe	30	9	10	10
ASEAN	16	2	9	5
Latin America	19	2	15	3
Other Asia	10	1	6	3
Middle East	8	2	4	2
OECD Pacific	2	1	1	0
Eurasia	10	3	3	3
Total	**224**	**41**	**115**	**67**

Then we estimate the share of new constructions versus existing assets still standing by 2050. The share of new buildings comes from the difference between both 2050 projected demand and current footprint, but also includes the actual volume of reconstructions (following demolition). Similarly, the share of buildings still standing will be impacted by the volume of demolitions. The International Energy Agency estimates this to amount to around 80 billion square meters by 2050[6]. While the data is split between both OECD and non-OECD countries, we affect key volumes to various regions of the world depending on their current floor area, and we affect these volumes across different building segments by assuming 70% of reconstruction will concern individual households, 20% collective residential, and the rest commercial buildings (Figure 12).

(1) ©OECD/IEA (2013), Technology Roadmap Energy Efficient Building envelopes. © OCED/IEA (b)(2013), Transition to Sustainable Buildings. UNEP (2016), Towards zero-emission efficient and resilient buildings. SDSN & FEMM (2019), Roadmap to 2050.
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(6) ©OECD/IEA (2013), Technology Roadmap Energy Efficient Building envelopes.

Figure 12 – 2050 building floor area (bn m²)

2050 building floor area	New constructions			Existing buildings still standing		
	Commercial buildings bn m²	Individual Households bn m²	Collective residential bn m²	Commercial buildings bn m²	Individual Households bn m²	Collective residential bn m²
Africa	11	19	15	0	7	4
China	8	11	31	9	4	22
India	11	22	15	0	7	2
North America	6	20	5	8	15	3
Europe	3	9	4	8	4	9
ASEAN	5	9	8	1	5	4
Latin America	7	19	5	1	9	1
Other Asia	2	1	2	1	4	2
Middle East	2	7	4	1	2	2
OECD Pacific	0	1	0	0	1	0
Eurasia	2	4	3	3	1	3
Total	**58**	**122**	**91**	**33**	**59**	**51**

Step 2: assess exact roof space suitable for distributed generation

Step 2 starts with assessing the corresponding roof space from the computed floor areas. We leverage various existing studies to come up with an estimate(1).

However, estimates vary significantly across sources. Deng et al. for instance estimate they vary between 17% and 100% (depending on the type of building). Taminiau and Byrne see them ranging between 36% and 58%, with an average at 45% for New York City. Apur and Egis (focusing on the Paris area) estimate collective residential at 15 – 20%, individual households at 50 – 60%, commercial buildings between 13 – 15% (for "vertical" settings) and 100% (for "horizontal" ones).

Roof space is not enough to determine how much distributed generation can be deployed as a percentage of that roof may already be occupied (HVAC chillers for instance) or be improper for solar (shaded areas, poor orientation, etc.). The suitable roof space is thus a share of the total roof space, and it must again be assessed. We leverage the same sources to come up with an estimate.

Once again, estimates vary. Apur and Egis are more conservative, with suitable roof spaces ranging around 10 – 20% (yet, they work on a fairly constrained Paris area). Deng et al. project a global average of around 33%, while Taminiau and Byrne estimate this ratio to peak at 70% in New York City. One thing is for sure, these ratios are likely to differ significantly from one region to another. Our estimate takes a central case assumption (Figure 13).

As economics become more interesting for distributed generation over time, we can expect building designs to accommodate more of it and maximize the benefit for consumers and the asset value. Our 2050 estimates account for:

- limited increase of Floor-to-Roof ratios (we do not expect at this stage building designs to fundamentally transform – an assumption which could be requalified at a later stage); and
- a maximization of suitable roof space (roofs designed specifically to accommodate greater surfaces of distributed generation).

It is worth noting that these ratios could in fact turn out to be significantly higher if a fundamental rearchitecting of building spaces emerges as a consequence of the clear economic value of distributed generation. Also, we have not taken into account the potential of harvesting distributed energy on building facades, a concept often coined as building-integrated photovoltaics(2). Again, a potential upside. Our estimates in this study thus remain conservative.

Figure 13 – Key ratios to assess distributed generation suitable space (%)

Suitable Roof space	Floor to Roof		Suitable Roof space	
	Current	2050	Current	2050
Individual Households	55%	55%	50%	70%
Individual HH Rural	55%	55%	50%	50%
Collective Residential	20%	20%	10%	70%
Commercial Horizontal	100%	100%	50%	70%
Commercial Vertical	15%	20%	10%	70%

(1) Apur and Egis (2015), Analyse de potentiel solaire. Toitures du Grand Paris. Deng et al (2015), Quantifying a realistic, worldwide wind and solar electricity supply. Taminiau J., Byrne J. (2020), City-scale urban sustainability: Spatiotemporal mapping of distributed solar power for New York City.
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Step 3: assess the energy potential of distributed generation

The next order of business is to derive from the suitable surface of distributed generation the actual potential for energy generation. We do not consider here anything related to potential curtailments and assume storage exists to maximize the use of existing installations in place, a key assumption obviously.

Solar irradiation varies from one region to another. We retrieve data (kWh/kW power) from Global Solar Atlas[1] (Figure 14). With current solar panel outputs of around 160W per square meters (giving us a power output per square meter), we can retrieve the potential of energy generation from the surface of distributed energy estimated in step 2. We apply to these values a downgrading factor of around 20%, to account for losses in the "Balance of System", a rather conservative assumption.

Figure 14 – Solar irradiation (kWh/kWp (per day))

	kWh/kWp (per day)		
Solar Irradiation	Min	Max	Average
Africa	4.48	4.74	4.63
China	2.95	3.17	3.08
India	4.21	4.51	4.41
North America	4.04	4.73	4.34
Europe	3.07	3.80	3.47
ASEAN	3.33	3.92	3.62
Latin America	3.93	4.27	4.08
Other Asia	2.93	3.93	3.60
Middle East	4.54	5.37	4.92
OECD Pacific	4.08	4.93	4.60
Eurasia	2.84	3.02	2.94

For 2050, we also assume that, with similar irradiation levels, progress on solar technologies will lift power ratings by around 30%, enabling 30% increased production per square meter.

Step 4: forecasting penetration of distributed generation

We base our forecasts on two scenarios previously developed by Schneider Electric[2]:

- "New Normal": in the current policy context (no further changes), we explore the "natural" rate of adoption of new technologies reaching maturity.
- "Back to 2050": a forceful policy context to reach a greenhouse gas emissions trajectory consistent with a 1.5-degree global warming by the end of the century, and effectively promoting the development of distributed generation globally.

In the "New Normal" scenario, we estimate the economics of distributed generation become obvious globally only in the decade to 2040, due largely to non-supportive policies slowing down its adoption. New constructions ramp up faster because of more compelling economics, notably in mature economies, with 40% of new buildings to 2050 equipped (compared to 30% for new economies). The trend is reversed on existing assets, with a more significant penetration in new economies (about 30% of the stock equipped, essentially due to lower resilience of the existing infrastructure fueling consumed-led demand) compared to mature economies which continue to lag behind (lack of an effective value chain, limited incentives).

In the "Back to 2050" scenario, supportive policies force the case in new constructions by 2025-2030 (this happens faster in mature economies but is quickly followed by new economies). By 2050, around two-thirds of the residual stock is also equipped with distributed generation.

(1) Global Solar Atlas (2021).
(2) Schneider Electric (b)(2021), Back to 2050.

Key results

We provide here only data for average values of solar irradiation. In practice, varying irradiation levels move those projections by +/-5%.

Current potential

Figure 15 – Current distributed generation potential

Current Distributed Generation potential	Individual Households	Collective Residential	Commercial Horizontal	Commercial Vertical	**Total**
Irradiation level			Average		
Africa	748	23	26	2	**799**
China	807	79	240	19	**1,144**
India	675	15	22	2	**714**
North America	1,355	22	362	19	**1,758**
Europe	484	35	211	16	**747**
ASEAN	447	17	36	3	**503**
Latin America	795	11	54	4	**864**
Other Asia	276	11	24	2	**313**
Middle East	272	11	69	4	**355**
OECD Pacific	87	1	21	1	**110**
Eurasia	135	10	59	5	**208**
Total	**6,081**	**234**	**1,124**	**77**	**7,516**

Future potential

Figure 16 – 2050 distributed generation potential – new constructions

	New constructions				
2050 Distributed Generation potential	Individual Households	Collective Residential	Commercial Horizontal	Commercial Vertical	**Total**
Irradiation level			Average		
Africa	2,148	609	586	333	**3,677**
China	819	838	293	151	**2,100**
India	2,340	575	576	328	**3,818**
North America	2,100	191	408	145	**2,844**
Europe	762	134	132	68	**1,096**
ASEAN	781	267	229	130	**1,407**
Latin America	1,891	171	376	193	**2,631**
Other Asia	105	52	69	36	**261**
Middle East	806	186	186	66	**1,244**
OECD Pacific	150	9	29	10	**198**
Eurasia	316	66	69	36	**487**
Total	**12,217**	**3,099**	**2,952**	**1,496**	**19,763**

Figure 17 – 2050 distributed generation potential – existing assets

2050 Distributed Generation potential	Existing buildings still standing				
	Individual Households	Collective Residential	Commercial Horizontal	Commercial Vertical	**Total**
Irradiation level	Average				
Africa	584	21	8	1	**614**
China	228	85	252	19	**584**
India	553	13	7	1	**573**
North America	1,130	16	412	22	**1,579**
Europe	235	38	246	19	**538**
ASEAN	318	17	29	2	**365**
Latin America	666	7	43	3	**719**
Other Asia	224	11	21	2	**259**
Middle East	170	10	72	4	**257**
OECD Pacific	77	0	24	1	**102**
Eurasia	41	10	67	5	**123**
Total	**4,225**	**228**	**1,181**	**79**	**5,714**

Forecasts

Figure 18 – Distributed generation scenarios

2050 Distributed Generation Scenarios	Schneider Electric New Normal scenario					Schneider Electric Back to 2050 scenario				
	Individual Households	Collective Residential	Commercial Horizontal	Commercial Vertical	**Total**	Individual Households	Collective Residential	Commercial Horizontal	Commercial Vertical	**Total**
Africa	1,206	189	152	85	**1,632**	2,062	410	240	134	**2,847**
China	268	260	85	32	**645**	680	600	244	54	**1,578**
India	902	177	149	84	**1,311**	1,927	383	277	155	**2,742**
North America	953	78	137	36	**1,204**	2,099	135	391	58	**2,683**
Europe	459	57	41	10	**567**	719	111	165	15	**1,010**
ASEAN	330	85	65	33	**513**	765	184	121	60	**1,129**
Latin America	1,106	53	106	49	**1,315**	1,846	116	198	90	**2,249**
Other Asia	54	17	18	9	**98**	214	41	42	15	**312**
Middle East	293	59	66	17	**434**	634	128	126	31	**919**
OECD Pacific	83	4	14	3	**104**	147	6	25	4	**183**
Eurasia	144	21	20	8	**192**	281	49	61	12	**403**
Total	**5,798**	**1,000**	**853**	**366**	**8,016**	**11,375**	**2,162**	**1,890**	**628**	**16,055**

Sensitivity analysis

We look here at the sensitivity of our results on key parameters.

Building footprints

We are assessing the impact of the projected floor area to the potential of distributed generation. In the evaluation currently presented, we have used the projection of floor area described above. Now, projecting floor area is subject to many uncertainties, as was highlighted in our recent Schneider Electric scenario exercise[1].

Projected floor area to 2050 reaches 415 billion square meters by 2050 (with around 324 billion square meters for residential, and 91 billion for commercial buildings), compared to 224 billion square meters currently. As described above, other external forecasts range between 360 and 430 billion square meters.

Our own estimates on this forecast vary across scenarios between 402 billion square meters ("Back to 2050" scenario, with 335 billion square meters of residential area and 67 billion square meters of commercial buildings) and 431 billion ("New Normal" scenario, with 354 billion square meters of residential area and 77 billion square meters of commercial buildings), or a variation of around +/-4%. The distribution across sectors is also changing with a greater residential footprint and a lower commercial one.

This will naturally have material impacts on the potential of distributed generation (Figure 19). We find, however, the changes to be limited, ranging well below 10%. The conclusion holds true even if we take into consideration the lowest of the external forecasts available (at 360 billion square meters, as discussed above).

Figure 19 – Sensitivity analysis – building footprints

Sensitivity – Buildings	Current	2050 projected	New Normal	Back to 2050
Residential floor area (sqm)	182	324	354	335
Commercial floor area (sqm)	41	91	77	67
Distributed generation potential (TWh)	**7,516**	**25,477**	**27,415**	**24,700**

Another limiting factor could be the extent to which such solutions develop in new economies' rural areas. The footprint of individual households in new economies' rural areas (excluding China) represents around 30% of the total footprint of individual households. This remains roughly stable to 2050 in our baseline projection and translates into a similar impact on the distributed generation potential. We believe, however, that those regions might in fact be prime customers of such alternative energy solutions, which is why we have included them in our report, although the solutions and delivery models are likely to differ from cities and mature economies, at least in the short run.

Floor-to-Roof and Suitable Roof Space

In this study, we have not taken any assumption on changes to the way current buildings are built and how this translates into changes in Floor-to-Roof ratios. Yet, we need to acknowledge that, as the economics of distributed generation become more compelling over time globally (and possibly sooner than anticipated), it will become common sense to evolve building configurations to maximize their potential penetration. The obvious reason to this would be that building assets would hold more value over time if their installed capacity is greater, as dwellers would find greater interest in maximizing their (free) distributed generation potential. Beyond Floor-to-Roof ratios, we can also anticipate that roof surfaces will be growingly dedicated to harnessing distributed generation, unlike today where roofs are often used to position other equipment (such as chillers). The Suitable Roof Space is thus likely to increase as a result of such design evolutions and we have taken here key assumptions on maximizing the potential (up to 70% across all building types).

We define four use cases to explore the sensitivity of our analysis to these key parameters (Figure 20):

- **Use case 1:** we assume here no change in building designs from today (hence no change on either the Floor-to-Roof or the Suitable Roof Space ratios). The potential of distributed generation is thus mainly driven by the increase in building stock. It still increases from 7,500TWh to 17,000TWh by 2050. This corresponds to a 30% reduction compared to our projected estimate.
- **Use case 2:** we increase the Floor-to-Roof ratio by 20% across the board (while keeping our baseline estimate for Suitable Roof Space at 70%). In practice, this means new buildings are designed to be more "horizontal", and with greater roof surface. This change increases the potential of distributed generation by 11%.
- **Use case 3:** we do not change the Floor-to-Roof ratio (same building configurations), but we maximize the Suitable Roof Space to 100% (compared to 70% in our baseline). This increases the potential of distributed generation by 33%.
- **Use case 4:** we combine both use cases 2 and 3 and reach a 50% increase.

While both ratios have a material impact on the potential of distributed generation, the most sensitive parameter is thus the Suitable Roof Space, which also turns out to be the least complicated parameter to change, as it has no impact on floor area.

(1) Schneider Electric (b)(2021), Back to 2050.

Figure 20 – Sensitivity analysis – technology and design

Sensitivity – Rooftop	Distributed Generation potential (TWh)	%
UC1 – Suitability ratio to current levels	17,205	-32%
Report baseline (2050)	25,477	0%
UC2 – Floor-to-Roof ratio increased by 20%	28,391	11%
UC3 – Suitability ratio increased to 100%	33,947	33%
UC 4 – Floor-to-Roof +20%, Suitability to 100%	38,109	50%

Solar Photovoltaic technology improvement

Another key assumption we took in this exercise is a projected improvement of solar photovoltaic technology, with 30% increase in energy harvesting capacity (per square meter) by 2050. This is an important assumption. Would no progress be made on that front by 2050, our modeling estimates that the projection would be reduced by around 20%, down from 25,000TWh to around 20,000TWh.

Conclusion

The above exercise on modeling the potential distributed generation is based on a significant number of assumptions on building footprint evolution, building design evolutions and solar photovoltaic technology improvements. We find that the two most sensitive parameters to our modeling exercise are the evolution of the suitable roof space ratio (around +/-30%) and the rate of technology improvement on solar technologies (around +/-20%).

Yet, both are also likely to be the most prone to positive evolutions going forward:

- As the economics of distributed generation invariably improve, the suitable roof space on new constructions is also bound to increase, given the extra value such development would provide on new assets, and the benefits to dwellers.
- Given the amount of research devoted to the development of new solar technologies, it can also be reasonably expected that progress will be made in energy harvesting capacity in the coming decades.

This is why we argue that the potential evaluated above is actually likely to be conservative.

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