Rooftop solar : a key tool in the energy transition, if properly managed

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Confidential

Key points

The unprecedented growth in photovoltaic energy - 345 to 375 GW installed worldwide by 2023 alone - is largely driven by decentralised installations on the roofs of homes or commercial and industrial buildings. According to some estimates, rooftop solar, also called distributed solar, will account for almost half of the total power installed each year, making it one of the key technologies in the energy transition, even though it is still underestimated by operators and governments alike, who are used to centralised management of their electricity grids. And this trend is set to accelerate, driven by the continuing fall in the price of solar panels and storage batteries, as well as by incentive policies. Whether they are seeking to curb energy crises, meet their environmental targets or simply reduce their energy imports, many governments have encouraged the adoption of solar power, simplifying the regulations governing these installations or introducing financial incentives such as feed-in tariffs, tax credits for the purchase of equipment, or purchase subsidies.

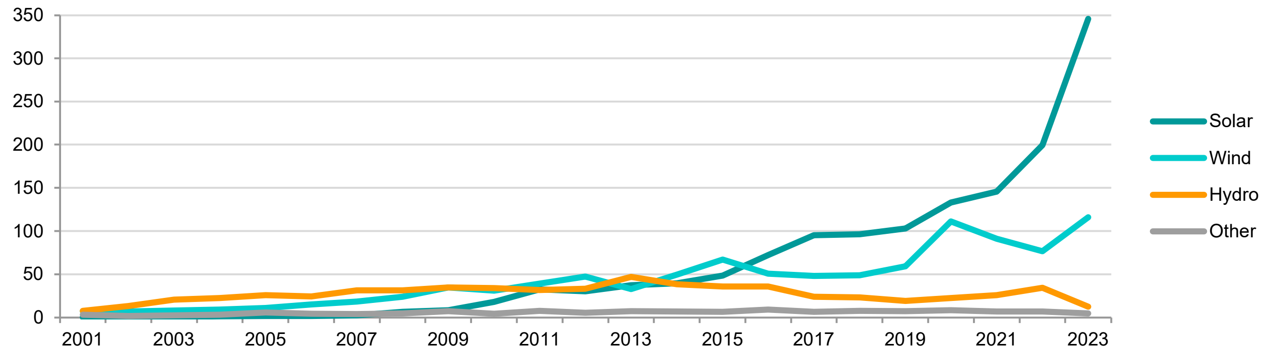
The deployment of decentralised solar energy has enabled some countries to respond to major crises, such as Puerto Rico after the Irma and Maria hurricanes. It is not, however, a universal panacea. In South Africa, individual installations have made a major contribution to helping the national operator Eskom overcome the crisis in which it was embroiled, giving it the room to manoeuvre it needed to stabilise its network and repair its thermal power stations. The same was not true in Lebanon, where the adoption of solar energy has, on the contrary, exacerbated the crisis at Electricité du Liban, depriving it of income without enabling it to benefit from its customers' surplus production. The difference between these two examples, examined in detail here, lies above all in the technical and financial regulatory support for the deployment of rooftop solar. Whereas South Africa and its municipalities have facilitated connection and offered self-producers the possibility of reselling their surplus, Lebanon, paralysed by the political crisis, has not managed to adopt the appropriate legislative framework, while EDL is seeking to protect its monopoly on electricity production.

States seeking to develop solar self-generation without jeopardising their grid or the incumbent operator must therefore take a number of regulatory and financial parameters into account. In addition to setting up a net metering system - practically a prerequisite for the adoption of rooftop solar - they must also ensure that feed-in tariffs and the allocation of fixed connection costs take into account the interests of both consumers and the incumbent operator. And even if there is no example of a large-scale blackout caused by the large-scale deployment of distributed solar, it is also a technical challenge.

1. Distributed solar power: a growing part of the global electricity mix

The installation of new solar power generation capacity has never been as massive as it was in 2023, reaching a total of between **345.8 GW**[1] according to figures from the specialist firm Ember, and **374.9 GW** according to the International Energy Agency (IEA). There has been an unprecedented acceleration in the construction of new solar capacity, both historically and in relation to other energy sources, renewable or otherwise.

Graph 1: Installations of additional renewable energy capacity, per year, in GW



Source : Ember Climate

1.1. Nearly half of all installations?

Within this unprecedented volume, a **significant proportion is made up of distributed solar installations**, installed on the roofs of private homes and collective residences, but also on industrial and commercial buildings, factories, warehouses, shopping centres, car park shadings, etc.

There are no authoritative figures for the total number or capacity of these installations - also known as rooftop solar – worldwide, nor for their proportion of new capacity installed in 2023. These small-scale installations - ranging from a few kW to several tens of MW - are not included in any global or, in many countries, national census.

However, there is every reason to believe that they **represent a significant proportion of total solar energy installations**, **ranging from more than a third to almost half of the total**. The association of European companies in the sector, **GlobalPower Europe, estimates that decentralised systems made up 47% of installations worldwide** between 2020 and 2022[2] . According to this organisation, the **total capacity of decentralised solar power installed in 2022, 118 GW, was practically identical to that of the new solar power plants built that year** (121 GW). The more conservative IEA estimated this share at 37% on average over the period 2013-2019[3].

The situation varies greatly from country to country; as we shall see below, the installed capacity of rooftop solar in South Africa is more than twice that of the country's existing utility-scale solar plants. In the United States, on the other hand, rooftop solar accounts for a small share of the total solar installed capacity[4]. But there are indications that **the phenomenon is structurally underestimated, even in countries where solar energy is highly developed**. In China, for example, the boom in private installations by individuals and

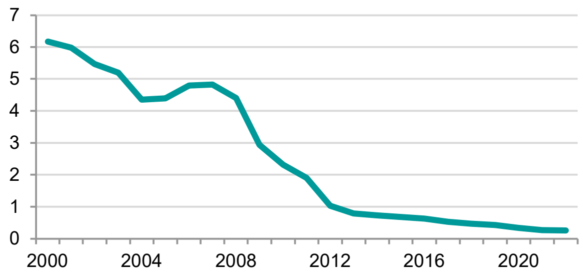
[1] 2023's record solar surge explained in six charts, Ember Climate, 30 May 2024
[2] Global Market Outlook For Solar Power 2023 - 2027, SolarPower Europe, 2023
[3] Renewables 2020 - Solar PV, International Energy Agency
[4] Why China's GDP Leaves Out Rooftop Solar Power Production, *Bloomberg*, 19 January 2024

businesses from 2021 onwards would explain the **growing discrepancy between electricity production and consumption figures, which, in 2023, was equivalent to 3.5% of national electricity production[5]**.

1.2. Massification set to increase

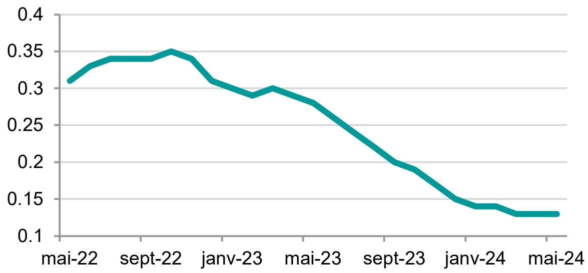
Decentralised solar energy is set to continue its strong growth in most regions of the world, driven by the **continuing fall in the price of solar modules**, the main component of solar panels. After being divided by 25 between 2000 and 2022 (Figure 1), prices are continuing to drop: spot prices fell some 50% in 2023 according to the IEA[6] , a trend confirmed by other sources, and which continued into the first half of 2024 (Figure 3). The IEA also notes a **historic increase in photovoltaic module production capacity**, which tripled since 2021, leading it to estimate that global supply (more than 80% Chinese) will reach 1,100 GW/year by the end of 2024.

Graph 2: Global price index for photovoltaic panels, USD/Watt



Source: IRENA via Our World In Data

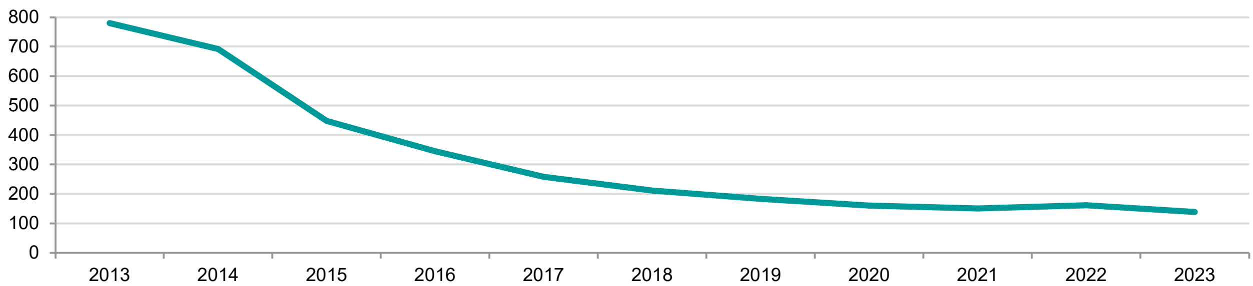
Graph 3: European spot price, standard monocrystalline solar modules, €/W



Source: PVXchange Price Index

The **fall in the cost of batteries** is also likely to accelerate the installation of solar panels: they considerably improve the usefulness and profitability of the system, making it possible to **consume electricity in the evening or at night, compensate for power cuts, and generate additional income[7]** Their prices were divided by almost 6 between 2013 and 2023 and, after a slight rise in 2022, the trend is downwards again (Figure 4).

Graph 4: Average cost of lithium-ion batteries, USD/kWh



Source: BloombergNEF

[5] Why China's GDP Leaves Out Rooftop Solar Power Production, *Bloomberg*, 19 January 2024
[6] Renewables 2023 - Analysis and forecast to 2028, International Energy Agency, January 2024
[7] Electricity storage: at the dawn of an energy revolution, Global Sovereign Advisory, September 2023

Finally, many countries are pursuing **policies to encourage the adoption of decentralised solar power**, including emerging countries that are heavily dependent on coal or gas. **At the beginning of 2024, Indonesia abolished the limit on the maximum capacity of installations** and the charges that had previously applied to industrial uses[8]. In October 2023, **Bangladesh made it compulsory to install solar panels** on new buildings over 92m². The power requirement is symbolic but means that a net metering system must be installed at the time of construction, making it easier to install panels later. In February, **India** announced that it was simplifying its connection and billing rules[9]. At the same time, **Prime Minister Narendra Modi granted USD 9 billion in subsidies to encourage private individuals to install solar panels**. The subsidies range from USD 360 to over USD 900 for each installation, depending on its output[10].

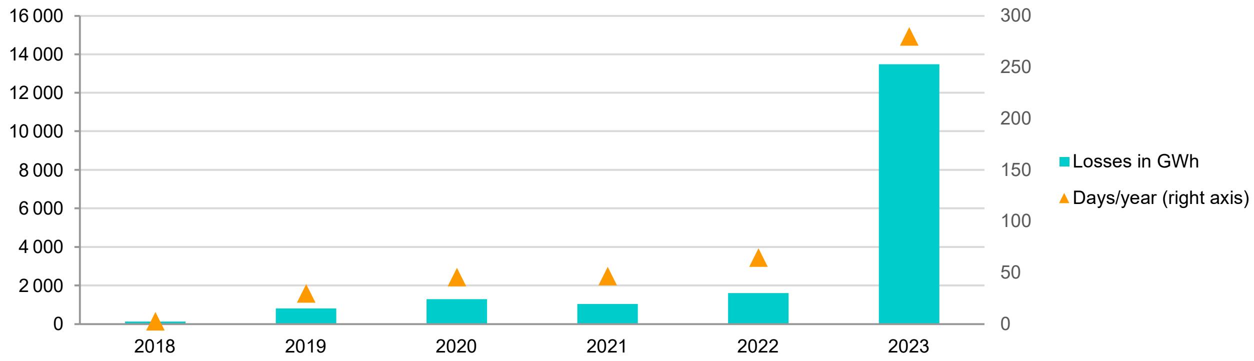
The trend is similar in developed countries. In a bid to reduce its dependence on Russian gas following the outbreak of war in Ukraine in February 2022, **the European Union adopted an "European Solar Roof Initiative"** as part of its Repower EU regulatory package**, which includes plans to equip all new non-residential buildings over 250 m² from 2026 and limit the time required to obtain planning permission**. Distributed solar power will thus make a massive contribution to the EU's target of reaching 600 GW of installed solar capacity by 2030 (260 GW by 2023). However, transposition will depend on the Member States. Scotland, for its part, also simplified its regulations and, above all, eliminated the capacity limit (previously 50 kW) in April, aligning itself with England, which had abolished its own much higher limit (1 MW) six months earlier[11] .

2. In South Africa, rooftop solar power helped Eskom turn its network around

2.1. An enduring energy crisis

After significantly increasing the number of people connected to the electricity grid - from less than 60% of the population in 1996 to more than 80% in 2006 - and generating a record volume of electricity in 2007 (263.4 TWh)[12] , **South Africa's state-owned electricity company Eskom has been facing a major crisis since 2007**. This crisis has been caused by a number of technical factors - drought affecting hydroelectric dams, breakdowns at coal-fired power stations, etc. - as well as political and financial factors. Under pressure, the group prioritized maximising its production, notably by **postponing maintenance operations** on its power plants, creating a **vicious circle of increasingly serious breakdowns**.

Graph 5: Eskom load shedding, by fiscal year, in days/year and undistributed GWh



Source: Eskom annual reports

[8] Developments in Indonesia's rooftop solar power regulatory regime, Herbert Smith Freehills, 14 March 2024
[9] Govt amends electricity consumers rules to fast track rooftop solar installations, *The Hindu Business Line*, 23 February 2024
[10] PM Surya Ghar Program to Offer ₹78,000 for 3 kW Residential Rooftop Solar Systems, *Mercom India*, 14 February 2024
[11] Changes to the planning process for solar energy in Scotland welcomed, *Scottish Business News*, 5 April 2024
[12] South Africa: Energy Country Profile, Our World in Data, consulted in June 2024

In order to reduce demand and protect its electricity network, Eskom has had to resort to loadshedding, planned, rolling power cuts of between 1,000 and 8,000 MW (graph 5). In addition, it went through numerous unscheduled power cuts. The electricity availability factor (EAF) of its power stations[13] collapsed, falling from 71% in 2017 to just 56% in 2023, according to data published by the group.

2.2. The growth of distributed solar power was encouraged and planned by the State

Faced with Eskom's inability to revive its production, which has become a major economic handicap and a subject of popular discontent, South African President **Cyril Ramaphosa presented an emergency programme in July 2022,** the **Energy Action Plan** (EAP)[14] . Noting delays in the construction of new thermal power stations, the worrying ageing of the coal-fired fleet - more than 40 years old on average - and a structural deficit of 6,000 MW (equivalent to around 10% of the country's total installed capacity) this action plan proposed **five areas for action, including the development of grid-connected rooftop solar power for homes and businesses**.

The main measure was introduced in February 2023, when the Treasury announced that private individuals could **recover up to 25% of the purchase price of their solar panels** (up to a limit of 15,000 rand, or 790 USD). At the same time several municipalities, whose networks provide the bulk of the country's electricity distribution, announced that they would be setting up **programmes to buy back the surplus electricity produced by their customers**. After Cape Town in January 2023, Johannesburg and Durban announced their intentions in the following months.

These measures to support self-generation by private individuals came in addition to the measures already in place to encourage self-generation by industry and business, in particular the exemption from licence fees for projects linked to power purchase agreements (PPAs) of less than 1 MW in 2017 (a limit raised to 100 MW by the Electricity Regulation Act of 2021) and the facilitation of **transfer contracts between producers and private consumers via the public electricity networks**, a practice known as wheeling. In January 2023, the Department of Energy also lifted the requirement for independent power producers (IPPs), whatever their capacity, to obtain a generation licence[15] .

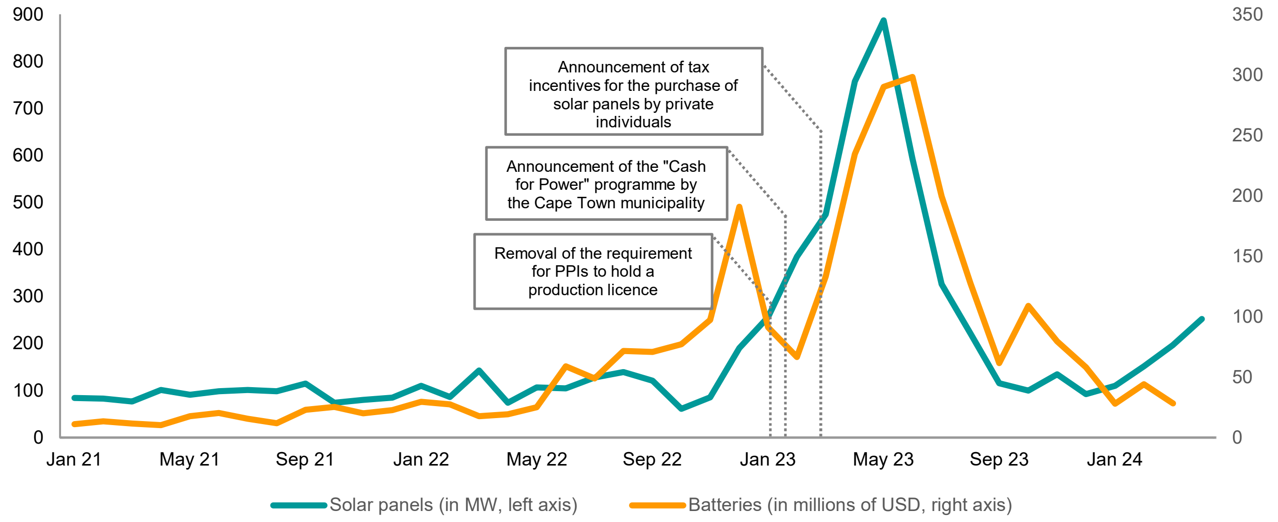
2.3. Accelerated adoption

The raft of measures adopted by the South African authorities has resulted in a **rapid increase in the installation of photovoltaic systems in South Africa** by individuals and businesses. **Imports of solar panels** (almost entirely from China), which had previously been stagnant (representing a capacity of around 100 MW per month) increased rapidly, reaching 887 MW in May 2023 alone (figure 6). **In 2023 alone, the equivalent of more than 4,300 MW of solar panels were imported from China, almost as much as the total for the previous four years (4,718 MW)**.

While some of these imports were destined for the large solar power plants built by independent private producers, they mainly fuelled the installation of self-generation capacity by private individuals. According to Eskom figures, total *rooftop solar* capacity in the country rose from **2,264 MW in July 2022 to 5,439 MW in April 2024** (graph 7), with this growth accelerating from January 2023, the date corresponding to the start of the peak in imports illustrated above.

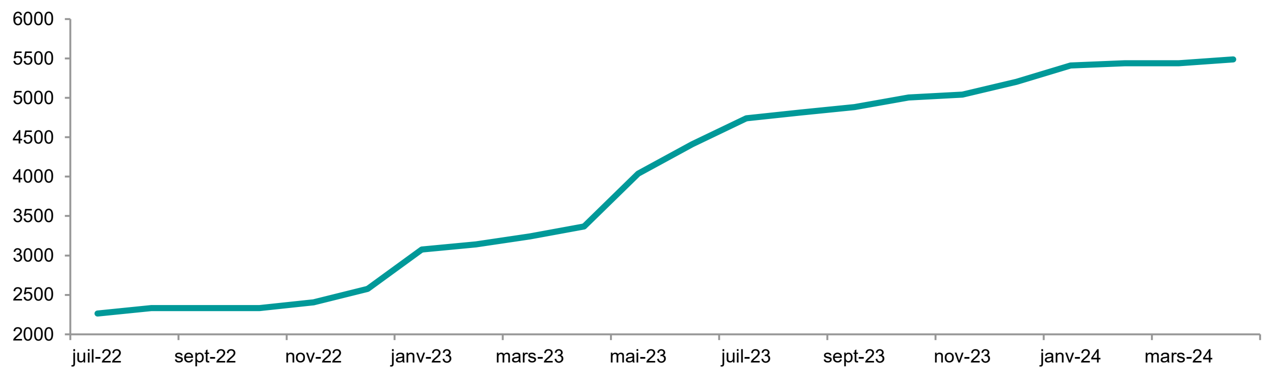
[13] The Electricity Availability Factor (EAF) represents the difference between maximum availability and unavailability (voluntary or involuntary outages),
[14] Confronting the energy crisis; an action plan to end load shedding, Presidency of the Republic of South Africa, July 2022
[15] South Africa exempts private generators from Generation Licence requirements, White & Case, January 2023

Figure 6: South African imports of solar panels and batteries



Sources: Ember Climate, Trademap

Figure 7: Estimated total decentralised solar power capacity, in MW



Source : Eskom

As Eskom has no way of directly measuring the total solar capacity of its customers (who do not have to declare their installations), the operator estimates it by measuring the differential between its own production and its demand projections. Other estimates carried out by independent experts arrive at similar orders of magnitude[16].

Some of the imported solar panels are also used for **self-generation solar systems not connected to the electricity grid**, which are not taken into account in Eskom's calculations. There is no estimate of the cumulative capacity of these systems, but they represent a significant market: by 2022, almost 150,000 poor households not connected to the electricity grid had benefited from an individual solar system under the government's Free Basic Alternative Energy (FBAE) programme[17]. A myriad of companies are also marketing solar panels to the poorest sections of the population, via pay-as-you-go (PAYG) rental or repayment schemes.

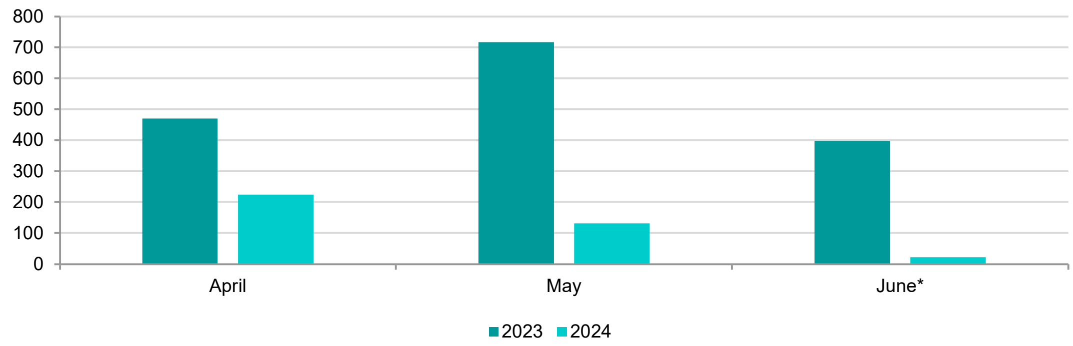
[16] South Africa's unprecedented rooftop solar boom, *Energy Monitor*, 14 August 2023
[17] Solar Energy for the Poorv, Department of Statistics of South Africa, 2 April 2024

The development of South Africa's self-generation capacity has been **much faster** than the construction of the utility-scale power plants launched in recent years in South Africa, for a comparable installed capacity. For example, **the 3,175 MW or so of rooftop solar capacity added in just 21 months between July 2022 and April 2024 should be compared with the 2,247 MW or so of combined capacity from the forty or so photovoltaic plants** built under the Renewable Energy Independent Power Producer Procurement Programme (REIPPP), a series of tenders reserved for IPPs conducted **over more than a decade** since 2011. Similarly, the combined capacity of distributed solar power is comparable to the **3,340 MW of wind power capacity** (for around thirty wind farms) built, again over more than ten years, as part of the REIPPP.

2.4. Distributed solar power, a key tool for putting an end to the electricity crisis

Eskom is still far from having solved its crisis, and many experts in the South African energy sector are warning of the possibility of a return to power cuts in the coming weeks, as the southern winter approaches. However, the situation has improved considerably: **on 14 June**, the operator celebrated **83 consecutive days without load shedding**, the longest uninterrupted period since 2019. Similarly, the energy availability factor (EAF) improved, returning in May to levels above 70%, which the operator had not achieved since 2021[18] . As this improvement occurred in the run-up to the elections, Eskom and the government were accused of having resorted to "costly" diesel-fired back-up power stations, which make it possible to cope with peaks in demand at the cost of a substantial fuel surcharge. In fact, **diesel and gas-fired power stations operated by Eskom and private producers have been much less in demand in recent months compared with the same period in 2023** (graph 7). Eskom's diesel purchases have also fallen considerably compared with last year[19] , invalidating the hypothesis that the energy crisis is being managed purely for electoral reasons.

Graph 7: Production by Eskom's back-up power stations and Eskom's gas turbines and PPIs, (GWh)



*Source: Eskom (*June 2024: until 7 June)*

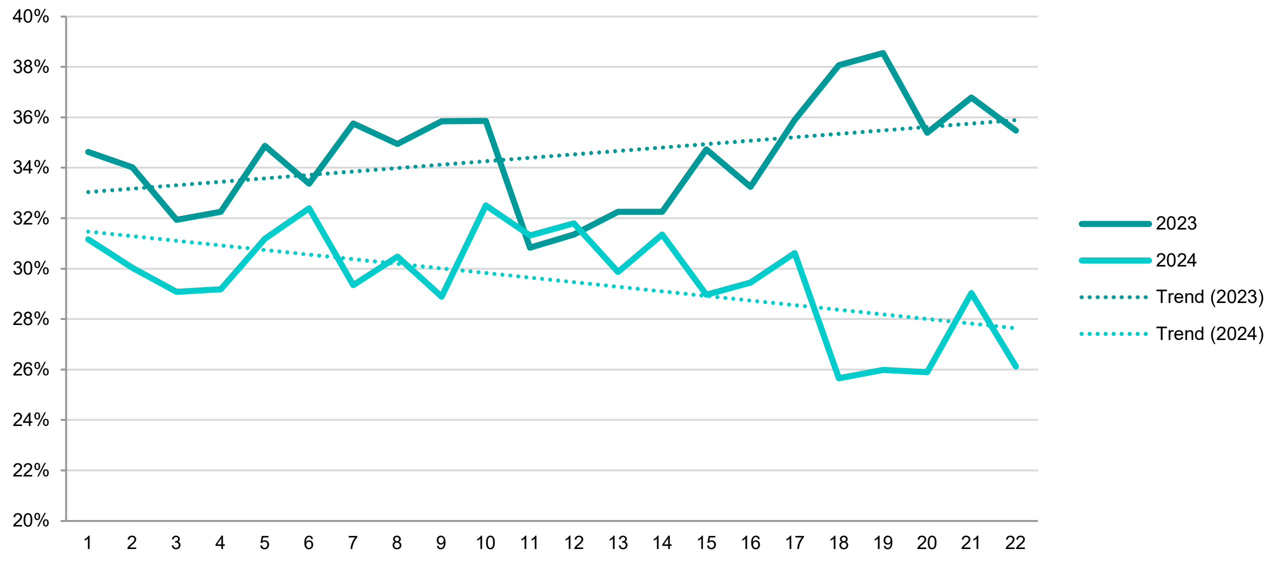
The end of load shedding cannot be explained exclusively by the growth in self-generated solar power. However, Eskom believes that it has played a key role in improving the situation, mainly by **reducing total demand on the electricity grid**. In fact, total demand has fallen from 220 TWh in 2019 to 207 TWh in 2023, even if this drop can also be explained by other factors, such as the economic slowdown.

This reduction is concentrated on midday - the period of maximum sunshine -, when decentralised solar power covers around **20% of national demand**, and does not substantially reduce peak consumption in the morning and evening. However, it does indirectly have a virtuous effect on these periods: according to Eskom's systems director Isabel Fick, **the reduction in overall demand has made it easier for the operator to replenish its generation capacity in order to better respond to demand peaks:** filling hydroelectric dams, stocking diesel

[18] Eskom breaches 'psychological mark' of 70% Energy Availability Factor, South African Government News Agency, 13 May 2024
[19] South Africa's blackouts crisis is 'fixed', says Eskom, *Financial Times*, 22 May 2024

and gas, etc.[20] . This reduced daytime demand on the network has also enabled Eskom to **carry out the maintenance work on its coal-fired power stations** (which provide most of the country's electricity production) that it had previously been forced to postpone. Unplanned outages, equivalent to 34% of Eskom's generation capacity at the beginning of June 2023, had fallen to 26% a year later, with a marked downward trend (graph 8).

Graph 8: Unscheduled outages (as a % of total capacity), weeks in the first 6 months of the year



Source : Eskom

The gradual addition of **storage batteries** by self-generators should gradually help to **reduce peaks in demand in the morning and evening**, as they will enable them to consume the energy accumulated during the day during these periods. No reliable data is available on the cumulative capacity of batteries installed in homes and businesses. But **imports of lithium-ion batteries have exploded in 2023: more than USD 1.7 billion**, eight times more than in 2021 and more than twice as much as in 2022 (graph 6).

3. In Lebanon, chaotic decentralisation does not benefit EDL

3.1. An economic, energy and electricity crisis

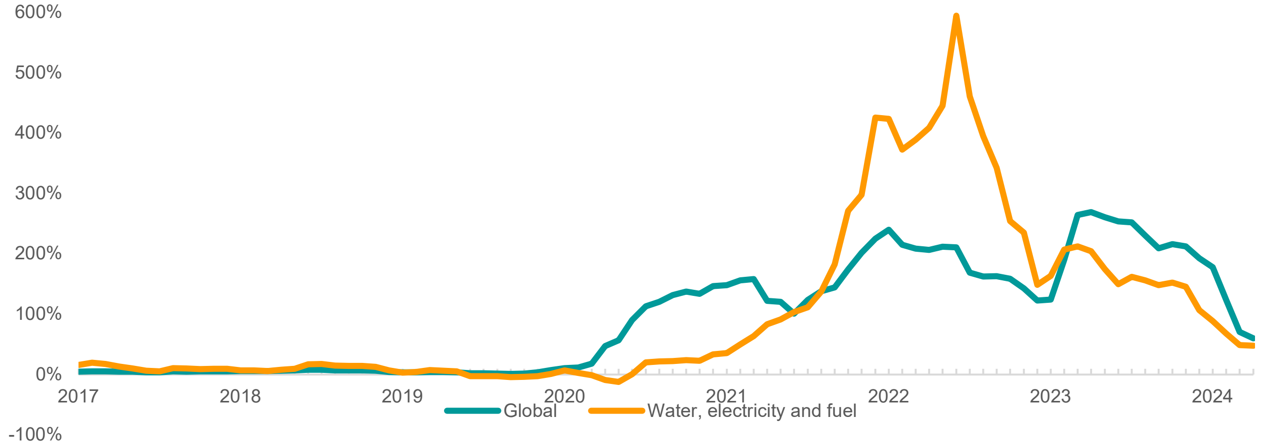
Described by the World Bank as one of the three greatest economic collapses since the 1850s[21], the Lebanese crisis has not only driven the majority of its population into poverty[22]. It has also plunged it into darkness. **Electricité du Liban** (EDL) has suffered greatly from the economic crisis: although the first power cuts date back to 2006, following the Israeli-Lebanese conflict, they became a regular occurrence in 2018. And while in **2019 more than 95% of Lebanon's electricity was produced from fuel oil**[23], rising fuel prices, hyperinflation and the devaluation of the Lebanese currency have made it impossible for the Lebanese state to buy fuel. **As a result, the country's electricity production will fall sharply from 2019, from 21,500 GWh that year to**

[20] Eskom's rooftop solar numbers and peak demand decline explained, *MyBroadband*, 10 May 2024
[21] World Bank, La crise libanaise : un grand déni sur fond de dépression délibérée, 25 January 2022
[22] According to Human Right Watch, 80% of the population lives below the poverty line in Lebanon.
[23] Source: International Energy Agency

10,300 GWh in 2021. Despite the announcement of a balanced budget in 2023[24] , on average, EDL currently provides only 3 to 4 hours of electricity a day.

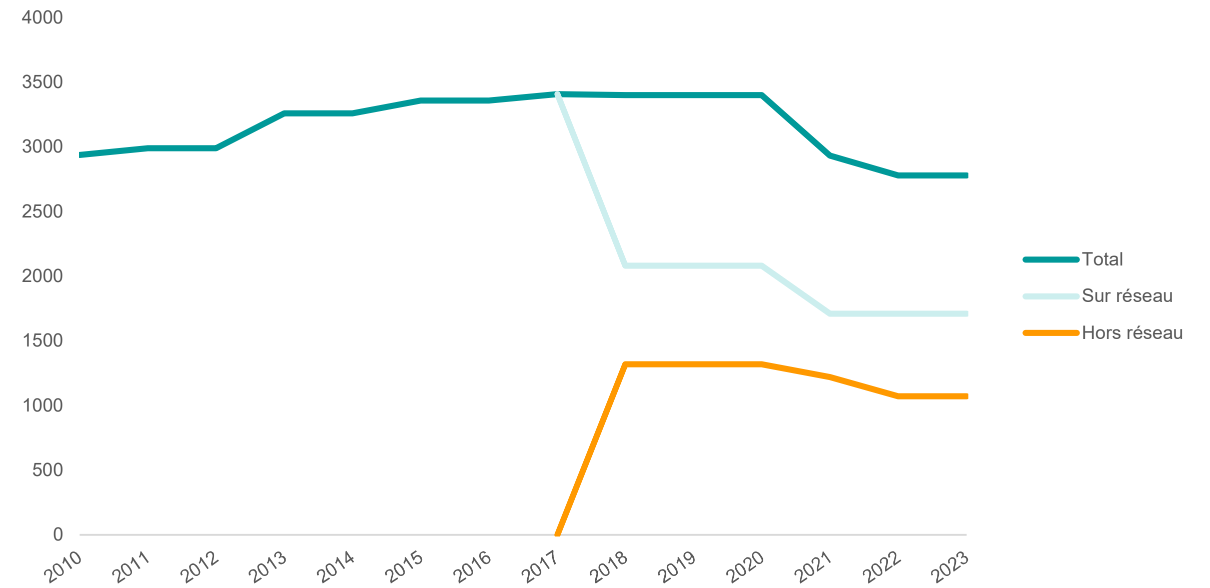
At the same time, the water, electricity and fuel sectors have seen galloping inflation reaching 600% in July 2022 (Graph 9), while **EDL has recorded net losses of $156 million in 2019[25]**.

Graph 9: Year-on-year inflation rate in Lebanon (%)



Source: Lebanon Central Administration of Statistics

Figure 10: Electrical power generated from hydrocarbons (MW)



Source: IRENA

Faced with EDL's shortcomings, many Lebanese installed diesel generators: according to the World Bank, 33,000 to 37,000 generators covered 37% of Lebanon's electricity demand in 2018[26]. **Self-generation of electricity - using diesel - had therefore developed even before the economic crisis exploded in 2019** (Figure 10). But it was itself brutally slowed by **the end of subsidies on petrol and heating oil decreed by**

[24] IciBeyrouth, EDL announces a balanced budget for the first time, 18 August 2023
[25] Libnanews, Major financial losses for EDL as it publishes its results for the period 2019 to 2022, 19 March 2024
[26] World Bank, Distributed Power Generation for Lebanon: Market Assessment and Policy Pathways, May 2022

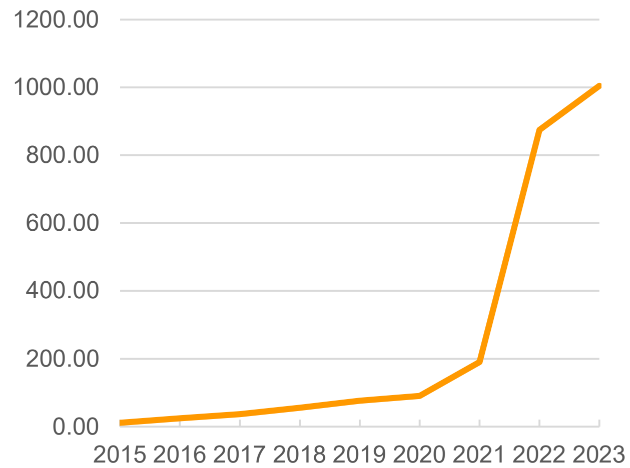
the Central Bank of Lebanon in August 2021[27]. In response, **many Lebanese have since turned to solar self-generation.**

3.2. Exponential growth in decentralised solar installations

In a country with more than 300 days of sunshine a year, solar energy has quickly demonstrated its advantages over other energy sources (Figure 2). According to the International Renewable Energy Agency (IRENA), **installed solar energy capacity in Lebanon increased 13-fold between 2019 and 2023, from 76 GW to more than 1,000 GW** (Figure 11). This **increase is almost entirely due to the installation of photovoltaic panels on private roofs**. Lebanon has just one solar power plant, the Beirut River Solar Snake, symbolically built opposite the Ministry of Energy, with a capacity of no more than 1 MW.

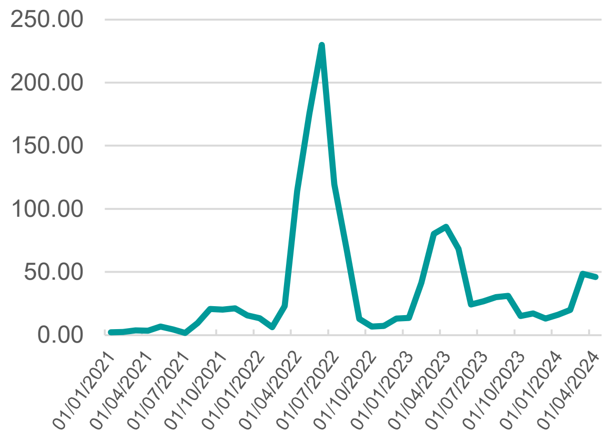
This enthusiasm is reflected in the trend in solar panel imports (from China) since 2021. After an initial increase after the summer of 2021, **Chinese exports peaked in July 2022, when they represented the equivalent of 229 MW of generating capacity** (Figure 12). In total, China exported more than 1,500 MW of solar panels to Lebanon between January 2017 and March 2024. This data corroborates estimates by Pierre El Khoury, Director of the Lebanese Center for Energy Conservation (LCEC), that cumulative solar energy capacity in Lebanon would exceed 1,500 MW by June 2024[28] .

Figure 11: Installed solar power capacity (MW)



Source: International Renewable Energy Agency

Figure 12: Monthly solar panel imports from China (MW)



Source : Ember Climate

In countries with net metering systems, this electricity is sold on and fed into the national grid. However, such a system has not been implemented in Lebanon. The EDL crisis and the 180% rise in electricity tariffs in April 2019 have prompted many solar panel owners to switch entirely to self-generation and disconnect entirely from the national grid.

3.3. Technical constraints, but above all governance constraints

Further development of decentralised solar power in Lebanon is now hampered by the **limited availability of suitable roofs, particularly in urban areas, as noted by installers**[29]. What's more, the market is approaching saturation point: the majority of households who could afford to install solar equipment did so between 2020 and 2023, and solar power remains a luxury **in a country where almost 80% of the population lives below the poverty line.**

[27] Courrier international, Déliquescence. With the lifting of fuel subsidies, "the Lebanese are hitting rock bottom", 13 August 2021
[28] L'Orient-Le Jour, Towards the end of the solar panel boom in Lebanon, 18 May 2024
[29] L'Orient-Le Jour, Towards the end of the solar panel boom in Lebanon, 18 May 2024

In this sense **the Decentralized Renewable Energy Law (DRE), adopted in December 2023 by the Lebanese Parliament, should enable the solar market in Lebanon to be liberalised**. The DRE would authorise peer-to-peer trading between buyers and sellers**,** i.e. the establishment of "mini-grids" located on the same or adjacent plots of land, without going through the national grid[30]. However, it would only apply to projects with a maximum capacity of 10MW and therefore connectable at low voltage. **Larger projects exceeding 10M W would have to be carried out by wheeling,** i.e. via the EDL network.

The provisions of the DRE – currently inapplicable – reflects EDL's fear of losing its monopoly on the electricity market. Moreover, no implementing decree has yet been adopted. Furthermore, the implementation of **the DRE remains conditional on the establishment of an Electricity Regulatory Authority**. One of the conditions for the release of World Bank funding for gas imports, **this key body has been waiting to be set up for more than two decades, in the absence of a political agreement**.

Lastly, **the difficulties faced by EDL and the Lebanese government are restricting the financing of larger-scale projects**. Launched in 2010 by the Central Bank of Lebanon, the National Energy Efficiency & Renewable Energy Action (NEEREA) financing mechanism made it possible to obtain up to $20 million at a rate of 2.5% to finance green projects[31]. By 2015, more than 200 projects had been approved under this scheme, totalling more than USD 250 million. However, the government was no longer able to finance it. Similarly, the US development agency USAID's Innovation for Affordable and Renewable Energy for All (INARA) project, worth USD 30 million, can no longer be carried out due to the failure of the Lebanese network.

Unlike the South African example (see previous chapter), **the decentralisation of solar energy in Lebanon is taking place without any support from the State** or EDL. On the **contrary, the public operator's desire to maintain its monopoly on electricity production seems to be leading, in the end, to its weakening: the increased use of self-generation is depriving it of customers, without allowing it to benefit from their surplus production**, which could be re-injected and thus improve the overall availability of electricity. Yet the Lebanese who can afford solar panels on their roofs are also the biggest consumers of energy and the ones who previously paid the highest energy bills[32]. By **2023, at least 17 Lebanese municipalities had already adopted larger-scale off-grid interconnected systems, combining solar and diesel power, to compensate for weaknesses in the national grid**[33]. As shown by the proliferation of these projects (municipalities, hospitals, universities, businesses, industries), **this phenomenon is set to increase despite EDL's determination to preserve its monopoly, dragging the operator into a vicious circle.**

At the same time, eleven photovoltaic power plant projects are being finalised. They should enable a total of 165 MW of solar energy to be deployed in the country. These contracts commit the companies to building the plants and selling the energy produced to EDL. After a process that began 6 years ago, the outgoing Minister of Energy and Water, Walid Fayad, signed the contracts in May 2023. However, the eleven consortiums involved still have to find the necessary funding. According to LCEC's Managing Director, the total cost is estimated at 99 million dollars[34] .

4. In Puerto Rico, a targeted response to a natural disaster

4.1. Adoption speeded up by the consequences of Irma and Maria

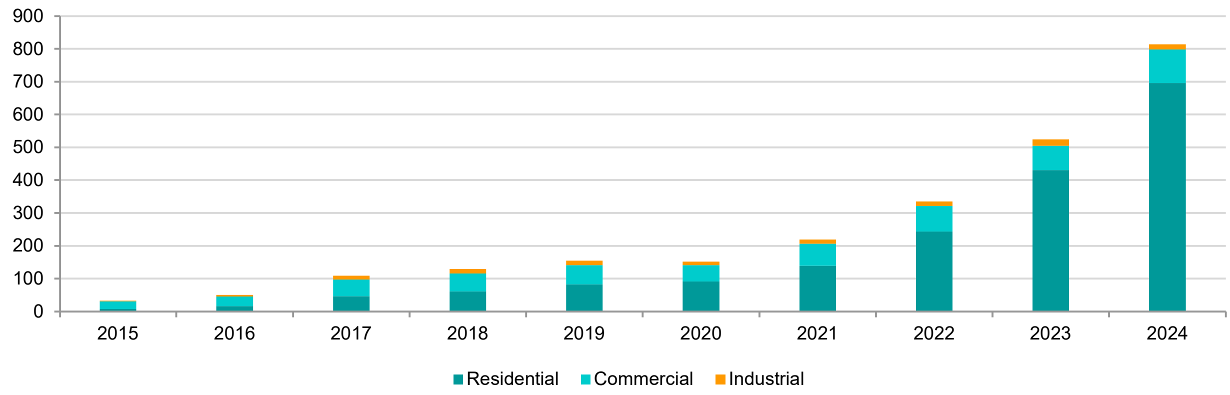
The US territory of Puerto Rico, in the Caribbean, offers an example of large-scale adoption of *rooftop solar* following a natural disaster. In September 2017, hurricanes *Irma* and *Maria*, which occurred just a few weeks apart, caused almost 3,000 deaths on the island and caused tens of billions of dollars in damage, **severely**

[30] PV Magazine, Lebanon introduces peer-to-peer renewable energy trading, 2 January 2024
[31] Middle East Eye, Avec l'énergie solaire, le Liban a enfin l'occasion de se détourner du tout pétrole, 1er November 2021
[32] It is estimated that before the crisis, around 25% of the Lebanese population did not pay their energy bill. This estimate takes into account the various Syrian and Palestinian refugee camps, administrations and Lebanese regions that pay less than others.
[33] Will Todman, Center For Strategic & International Studies, Powering recovery. Reform, Reconstruction, and Renewables in Conflict Affected States in the Arab World, March 2023
[34] L'Orient-Le Jour, Les contrats pour 11 parcs solaires à travers tout le Liban enfin signés, 6 May 2023

affecting its electricity production capacity and transmission network, leaving almost all of the island's 3.3 million inhabitants in the dark. The episode is considered to be the **most serious blackout in the history of the United States**.

With the national operator PREPA (Puerto Rico Electric Power Authority) saddled with some USD 9 billion in debt, **the US federal government earmarked more than USD 12.8 billion to restore and strengthen the island's electricity network and production capacity**. But **despite the scale of the resources released, the recovery was only gradual: hundreds of thousands of residents remained without electricity for several months, some for almost a year**. Five years after the hurricane, only a fraction of the funds mobilised had been used, mainly due to disagreements between the federal emergency aid agency, FEMA, and the Puerto Rican authorities[35] . Finally, other smaller hurricanes have regularly caused new power outages of varying degrees of severity.

Figure 12: Installed solar capacity in Puerto Rico (MW)



NB: Figures for March of each year. Source: United States Energy Information Agency

This situation prompted many Puerto Ricans to install photovoltaic panels on their roofs to help them cope with electricity shortages. **Although this trend began before the hurricanes, it accelerated considerably afterwards. Total photovoltaic capacity connected to the national grid rose from just over 22 MW in 2014 to 813 MW in March 2024** (Figure 12). **The number of homes equipped has also soared, from 1,178 to more than 114,000 over the same period, in addition to more than 3,000 businesses and industrial sites.**

This popular enthusiasm has been **supported by the federal authorities,** who since 2020 **allocated almost USD 2 billion to support rooftop solar** (and now battery storage) via various budget headings. The emergency aid granted after *Irma* and *Maria* has since been supplemented by a disaster mitigation fund, a Covid-19 relief fund, the Environmental Protection Agency's "Solar For All" programme, and a congressional allocation of USD 1 billion earmarked for the deployment of solar energy to the island's most vulnerable communities. This aid, of which only a small part has been spent, has been added to other incentives already put in place by the local authorities, including subsidies for the purchase of solar panels and feed-in tariffs. However, this roll-out has met with some political and administrative resistance, notably from the Financial Oversight and Management Board for Puerto Rico (FOMB) but also from LUMA, which took over distribution and transmission activities from PREPA in 2021 and whose revenues are threatened by the development of decentralised solar power[36].

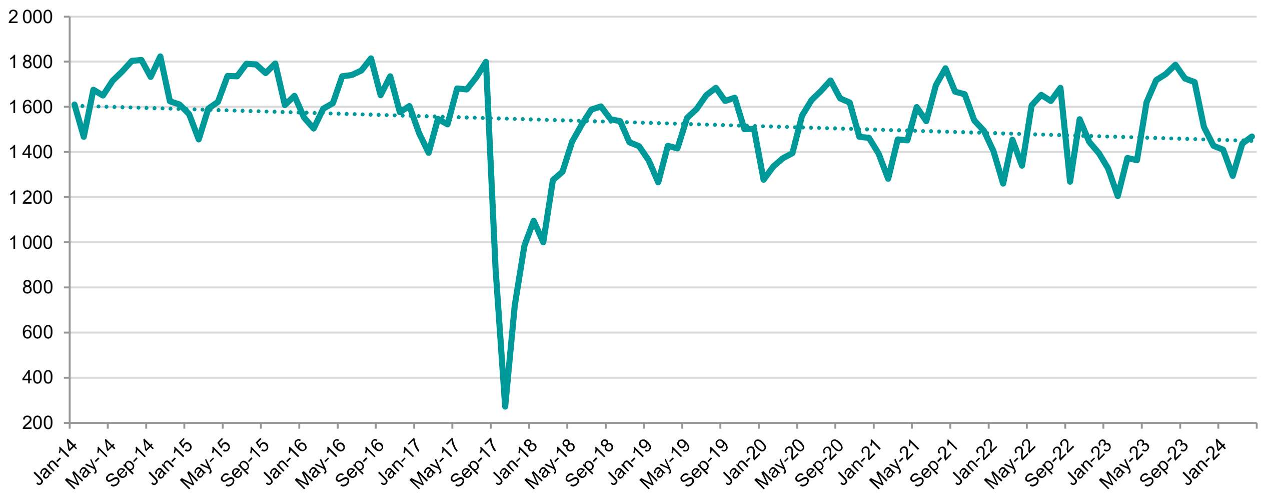
[35] Puerto Rico's power grid is struggling 5 years after Hurricane Maria. Here's why, ABC News, 2 September 2022
[36] Solar at a crossroads in Puerto Rico, Institute for Energy Economics and Financial Analysis, June 2024

4.2. A downward effect on conventional production

The cumulative capacity of Puerto Rico's *rooftop solar system* - some 800 MW - is still relatively low compared with the country's **conventional generation methods** (around 5,800 MW of cumulative installed capacity). And the surplus production fed back into the grid by self-generators represents only a tiny proportion of the energy distributed nationally. But the impact of the deployment of solar self-generation is being felt in other ways, mainly through the **year-on-year reduction in electricity production from conventional sources**. This has fallen from 1,600 GWh per month in 2014 to just over 1,400 GWh per month today (Figure 13).

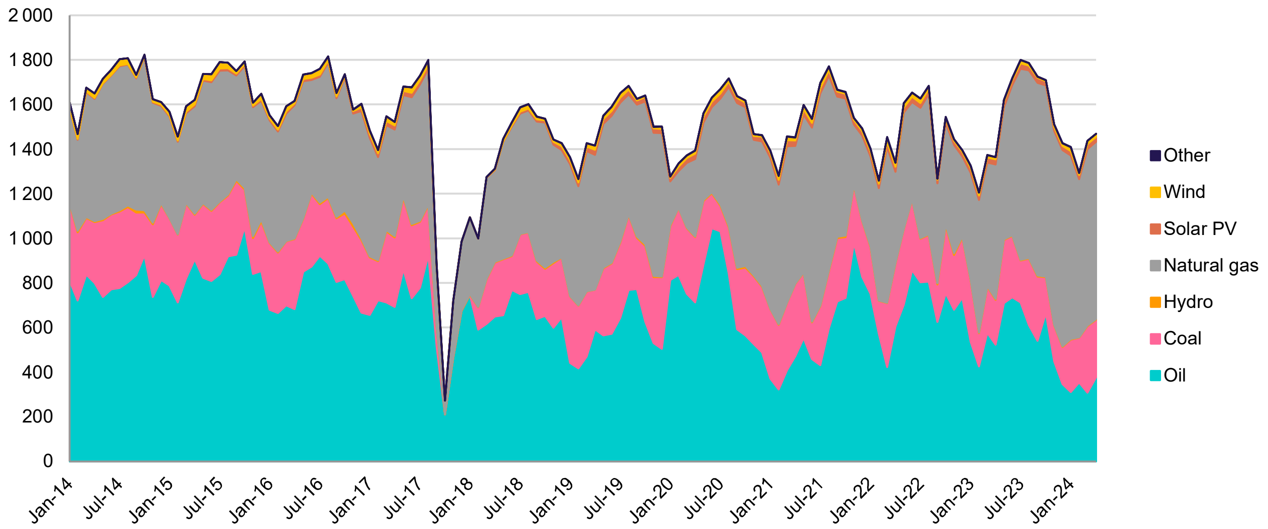
This **fall is particularly marked for generation from oil and coal** (Figure 14), partially offset by an increase in production from natural gas. This is a financial relief for the island, **which imports all its fuel oil, coal and gas.**

Figure 13: Net monthly electricity generation, GWh/month



Source: Sistema de Indicadores de Puerto Rico

Figure 14: Net monthly electricity generation, by source, in GWh



Source: Sistema de Indicadores de Puerto Rico

5. A technical and financial challenge for operators and public authorities

5.1. Net metering is a prerequisite

For political authorities and grid operators alike, one of the first technical and regulatory challenges is the introduction of a **net metering system**, enabling self-generators to sell surplus electricity back to the national grid. This measure is a **powerful lever for the adoption of decentralised solar power**, since it offers consumers an additional source of income. In some cases, it can also **benefit the national grid by compensating for shortfalls in conventional generation capacity**, as seen in the South African example.

According to a count carried out by the international organisation Renewable Energy Policy Network for the 21st Century (REN21), **by the end of 2022, 83 countries had adopted net metering regulations at national or regional level**[37]. The adoption of net metering is almost universal in high- and middle-income countries, but only a few low-income countries have introduced it.

Adopting appropriate legislation is not enough. Implementing net metering requires investments such as changing meters (which may, however, be at the customer's expense) or other measures to adapt the network. It also assumes that the electricity network operator has the technical and organisational capacity to implement these changes.

5.2. Technical adaptations are essential, and sometimes costly

The connection of a large number of solar panels - producing intermittently - also has technical consequences for the electricity network: voltage fluctuations, **uncontrolled variations in electrical frequency**, **risks of overvoltage**, etc.[38] . While operators know how to manage their high- or medium-voltage "core network" in real time, this is not always the case for low-voltage terminations[39] . Deploying self-generated solar power may therefore require **investment in real-time grid management tools**, or even the **reinforcement of high-voltage lines** to evacuate surplus electricity from the sunniest regions to the rest of the national grid. In Australia, several regions have imposed a **mechanism for automatically disconnecting private solar installations to avoid power surges during peak production periods**[40]. Australia's electricity grid regulator, AEMO, now wants to extend this curtailment system nationwide[41]. These technical risks are real, but they are well identified, and there are no examples of large-scale power cuts caused by distributed solar power.

However, **the gradual adoption of batteries** by self-generating customers is helping to limit these problems, by 'smoothing' production and therefore reducing the total power delivered during periods of maximum sunshine. Installed in sufficient numbers, their aggregate storage power can even be used to create a Virtual Power Plant (VPP), which the electricity system operator can call on to meet peaks in demand. These systems are managed by the companies that install solar panels and batteries on private homes, such as Tesla in the United States. VPPs are already operational in around twenty American states[42] (notably California, where they can even participate in the wholesale electricity market), as well as in Europe, the UK and South Africa.

5.3. A financial risk for operators and local authorities

In addition to the technical risks it poses to electricity infrastructures, the large-scale development of distributed solar power also represents **a financial challenge for the incumbent players in the electricity market**, whether they be generation companies, those responsible for managing the grid (when these services are split up) or distribution to end customers (which may be owned by local authorities).

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[37] Renewables 2023 Global Status Report - Renewables in Energy Supply, REN21, June 2023
[38] Rooftop Solar PV Penetration Impacts on Distribution Network and Further Growth Factors-A Comprehensive Review, Uzum et al, *Electronics*, 2021,
[39] How grid operators can integrate the coming wave of renewable energy, McKinsey, 8 February 2024
[40] Remote disconnect and reconnection of electricity generating plants, South Australian Government Department of Energy and Mines, accessed June 2024.
[41] Rooftop solar switch-off: Why and where it's being used - and where it's headed, *Renew Economy*, October **2023**
[42] Pathways to Commercial Liftoff: Virtual Power Plants, US Department of Energy, September 2023

In South Africa, some municipal operators responsible for "last mile" distribution are seeing a **reduction in the amount of electricity sold to their constituents**. The financial impact is even greater for those who have set up systems to buy back surplus self-generated electricity. For example, Buffalo City alone (population 730,000) estimated its annual shortfall in 2023 at around USD 18 million[43]. Electricity sales are one of the main sources of revenue for South African municipalities. This drop in revenue is being passed on to Eskom, which has seen its sales to municipal operators fall by 2.3% between 2022 and 2023 - even though this drop is also attributable to its own production difficulties. However, network maintenance needs are not decreasing, and are even tending to increase (see above). In response, Eskom has more than trebled the fixed monthly charges applied to its subscribers[44].

These potential losses of revenue are also leading some incumbent operators to seek to slow down the deployment of distributed solar power. For example, India's municipal distribution companies - even though most of them are state-owned - have remained reluctant to apply legislation facilitating the connection of solar self-generators[45]. As a result, India has achieved barely 20% of its rooftop solar deployment targets. In California, the operators PG&E, SCE and SDG&E, seeking to protect their oligopoly on electricity generation, obtained a **drastic reduction in the feed-in tariff for private customers** in April 2023, which led to a drop of more than 70% in new solar system installations[46].

However, the potential loss of revenue for operators or public authorities is offset by other benefits: greater grid reliability, less need to invest in power generation or wholesale electricity purchases. The entities involved therefore need to **strike the right balance between the advantages and disadvantages of distributed solar power.**

The association Sustainable Energy Africa, which supports public authorities in South Africa and the rest of the continent, advises setting **feed-in tariffs that are sufficiently attractive to encourage the uptake of solar energy, but that also take into account the interests of the electricity grid operator**[47]. The allocation of fixed costs incurred by new installations (connection, metering, network adaptation, etc.) must also be subject to clear and viable "rules of the game" for both consumers and network operators.

[43] Near Fourfold Surge in Rooftop Solar Slashes Eskom, City Revenue, *Bloomberg*, 6 October 2023
[44] Electricity price warning for South Africans with solar power, *Mybroadband*, 30 May 2024
[45] Government Points to DISCOMs' Role in Tepid Rooftop Solar Installations, *Mercom India*, 27 December 2022
[46] Impact of NEM-3 on California's renewable energy progress and solar jobs, California Solar + Storage Association, November 2023
[47] Tariff Setting for Embedded Generation, Sustainable Energy Africa, March 2023