POSITION PAPER

Unlocking grid capacity for rapid RES (renewable energy sources) deployment in South Africa

The essential role of RES congestion curtailment to accelerate RES deployment and contribute to the reduction of load shedding

Confidential

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Executive Summary

Renewable energy sources (RES) are abundant in South Africa – and they are the fastest way to reduce load-shedding if a RES curtailment framework is in place. The persistent load shedding crisis in South Africa is caused by a power generation deficit of at least 6 GW. RES can be a cheap and fast remedy to this crisis. To ensure system security in the mid and long term, the substantial growth of RES will need to be accompanied by accelerated investments in grids and flexible, fast resources for their successful integration into the power systems. However, grid planning and expansion takes time and will only become effective in five to ten years from now. In the very short term (immediate action), significant amounts of RES in the order of magnitude of several gigawatts could be deployed even within the constrained areas of the existing power grid infrastructure, if only a certain operational framework – RES curtailment – gets implemented. This framework is laid out in this paper and could become effective within weeks. It could make a substantial contribution in the shortest possible time (2 years or less) to sustainably mitigate load shedding.

"Curtailment" means making optimal use of existing power grids to accommodate maximum RES. It refers to the active control (reduction) of the output of RES plants as response to system security needs or temporary transmission capacity constraints. Preliminary analysis of ESKOM's strategic grid planning confirms that by accepting a reasonable share of no more than 10% curtailment, the RES hosting capacity for the Western Cape Region could be almost doubled. Round about 4 GW of additional RES capacity could be connected to the grid almost immediately, and more than 90% of these RES plants' electricity production could be safely integrated into the grid. Studies are being concluded to confirm these results also for other provinces.

Curtailment is international *best practice* in grid planning and operations. North-eastern German TSO 50Hertz (grid region with 18 million people, 100 TWh annual load) is one of the European frontrunners for the integration of variable RES – more than 60% on an annual average. At 50Hertz, like many other TSOs, curtailment has been a standard operation procedure for more than a decade. It has proven to be a highly efficient and effective way of grid operation with high shares of RES.

The economics of curtailment: minimizing system expenditure, maximizing RES uptake, gaining speed. With every kWh of additional RES, another kWh from another, much more expensive source can be avoided (so-called "merit-order effect of renewables"). At many times, in South Africa, RES will replace diesel generators or avoid load shedding – both of which have massively higher cost to society than RES which are in fact one of the cheapest possible electricity sources. Even if the effective cost of RES rises by roughly 10% due to deemed energy during periods of curtailment, their cost will be still something like 5 to 50 times cheaper than the alternative, marginal generation sources (diesel) or even the "cost of unserved energy" due to outages or curtailment. *Bottom line:* The value of RES integrated energy is very high, as the cost of alternative supply options is much higher, ensuring a positive socio-economic impact even for high curtailment levels. RES curtailment is a precondition ("the price to pay"), i.e. a small share of curtailment enables the integration of the rest of renewable electricity from the respective RES plants.

***Take-or-pay arrangements* and socialization of costs, a relatively low risk and a much higher benefit to society.** A key point of consideration for the application of curtailment frameworks is who should bear the costs for the deemed (curtailed) energy. International experience underlines the merits of a *take-or-pay regime* in which curtailment cost is socialized, and RES producers are reimbursed for every kWh of curtailed energy (above a relatively low threshold) at the same price that they would have earned by selling their electricity. Without the security of a take-or-pay arrangement, RES developers would factor this risk in their financial estimations and increase their bids by adding a risk premium due to the expected curtailment. A transparent congestion management framework ensures a *level playing field* between public and private IPPs in the application of a curtailment framework. The application of a take-or-pay regime, combined to a socialization of respective costs, can largely ensure this condition. During the application of congestion management, ESKOM will ensure that the deemed energy is supplied by the next committed plant in a cost-optimal way. Curtailment costs can then be passed through to the tariff.

Making it happen: ESKOM is ready to implement a RES curtailment framework. ESKOM experts have confirmed their organization's readiness to implement a curtailment framework almost immediately. The implementation concentrates on three main domains in ESKOM:

1. *System Operations:* Currently, curtailment is already applied in ESKOM, but only as a niche process for system-wide control actions/constraints. The extension of this concept towards a congestion management framework is missing, but possible. There is a wide agreement on the role of RES as solution of the generation supply gap and reduction of load shedding. ESKOM can support the immediate deployment of additional multiple gigawatts of RES capacity if there is also a commitment to start preparations for the instruments required when additional capacity is going online.
2. *Market operations:* In view of the prospective REI4P Bid Window 7, the time pressure on the market operations department is high, as the needed contractual amendments to fit a future curtailment framework have to be agreed now and be in place immediately. There is a great agreement on the merits of a take-or-pay regime, combined to a socialization of the congestion management costs. Going forward, grid codes and IPP contracts may need to be reviewed.
3. *Grid planning:* Curtailment adds extra grid hosting capacity in the short term, and is a new "philosophy" of efficient grid planning in the mid and long term. Again, there is great agreement on the merits of curtailment as key parameter in a cost-benefit assessment process for grid planning. In view of the upcoming next REI4P round, the grid planning department should swiftly implement new grid hosting capacity estimation methodologies for the different areas in the system and provide this information to the IPP Office.

"Taking the fear away" is an essential element of a communication strategy. Experience shows that the false perception of "wasted energy" from "expensive and unreliable RES plants" can be a significant hurdle. For this, it is necessary to deploy an active communication strategy to educate stakeholders and the public. A communication strategy should aim on how to take the fear away from decision-makers and the public.

Outlook on the transition to higher RES shares: curtailment is here to stay – and it will trigger innovation. The international experience shows three trends in systems that experience curtailment. Firstly, curtailment is a very efficient trigger for grid expansion in systems with variable RES, acting as additional signal for the assessment of respective costs and expected benefits. Secondly, it pushes TSOs to technical and operational excellence to reduce curtailment. Thirdly, curtailment acts as an entrepreneurial inspiration, since new business ideas (e.g., storage, power-to-hydrogen, power-to-heat) come into fruition on using the local excess (otherwise curtailed) RES energy.

Next steps and key decisions to be taken: embracing the opportunity of REI4P Bid Window 7. Our conclusion is that ESKOM is ready to support the immediate deployment of such RES capacities, relying largely on existing processes. Key decisions required are the following:

- *ESKOM* to support the curtailment framework presented hereafter and to initiate the actions for the implementation of automated processes for curtailment of multiple RES plants.
- *NERSA,* in line with international best practice, to endorse the application of RES curtailment framework in order to maximize the availability of RES generation while minimizing the overall cost to society.
- *IPP Office* to include the curtailment framework into the upcoming REI4P Bid Window 7 and ideally creating a "fast-track" option for prequalified RES projects from previous Bid Windows.

1. Renewable energy sources (RES) are abundant in South Africa – and they are the fastest way to reduce load-shedding

The South African electricity system suffers from a **massive generation performance deficit**, resulting in daily load-shedding reaching capacity levels of 5-6 GW ("load shedding stage 6"). Yet, **South Africa has some of the world's best wind and solar resources and abundance of space,** placing the country in an extremely promising position for a rapid transition towards increased renewable-based, highly cost-competitive and secure energy supply. The availability and price-competitiveness of RES is manifested by the results of recent auctioning rounds, with bids as low as R505.47MWh for onshore-wind and R469.50MWh for photovoltaic (PV) plants in the recent Bid Window 6 of the REI4P (Renewable Energy Independent Power Producer Purchasing Program).[1] Furthermore, RES plants can be rapidly deployed, with construction timelines being as short as 2 years for large, utility-scale projects, which makes them the fastest way to reduce the load-shedding problem the country faces. **We therefore believe that RES can be a cheap and fast solution to the energy crisis**.

The global RES deployment levels reveal that RES will dominate the growth of global electricity supply in the next three years. Variable renewables – wind and solar PV – continued to see strong growth in combined capacity, up nearly 18%, corresponding to about 300 GW in additional installed capacity, which is greater than the current combined wind and solar PV cumulative capacity in the United States (approximately 280 GW). In countries with high variable renewables penetration, variable wind and solar PV can make up more than 60% of the total generation capacity (e.g. Denmark, Germany)[2] and reaches even higher levels on specific control areas. For example, in the control area of 50Hertz Transmission in Germany[3], almost two thirds of the annual demand is supplied by variable RES.[4] However, variable RES resources such as wind and solar energy are often treated with skepticism, as to how far they can form the basis of a reliable power supply. To ensure system security, the substantial growth of renewables will need to be accompanied by accelerated investments in grids (expansion, strength and stability) and flexible, fast resources for their successful integration in power systems.

2. South Africa's grid has not been optimized for large-scale RES deployment – RES curtailment framework a quick remedy

Currently, there are **three main types of RES deployment processes in South Africa**, creating a global framework that aims to guarantee the energy security of the country and enable the participation of RES investors:

- **Public IPPs**: Large/utility scale RES projects by investors selected and managed through the public auctioning program REI4P (Renewable Energy Independent Power Producer Procurement Programme), run by the Department of Mineral Resources and Energy (DMRE) IPP Office. These projects form part of the country's energy strategy and are planned through the Integrated Resource Plan (IRP).
- **Private IPPs**: Large/utility scale RES projects by investors who enter into bilateral Power Purchase Agreements (PPAs) with customers (typically industrial off-takers). These RES projects request grid connection without prior auctioning process and are subject to wheeling charges for the grid usage.
- **Decentralized small RES:** Typically roof-top photovoltaics (PV), connected on the distribution grids and at municipality level. A boom in such installations is observed as individual households are seeking independent solutions to load shedding, driven by a combination of falling PV and battery prices and good incentive schemes in some areas in the country.

[1] Source: IPP Office www.ipp-renewables.co.za
[2] Source: IEA Electricity Market Report 2023: **https://www.iea.org/reports/electricity-market-report-2023/executive-summary**
[3] 50Hertz Transmission is one of four TSOs in Germany, serving 18 million customers in the North-Eastern part of the country with an annual total load of about 100 TWh. Two thirds of this energy is delivered by RES from within the 50Hertz grid area.
[4] Source: 50Hertz Facts and Figures Report 2022: **https://www.50hertz.com/xspProxy/api/staticfiles/50hertz-client/dokumente/medien/publikationen/50hertz_facts_and_figures2022.pdf**

The existence of these parallel RES deployment processes creates a situation where **public and private IPPs RES projects compete for the same grid capacity**. The competition between bids leads to producers seeking areas where they can reach the lower overall Levelised Cost of Electricity (LCOE). The same holds also for private IPPs. This can lead to a situation of candidate RES projects (public and private) becoming concentrated in areas of (somehow) higher RES potential but scarce grid capacity. As these processes run in parallel, a queuing problem arises, leading to the exclusion of projects on a first-come-first-served basis. This issue was experienced in the adjudication process of Bid Window 6 of the REI4P, where 3.2 GW RES projects could not be connected to the existing grid (and therefore were incapable of being awarded preferred bidder status under the program). The deployment of more RES capacities is often encumbered by the lack of transmission capacity in the areas with abundant renewable energy resources. This **scarcity of available grid capacity is the key challenge for further RES deployment.**

Strategic grid planning and development is of utmost importance, but time consuming – building new power lines can easily take up to ten years or longer from concept inception. The prevailing load shedding situation requires more urgency. Innovative solutions to immediately resolve grid constraints are required. As a short-term remedy and enabler for the integration of higher shares of variable RES, it is critical **to make the most of the existing grid**. Hence, **a RES curtailment framework is proposed** which will allow the system operator to unlock more capacity in constrained grid areas. The figure below presents the results of a recent survey among RES developers in South Africa, regarding their willingness to accept curtailment in principle, as a means to improve grid integration. The results show that the industry accepts curtailment by a wide consensus. What is worth mentioning, is that this holds true especially for RES developers connected in areas with scarce grid capacity, showing their comprehension on the need for active RES management for ensuring integration of higher RES shares.

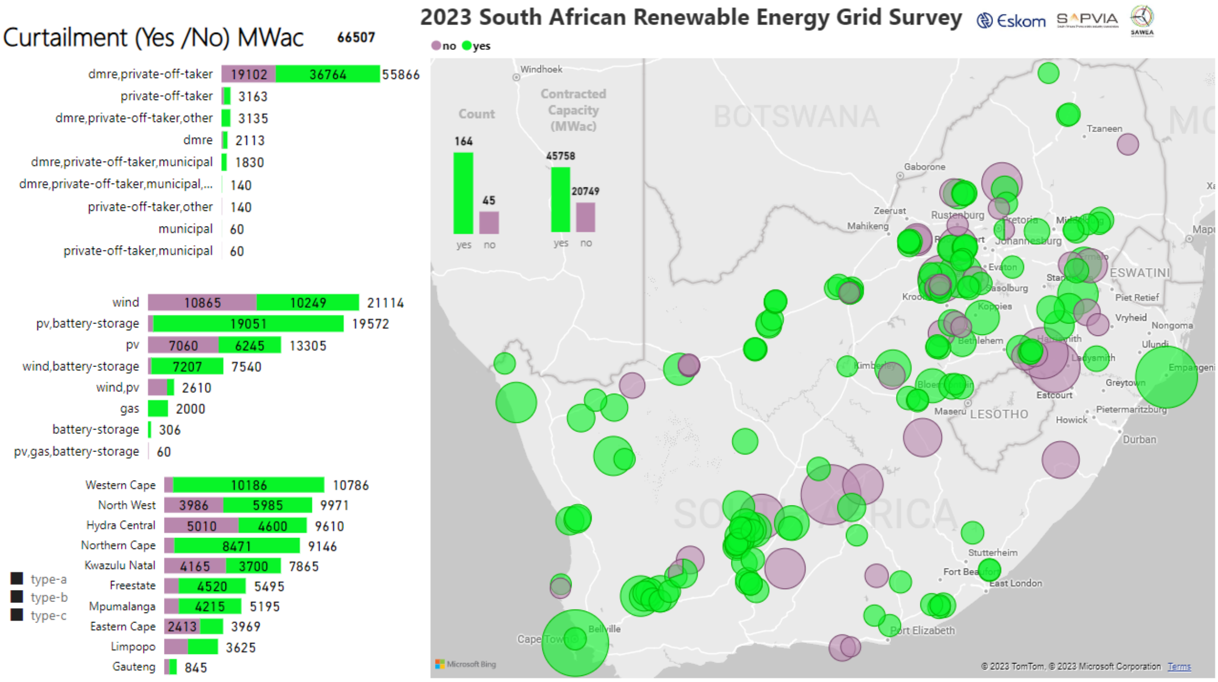

Figure 1: Results from a survey regarding the position of RES developers on curtailment.[5]

In this paper we present the general mechanism of such a curtailment framework based on international best practices and show how this forms a new philosophy that enables the grid planner to take optimal decisions on the system expansion, by weighing the costs from RES curtailment against the benefits from RES integration. In line with the urgency of the current energy crisis in the country, we differentiate between the very short-term ("immediate action") and the mid-to long-term perspectives. **The focus of this paper is to show how a curtailment framework**

[5] Source: ESKOM Strategic Grid Planning Department

can support in the short-term immediate actions needed to connect more RES projects to the ESKOM grid, with a focus on the new, upcoming REI4P auction round. In parallel, we show the compatibility with the general RES deployment framework in the country and how such a curtailment framework can be a new "philosophy" to enable increased integration of RES in the country.

3. The concept of "curtailment" in a nutshell: making optimal use of constrained power grids to accommodate maximum RES

Curtailment refers to the active control (reduction) of the output of RES plants as response to system security needs. Typically there are different reasons for RES curtailment, which can be classified in two categories:[6]

i) **System-wide events:** system balancing and load-following limitations, linked to insufficient flexibility levels of the conventional fleet. In such cases, RES curtailment is implemented on a system-wide scale.

   (1) **System balancing:** during periods of global RES oversupply (during low-load periods), conventional power plants reach their minimum operational limits (minimum generation) or the system reaches its stability limits (e.g. inertia). Typically, this occurs in systems with large-scale conventional units with high start-up/shut-down times and costs (e.g. coal and/or nuclear).

   (2) **Load-following:** conventional power plants cannot adapt net load to the changes in the system during steep fluctuations in RES infeed. Typically, this occurs in systems where the conventional fleet has slow ramping capabilities.

ii) **Grid capacity constraints:** RES oversupply **in specific areas** leading to a (temporary) overloading of grid elements. A useful analogy to understand this is presented in the figure below, showing a supply area including demand (LOAD) and variable supply (GX). The export or import from the supply area is defined by the instantaneous balance of load and generation, e.g. the area is exporting when the generation exceeds the load. The limit of the export is defined by the *network transfer capacity* to other supply areas, similar to the size of a pipe providing water. When the export limit is reached, any further increase of generation in the supply area leads to a spilling of the extra generation, due to the constrained network capacity, (similar to spilling water in case the pipe is full). In such cases, and in order to keep the overall balance in the system, a **congestion management process** is activated, leading to the **re-dispatching of the system**, i.e. the spilled energy on the one side of the congestion is replaced by an equal amount of energy produced by ramping up a generator on the other side of the congestion (or reducing load where this is not possible). This paper focuses on this type of curtailment. In this respect, in the remainder of the paper, the notion of curtailment is considered related to congestion management and re-dispatching and is sometimes used interchangeably.

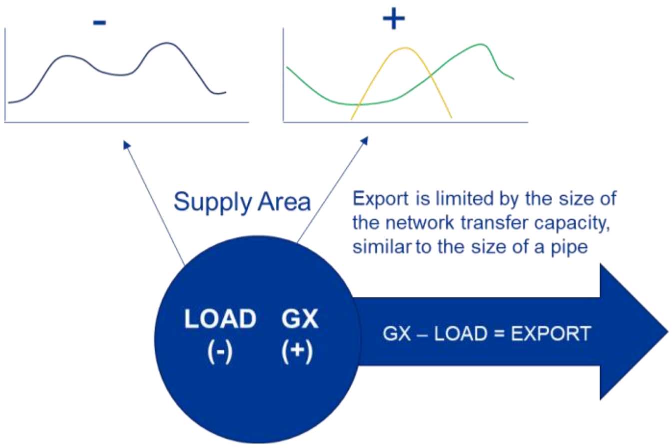

Figure 2: Impact of grid constraints in the export from an area – Analogy to a pipeline[7]

[6] Source: Lori Bird, Jaquelin Cochran, and Xi Wang Wind and Solar Energy Curtailment: Experience and Practices in the United States **https://www.nrel.gov/docs/fy14osti/60983.pdf**

[7] Source: ESKOM Strategic Grid Planning Department

4. RES curtailment for congestion management - international best practice for efficient RES grid integration

The international experience shows that RES deployment requires management of scarce grid capacity.[8] Typically this is due to the combination of two main reasons: a) areas with good RES potential and abundant space are often far from load centers, where grid is generally weak and b) the speed in RES deployment (2-3 years) quickly becomes a challenge, as grid expansion cannot (and, in fact, does not need to) keep up the pace. Building new transmission corridors can take easily more than 10 years. In this respect, **system planners are typically faced with the challenge of how to integrate higher levels of variable RES in constrained grids. The adoption of a RES curtailment framework is a necessary approach for bridging this gap**. The general concept is applied in two steps: a) connection of RES plants with "nameplate" peak capacity that exceeds the grid hosting capacity[9] (i.e. allowing for a certain level of overloads/congestions), b) installing operational mechanisms that guarantee the curtailment of the production in cases the system faces security threats.

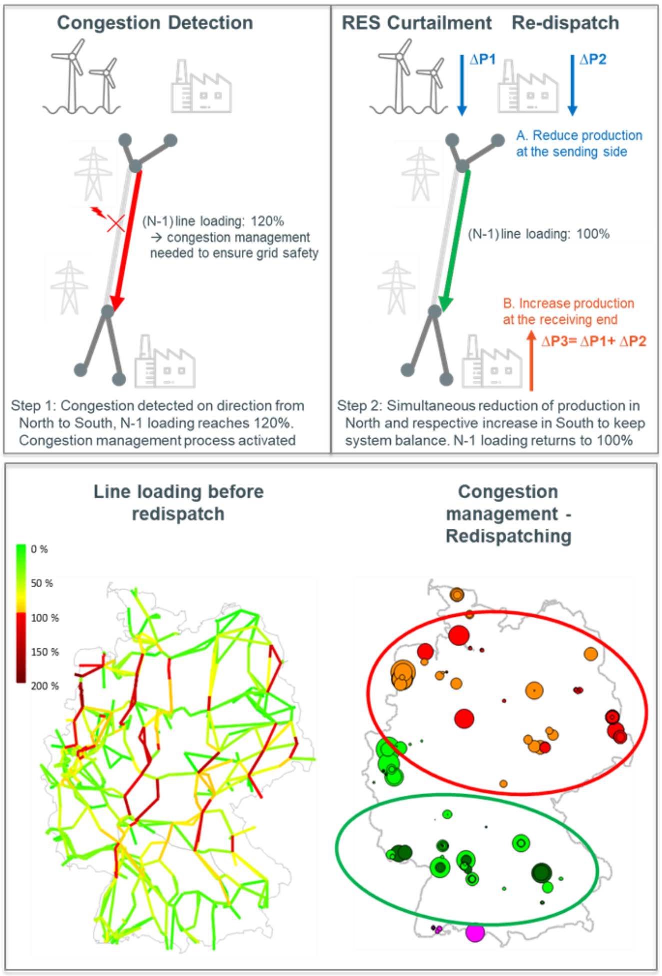

Figure 3: Congestion management process – example implementation in Germany

As mentioned, the application of a curtailment framework is linked to a **congestion management process.** In systems with higher RES shares, this process is a key part of system operational procedures. In the figure below, the graphical presentation of the concept is shown, together with an example of its implementation in Germany. As can be seen, in cases of congestion, the supply on the sending area should be reduced and be replaced by increased production on the receiving area. In the case of Germany, the grid is congested in the North-South direction due to

[8] Source: Lori Bird, Jaquelin Cochran, and Xi Wang Wind and Solar Energy Curtailment: Experience and Practices in the United States **https://www.nrel.gov/docs/fy14osti/60983.pdf**

[9] As grid hosting capacity we refer to the maximum amount of new RES capacity that can be added to the grid without causing a violation.

oversupply in the North (high wind infeeds). The congestion is removed by the simultaneous reduction of production in the North (curtailment) and increase in the South. During implementation in meshed grids, multiple congestions may appear that should be treated by combined re-dispatching actions by the system operator. This increases the complexity of system operational procedures.

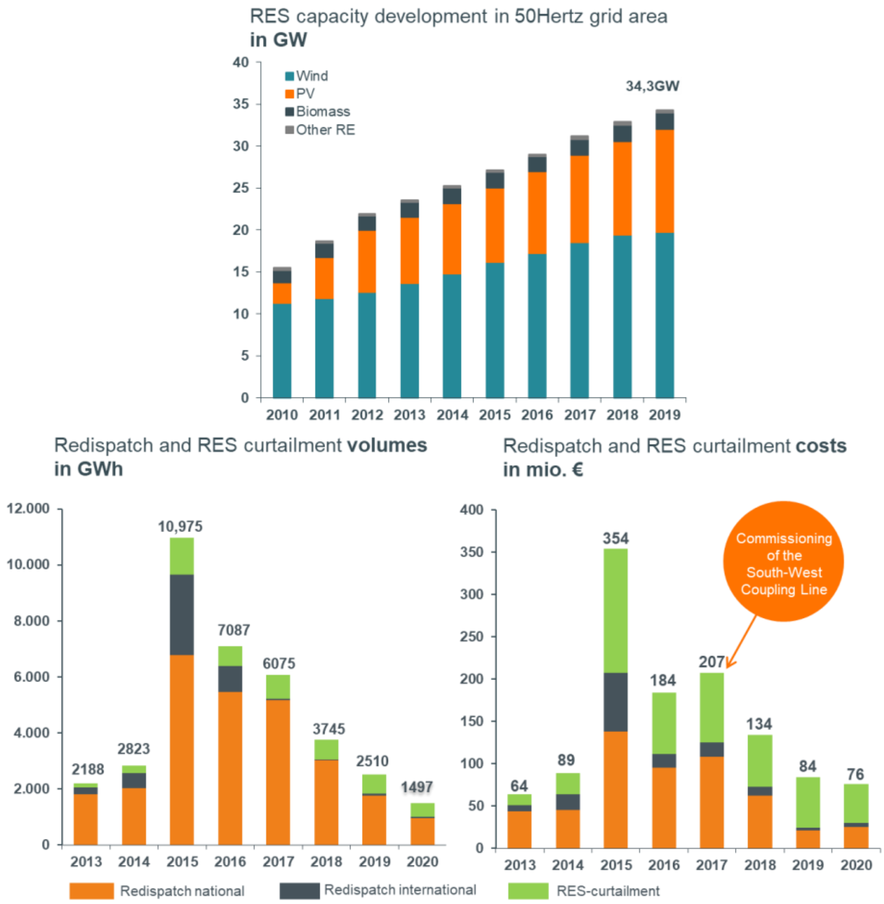

Figure 4: RES deployment in 50Hertz area and evolution of the volumes and costs of RES curtailment.[10]

Typically, the implementation of such a framework incurs curtailment volumes that constantly appear and vary between different years. Higher curtailment volumes and costs are experienced during rapid acceleration of RES deployment, followed by reduction as grid development is catching up. This is the exact trend observed in Germany, during the massive expansion of RES plants in the last 20 years. As can be seen in the figure 4, the RES capacity in the 50Hertz grid area more than doubled in the period between 2010 and 2019. The system experienced increased curtailment levels initially, that were reduced through a combination of system operational measures and grid expansion. In fact, proposals for the construction of new power lines are assessed on a cost-benefit basis. **A certain level of curtailment may always be tolerated as long as its cost to society stays below the cost of a new power line**. The figure below shows the impact of an extraordinarily cost-efficient new power line, so-called "South-West Coupling Line", in one part of the 50Hertz grid. As can be seen, the commissioning of this line in 2017 enabled the TSO to drastically limit the respective curtailment volumes and costs.

RES portfolio effect: "statistical smoothing" increases RES grid hosting capacity

Curtailment is related to RES oversupply events, globally or in specific areas. Due to the variable nature of RES, the RES production in larger geographic areas with a diverse mix of wind and PV plants follows a **"portfolio effect",**

[10] The figure presents volumes and costs for the 3 main types of re-dispatching actions: a) *Re-dispatch national* refers to actions from conventional units in the German system, b) *Re-dispatch international* refers to actions from conventional units that are situated outside Germany (cross-border re-dispatching) and c) *RES curtailment* refers to actions for RES units in Germany.

namely production profiles are complementary or non-correlated for a high share of time. This translates into low number of RES oversupply events, and subsequently reduces the need for curtailment. This effect can be expected also in South Africa on a national and regional level, as RES penetration levels increase. On a national level, the country spans across a very large geographic area, enabling the so called **"statistical smoothing" between resources that are geographically spread**. Typical examples of this are a) wind power peaks appear with time lag across different areas as wind fronts take hours to travel across the country, b) ramps from PV production during sunrise/sunset times are smoothed out, as the sun's path has a time difference of about 1 hour from East to West coast. On a more regional level, wind and solar production complement each other due to their different profiles, smoothing out the RES production in the area. **A strategic deployment of RES with respect to type and location can therefore significantly reduce the variability of RES infeeds, and facilitate the deployment of more RES**.

This concept is directly related to the implementation of a curtailment framework. The current connection requirements assume that the maximum capacity should be catered for and require guaranteeing full evacuation of produced power for most of the time[11]. This translates into defining the maximum RES capacity that can be connected to the system based on to the worst RES oversupply scenario (taking into account the location, type and size of RES plants). This is normally a rather scarce event e.g. maximum wind production from all wind parks in the region during early morning on a weekend during a period of the year with lower demand, like summer. This however in practice means that the infrastructure is under-utilized, as for most of time there is free grid capacity. Curtailment allows for more RES to be connected. By curtailing a small share of production during oversupply periods, the system can integrate the bulk of RES production during all the rest of the time. Same as before, the system operator ensures system security, but does not guarantee full evacuation of the production. In this case, **the decision of how much hosting capacity to allow becomes a cost/benefit assessment**, i.e. the benefits from the integration of higher RES shares and better utilization of the infrastructure versus the costs of RES curtailment.

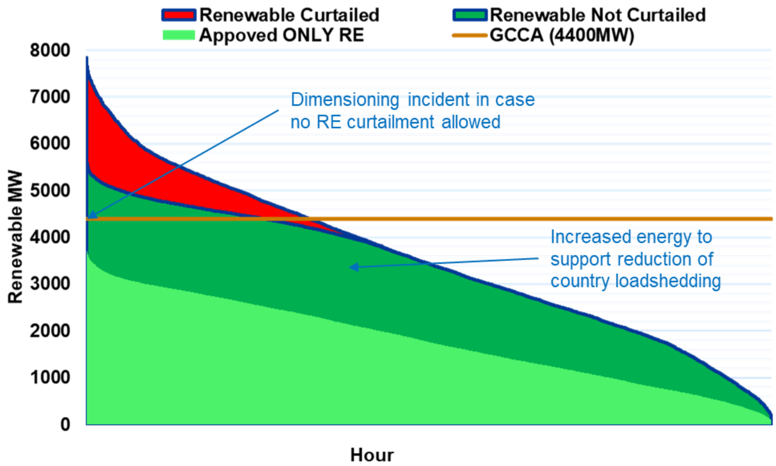

Figure 5: RES capacity and curtailment required for Transfer Limit Capacity management in the Western Cape[12]

This concept is presented in the figure above for an example for the Western Cape area, where the grid hosting capacity is estimated for a case with and without curtailment. These are results of a preliminary analysis of ESKOM's Strategic Grid Planning for a full year (8760 hours - operational incidents) in the form of a generation duration curve, where the RES production is ranked in a descending order (rather than chronologically). The light green area indicates the RES supply in the area without accepting any curtailment; in this case the grid can host a total RES capacity of 4400 MW based on the GCCA methodology (corresponding to the currently approved RE projects from Bid W1 to date). The figure shows clearly that this maximum capacity will hardly be needed (very sharp peak of only

[11] In some PPAs there is an agreed percentage of time where curtailment is allowed (typically 5%) to accommodate grid unavailability due to maintenance, etc.
[12] Source: ESKOM Strategic Grid Planning Department

a few hours duration at the very left of the light green area). Let's now assume the connection of additional 4000 MW which were denied grid access under the very strict condition of "100% feed-in". First of all, we need to consider the balance of RES generation and customers' demand on a regional level – just as an illustrative example, a case of simultaneous 5.4 GW RES generation and 1 GW load leads to an export of 4.4 GW which is the area Transfer Limit Capacity. The dark green area shows the additional RES feed-in that can be accommodated. Only once the RES production minus the load in the area exceeds the Transfer Limit Capacity, the oversupply will need to be curtailed. The results show that moderate curtailment applies to snapshots of RES oversupply, amounting to less than 10% of the produced energy (red area in the graph). Therefore, **by accepting curtailment, the RES hosting capacity for the Western Cape can be almost doubled, and 90% of the RES production can be safely integrated** (dark green area in the graph). Studies are being concluded to confirm these results also for other provinces.

5. Why curtail? Understanding the economics of curtailment: minimizing system expenditure, maximizing RES uptake, gaining speed

A key question raised as criticism for the application of curtailment frameworks is: why it would make sense to "throw away" readily available and cheap/zero-marginal-cost energy. Understanding the economics of curtailment is important for providing answers and avoiding respective misconceptions. What is important to understand is that curtailed energy is a precondition ("the price to pay") for integrating the rest of renewable electricity from the respective RES plants. **This practically means that x% of curtailed RES energy (e.g. 10%) equals (100-x)% of additional RES integrated energy (e.g. 90%).** For this, one should pose two main questions related to the system value of curtailed and integrated RES energy: a) what is the system value of the curtailed RES energy? and b) what is the cost of energy that the RES integrated energy replaces, namely the cost of alternative supply options?

System value of curtailed energy: Unlike other commodities, electricity cannot be easily stored. Batteries and pumped-hydro-schemes are, in principle, options for electricity storage, but they do come at a price and with very limited capacity in relation to the country's total demand. Hence, the system value of electricity is changing in time and space. Available power plants are ranked and dispatched based on an ascending order of cost, the so-called merit order. Least-cost generators are RES, followed by nuclear and coal. Whenever these generators cannot cover the demand (scarcity situations), highest-cost generators, oil and gas, will have to be dispatched and will determine the "marginal price" of electricity. If even oil and gas are not sufficient to cover the demand, load shedding will be the last resort – not carrying an explicit price tag, but effectively causing damage to society and economy which is yet higher than the cost of oil and gas plants. RES, which are producing at close-to-zero marginal cost, lead to a reduction of the system costs, as they avoid the need for the most expensive generation options (including load shedding) at the very right of the merit order. This effect is shown in the figure below, where we compare the system supply two cases: low RES and high RES. As can be seen, the introduction of RES shifts the merit order to the right and reduces the use of expensive marginal units (e.g. oil). The system value of curtailed energy is reflected by the costs of the next unit committed to replace the curtailed energy (see figure). **As curtailment occurs in situations of oversupply, the respective system value of electricity is always low and curtailed energy does not burden the system in situations of scarcity.** In systems with higher RES penetration levels, this impact becomes even more extreme, with system value of electricity becoming even negative in certain hours due to oversupply, signaling the need to curtail or reduce production from conventional units.

Cost of alternative supply options: The system value of RES integrated energy is equal to the cost of alternative supply options in the system. In systems experiencing generation shortages as in South Africa, these alternative supply options are very expensive diesel generators and load shedding with immense societal costs. As a *back-of-the-envelope* illustration, let's consider the following numbers. The average tariff of successful Bid Window 6 photovoltaic (PV) projects was R 556 /MWh. Assuming 10% curtailment under a "take-or-pay" regime (i.e. IPPs will be paid a fixed tariff no matter whether their electricity could be evacuated on the grid or not), the average tariff integrated renewable energy becomes R 618/MWh (that is R$^{556}/_{90\%}$/MWh). This energy will replace the generation technology at the highest marginal cost, which will mostly be Diesel generators (approx. R 5500 /MWh) – or reduce load shedding. The cost related to societal and economic damage of "cost of unserved energy (COUE)" due to unplanned power outages or "cost of load-shedding (COLS)", is estimated[13] to be in the order of magnitude between 29,050 and 101,730 ZAR/MWh. As can be seen, the value of RES integrated energy is very high, as the cost of alternative supply options is much higher, ensuring a positive socio-economic impact even for high curtailment levels.

The economics of curtailment therefore reveal that the energy "thrown away" due to curtailment has actually low value for the system and is the necessary precondition for the integration of the rest of the RES production, which in turn has an immense value for the system.

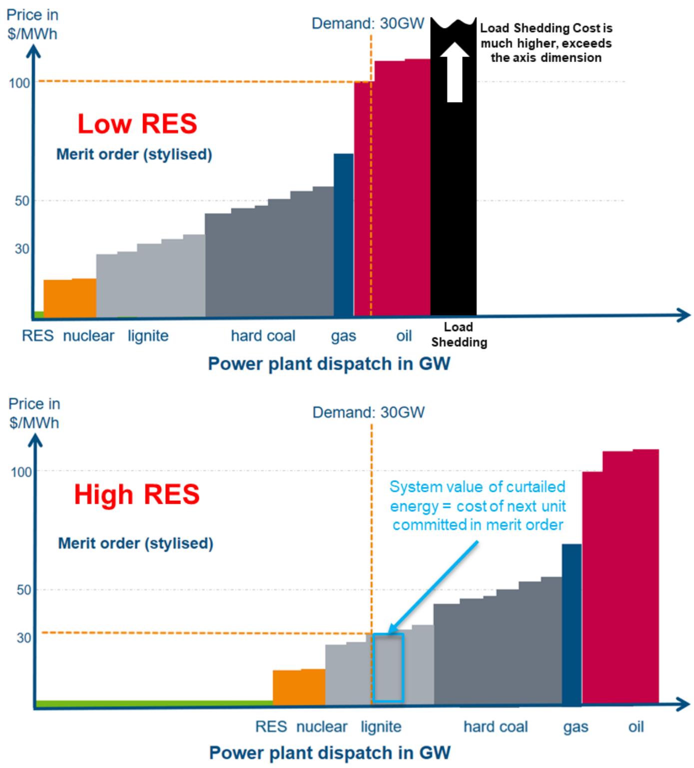

Figure 6: RES merit-order effect and system value of curtailment

6. Who should pay for it: take-or-pay arrangements and socialization of costs

Another key point of consideration for the application of curtailment frameworks is who should bear the costs for the deemed energy. This issue revolves around three main questions:

a) What is the impact to RES developers and how to ensure this will not burden the socio-economic welfare in the long term?
b) How to optimally remunerate the costs from the implementation of a curtailment framework?
c) How to ensure a level playing field taking into account the specificities in the RES deployment processes in South Africa?

a) Take-or-pay regimes reduce risks for RES developers, guarantee minimum bids and incentivize reduction of curtailment in the long term

Curtailment translates into an amount of deemed RES energy. RES developers typically develop business plans based on the total expected produced energy during the lifetime of the RES plant. The final bid comes roughly as

[13] Source: NERSA, "The Review of Eskom's Cost of Unserved Energy Methodology" by ESKOM, 31 March 2022

the result of the estimation of the total costs for the project divided by the expected produced energy. Curtailment introduces uncertainty to this estimation, as it affects the expected RES production. Developers typically request an agreement on a cap on the curtailed energy (e.g. 2-3%). After this threshold, the deemed energy should be paid under a take-or-pay arrangement (as if it had been produced). Without the security of a take-or-pay arrangement, RES developers typically factor this risk in their financial estimations and increase their bids by adding a risk premium due to the expected curtailment. These higher bid prices apply for the whole project lifetime (typically 20 years) and therefore may lead to financial losses for electricity customers, as curtailment levels could be reduced after some years. In this respect, **the implementation of take-or-pay regime without caps is the best option for the system aiming to reduce risks for developers and guarantee minimum bids**, while at the same time create incentives for the implementation of swift measures to reduce curtailment.

b) Socialization of costs is a standard international practice for the remuneration of curtailment frameworks

As discussed, in case of curtailment due to grid constraints, the curtailed energy should be replaced by the activation of conventional generation (or demand side management) in the opposite side of the congestion. Congestion management processes are applied to ensure equal treatment of curtailed RES generators and cost-optimal re-dispatching of conventional units. Typically this process is coordinated by an operational optimization algorithm aiming to minimize curtailment volumes and re-dispatching costs. Two main parameters define optimal re-dispatching, namely 1) the position of the unit with respect to the congestion (how effectively it can remove the congestion to reduce curtailment volumes) and 2) the respective activation costs (merit-order activation of conventional units to minimize re-dispatching costs). These extra activation costs are the system costs due to the curtailed energy.

The application of a congestion management is the product of a system-wide optimization process and can serve additional purposes, e.g. co-optimize the system balancing. In meshed grids, it is becoming very difficult to link re-dispatch actions to specific pairs or subsets of generators re-dispatching actions of single units may impact multiple lines in the system and a single congestion may be affected by multiple units. Congestion management process is seen as a grid operational mechanism that the system operator uses to manage situations of grid scarcity. According to the international practices**, congestion management costs are socialized (pass-through) as system services.[14].** In other words, the society has to guarantee the connection of RES capacity as it brings long term positive socio-economic benefits and bear the costs due to the temporal grid scarcity due to lagging grid expansion.

c) Compatibility with RES deployment frameworks in South Africa: ensuring a level playing field

As discussed, two main RES deployment processes for large-scale projects run in parallel in South Africa, namely public and private IPP. In this respect, it is important to **ensure a level playing field** in the application of a congestion management framework. **This can be guaranteed by ensuring that curtailment is performed on the basis of technical reasons based on the respective grid constraints at each time.** The application of a take-or-pay regime combined to a socialization of respective costs can largely ensure this condition.

- **Public IPPs: good fit with the current framework**
  Public IPPs have direct contractual arrangements with ESKOM as buyer of the produced energy, which regulate curtailment on a take-or-pay regime without caps. A curtailment framework can be directly applied in this respect. The main change is that higher volumes for grid-related curtailment are to be expected. RES producers will participate in the REI4P auctions with minimal bids as their remuneration will be independent of the actual curtailment level each year. Through a non-discriminatory congestion management process (as described above), ESKOM will ensure that the deemed energy is supplied by the next committed plant in a cost-optimal

[14] For the vast majority of countries in Europe, congestion management costs are allocated to transmission tariffs, i.e. Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Great Britain, Ireland, Italy, Luxemburg, Netherlands, Northern Ireland, Norway, Poland, Romania, Serbia, Slovakia, Slovenia, Spain and Switzerland. For more details see the ENTSOE Overview of Transmission Tariffs in Europe (Synthesis 2020): **https://eepublicdownloads.entsoe.eu/clean-documents/mc-documents/l_entso-e_TTO-Report_2020_03.pdf**, Table 5.1 on the costs included in the calculation of the Unit Transmission Tariffs.

way. Through this process, ESKOM will transparently monitor the congestion management costs, corresponding to the cost of the energy supplied and report it to the regulator. These curtailment costs could then be passed through to the tariff.

- **Private IPPs: same operational application with possible mechanisms to share risks**
  Private IPPs have direct bilateral contracts to private off-takers, defining tariff and produced energy volumes. The agreement is private and not disclosed to ESKOM. ESKOM regulates the grid connection and operational responsibilities with the private IPP through the Connection and Use of System Agreement. In cases the IPP supply is not sufficient to cover the off-taker demand, ESKOM supplies this energy as "provider of last resort". This is often based on the so-called "Megaflex" tariff, corresponding to the average volumetric cost of supply in the system.
  The curtailment framework could be **operationally** applied in the same way for private IPPs, **ensuring a level playing field.** A transparent congestion management framework enables the TSOs to treat all IPPs uniformly in the re-dispatching process. This framework does not interfere with the private transaction between RES supplier and off-taker and does not necessitate the disclosure of any contractual information, such as price and volumes. When the RES unit is curtailed, ESKOM will provide this energy to the off-taker. **In case it is deemed necessary, mechanisms could be considered to share the congestion curtailment risk with private off-takers.**

For system planning purposes regarding the implementation of the congestion management framework, it is necessary that there is **credible and detailed information on all the RES projects (e.g. type and location)**. Due to the parallel RES deployment processes, allowing bidding in different timeframes creates issues with the assessment of available grid capacity during bid evaluation. A case-by-case project assessment is not possible, as the curtailment level may change if new projects are introduced. **For this, it is important to address the RES queuing problem experienced at the moment and to ensure that credible RES projects are introduced in the assessment.**

7. Making it happen: key aspects for the implementation of a RES curtailment framework within ESKOM

ESKOM is the key actor in the implementation of a curtailment framework. Together with ESKOM experts, we assessed the readiness of the organization and identified possible gaps and barriers. The assessment has been performed, taking into account three timeframes, as shown in the figure below:

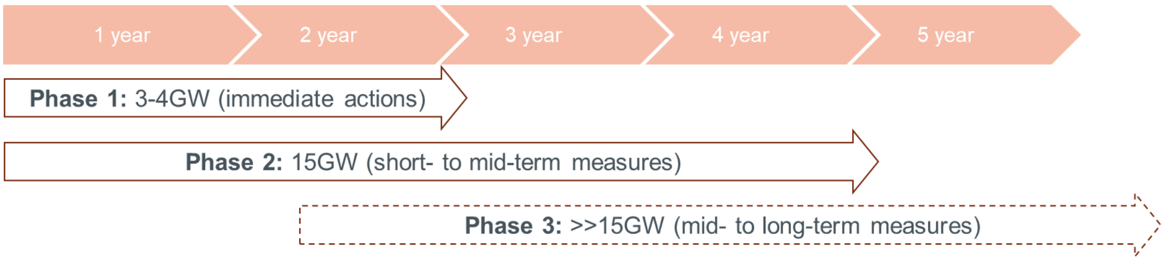

Figure 7: Overview of the key phases for the implementation of a curtailment framework in ESKOM

a) **Phase 1 (immediate actions)**, namely assessing the readiness, barriers and needed measures for an immediate deployment of additional 3-4GW RES capacity into the existing grid which could become operational **in the next 2 years** as a measure for addressing the energy crisis. This capacity refers to additional capacity on top of what has already been accounted for in the last GCCA.
b) **Phase 2 (short- to mid-term measures)**, namely assessing the readiness, barriers and needed measures for ramping up the RES capacity up to 15GW in the next 4 years (in line with the recent plans communicated by the electricity minister).

c) **Phase 3 (mid- to long-term measures)**, namely assessing the compatibility of the framework to a higher deployment of RES capacity and a deep decarbonisation of the South African energy system.

The implementation of a curtailment framework concentrates on three main domains in ESKOM as depicted in the Figure below: 1) System Operations, 2) Market Operations and 3) Grid Planning. A key conclusion from the discussions was the strong need to communicate the framework openly to related stakeholders and general public. In this respect, the results of the gap analysis should feed in a concise communication strategy. In this section, we present the results of the gap analysis per domain, focusing on the two first phases since both of them require immediate action or immediate preparation for action. In the next sections we dive deeper on the general considerations on the compatibility of phase 3 and the communication plan.

Figure 8: Overview of the key domains for the implementation of a curtailment framework in ESKOM

1. Operationalisation of the curtailment framework

The ESKOM system operations department is central for ensuring a timely implementation of a curtailment framework. Currently, curtailment is applied in ESKOM but is only a niche process, for system-wide control actions/constraints. The extension of this concept towards a congestion management framework is missing. The interaction with key decision-makers at Eskom revealed a wide agreement on the role of RES as solution of the generation supply gap and reduction of load shedding. **The key conclusion is that ESKOM can only enter Phase 1 with immediate effect. There must also be a commitment to immediately start preparations for everything to be in place before Phase 2 resources go online.** An overview of the key conclusions is as follows:

- **Phase 1:** In the very short term, System Operator confirms that with such a curtailment framework in place, there are no major obstacles to an immediate connection of more RES capacity to the grid. In practice, the current manual procedures in place can be applied for the immediate operationalization of a curtailment framework, namely defining the re-dispatching actions and issuing respective instructions to generators (the current setup allows to manually manage up to about 80 generators). This remarkable readiness for introduction of 3-4GW RES capacity in a relatively short time is a clear manifestation of the capabilities developed by the ESKOM system operations team due to the daily operation of the system under the current, extreme conditions of daily load-shedding. Possible gaps identified are:
  - **a) Capacity building:** To support this a rapid implementation, it is necessary that the ESKOM staff get training through peer-to-peer exchanges with TSOs operating systems with high RES shares.
- **Phase 2:** However, such manual procedures are not sufficient when moving to the next level of RES deployment. The international experience from systems with high RES penetration levels shows that the system operator will need more advanced tools and processes and should upskill resources. **This process has to start**

immediately, to ensure that those elements are in place before Phase 2 resources go online. The key gaps identified are summarized below:

a) **RES forecasting:** Currently, ESKOM relies mainly on forecasts provided by the IPPs. Accuracy is incentivized by a penalization of forecast errors and is thus far deemed acceptable. However, with higher RES penetration levels, ESKOM should develop its own forecasting capabilities as a) forecast errors may have detrimental effects on system operation with higher RES capacities and b) the system state will become increasingly difficult to assess with higher shares of RES embedded in lower voltage levels.

b) **Congestion management planning tool:** As RES levels increase, the congestion management process becomes much more complicated. ESKOM should extend the current tools to ensure that the operational decisions come from an overall optimization process (i.e. optimize re-dispatching actions from multiple units towards multiple congested lines and in some cases combined to balancing decisions).

c) **Re-dispatch instruction and communication system:** With higher RES shares, the current system for issuing re-dispatching orders should be further developed and automated, to manage a higher number and frequency of actions. This could be included in the SCADA system or be developed as an additional layer.

d) **Visualisation tool for grid congestion mapping:** with higher RES shares, system operators should have much higher and immediate visibility of network constraints to ensure safe system operation. ESKOM should deploy a visualization tool that will allow the automated mapping of the system risks by issuing flags in cases of security threats (e.g. transport levels are exceeded, stability limits are reached).

e) **Re-dispatch log and clearing/settlement tool:** The IT infrastructure on monitoring and settlement of the congestion management process should be implemented, to meet regulatory requirements. This should ensure the proper settlement of all generators participating in re-dispatching actions.

f) **Operational planning processes:** With higher RES shares, a rolling planning framework should be in place, ensuring the adaptation of system operational planning decisions based on possible changes in operational conditions due to rapid changes in RES infeeds. This may necessitate the introduction of new processes to ensure the continuous adaptation of operational planning decisions in high frequency. Furthermore, a review of the load shedding protocols may be needed.

g) **Maintenance planning processes:** Once additional RES get rapidly connected, more intensive maintenance may be needed to ensure optimal operation of existing assets in constrained networks. The impact and duration of planned outages should be reduced and grid maintenance will need to be done more efficiently, e.g. live as far as possible. System restoration processes for different areas may need to be adapted, e.g. EPP's, staff location, numbers, spares holdings etc.

h) **Human Resources:** The international practice shows that the implementation of extensive congestion management processes needs an increase in human resources, to manage the increasing tasks, but also including new types of profiles to manage new tasks (e.g. forecasting team, data management team). In addition, a respective adaptation of the organization of the operations department may be needed.

2. Institutional framework and market mechanisms

The ESKOM market operations department is central for ensuring that the overall institutional framework and operational agreements are suitable for the immediate roll-out of a curtailment framework. In view of the prospective auction round, the time pressure on the market operations department is high, as they should assess the needed contractual amendments to fit a future curtailment framework. In this respect, the key conditions for the framework have to be agreed now and be in place for phase 1. **The interaction with the market operations department at Eskom revealed a wide agreement on the merits of a take-or-pay regime, combined to a socialization (pass-through) of the congestion management costs.** An overview of the key conclusions is as follows:

- **Phase 1:** In the very short term, market operations department at ESKOM confirms that the current contractual conditions can accommodate a curtailment framework, as they are based on take-or-pay clauses.

Main gaps identified are:

a) **Remuneration framework:** NERSA should accept the curtailment framework (i.e. based on the principles of operation of a congestion management process) and approve the socialization of related costs.

b) **Grid code review:** No major gaps on the grid code were identified, but a thorough review is proposed in the short term, to ensure that there are no legal gaps on the implementation of curtailment framework. Possible issue reported was the strict formulation in the grid connection code regarding the necessity of ensuring hosting capacity to fully evacuate all generated energy. In case this is identified as an issue, a proposed short-term remedy would be to regulate it through the contractual agreement.

c) **Adaptation of contracts:** A review of the Connection and Use of System Agreement may be needed to incorporate possible changes and regulate the curtailment framework.

d) **Reporting on curtailed energy forecast to NERSA:** ESKOM should be able to forecast the expected curtailed energy for the next year(s) and provide it to NERSA for the financial statements. This reporting should be based on detailed technical studies and will become standard process for the cost estimation.

- **Phase 2:** The preparation of higher RES deployment necessitates the introduction of elements for steering RES to areas that are more suited with respect to the available grid capacity.

a) **Policy instruments for steering RES deployment:** With higher RES shares, it is important to have a framework in place that can guide the RES deployment in terms of mix and location, to maximize social welfare in the different stages. In essence, instruments are needed to reflect the impact of new projects on expected increasing curtailment in a region.

b) **Grid code amendment:** An amendment of the grid code in the short- to mid-term timeframe should be performed in case the grid code review reveals prominent issues that cannot be regulated through the contractual frameworks. As such amendments should pass through a full process, this process should be planned well in advance to ensure that it will not block the deployment of phase 2.

c) **Tariff reform:** A tuning of the tariff structure may be needed, to ensure that the tariff properly reflects operational and capital system costs.

3. Grid development and steer RES deployment

The ESKOM grid planning department is responsible for assessing the extra grid hosting capacity in the short term, and to implement the new "philosophy" of grid planning based on curtailment frameworks. **The interaction with the grid development department at Eskom revealed a wide agreement on the merits of including a curtailment as key parameter in cost-benefit assessment process for grid planning.** In view of the upcoming next auction round, the grid development department should swiftly implement new grid hosting capacity estimation methodologies for the different areas in the system and provide this information to the IPP office. An overview of the key conclusions is as follows:

- **Phase 1:** For the immediate action, grid planning department at ESKOM confirms that allowing curtailment can lead to high gains in grid hosting capacity in congested areas. Main gaps identified are:

a) **RES queuing:** To ensure a proper estimation of added hosting capacity with curtailment, the uncertainties introduced in the planning process due to the queuing problem should be removed.

b) **Grid hosting capacity with curtailment:** The department already implemented and tested new methodologies for the estimation of hosting capacity with curtailment with remarkable results and demonstrated full readiness for rolling it out in the other system areas. Key next step is to roll out the assessment for all involved RES deployment areas in the system.

c) **Grid investments for resolving local grid congestions:** A review of the grid design in constrained network areas may be needed, to identify network elements impeding grid hosting capacity. Immediate investments may be needed to remove such local congestions that may block grid transfer capacity.

- **Phase 2:** In the short term, grid development department at ESKOM should ensure that the system is ready to host higher RES shares and that the new RES capacities can be steered in terms of mix and locations to ensure maximum portfolio effect benefits for the society. Main gaps identified are:
  - **a) System stability:** Transitioning from 80% coal-based generation towards a RES-dominated system will require new concepts for ensuring system stability, when firm capacity is replaced by RES. The system should ensure the existence of sufficient resources for provision of inertia.
  - **b) Unlock grid flexibility:** International experience shows that different strategies can be employed to enable more flexibility in the local grids, to allow the management of temporary overloads. Technologies to be considered are energy storage, DLR (dynamic line rating), HTLS (High Temperature Low Sag Conductors) and improvement of thermal rating of secondary equipment such as transformers/substations (which seem to be the bottleneck in many cases).
  - **c) Methodology for steering of RES deployment:** A strategic deployment of renewables in terms of mix (taking advantage of "portfolio effect", i.e. solar and wind being complementary in many areas) and geography (taking into account the grid capacity available in each deployment phase) could ease and speed up the introduction of renewables in the South African power system. This could be achieved by a new scheme of prioritization of location and type of RES projects based on the available grid capacity. This will allow connecting plants and energy storage firstly in the areas where the grid is stronger in a more "evolutionary approach". The grid planning department should be able to perform studies to quantify the impact and tune the policy instruments for the steering of RES deployment.

8. Communication Strategy: "Taking the fear away"

One of the key problems with acceptance of a RES curtailment framework is stakeholder acceptance. Experience shows that the perception of "wasted energy" from "expensive and unreliable plants" can be a significant hurdle. For this, it is necessary to deploy an active communication strategy that can educate stakeholders and public. Moreover, this is a great opportunity for ESKOM to reverse the negative image and be promoted as the facilitator or energy transition in the country.

The "elephant in the room" when talking about curtailment seems to be people's fear of the unknown. A communication strategy should aim on how to take the fear away from decision makers and the public. This strategy should create a positive curtailment and RES narrative. Key outline of such a narrative is presented in this paper and is summarized below:

1. **RES is the fastest and cheaper generation capacity to effectively reduce load shedding.** Significant RES capacity can come online in 2-3 years.
2. **RES curtailment means RES integration**. Accepting a small percentage of curtailment is the price to pay to integrate the rest of RES production to the grid.
3. **RES curtailment brings optimal use of infrastructure.** Through the application of modern approaches for grid congestion management, the hosting capacity of existing infrastructure is maximized.
4. **RES curtailment will increase energy security,** ESKOM is very capable to operate system with higher RES shares – more RES energy in the system will reduce current operational risks due to load shedding.
5. **RES curtailment makes economic sense.** We curtail when we have an oversupply from RES. Curtailed RES energy has low value for the system, while the integrated RES energy replaces alternative supply options with much higher costs.
6. **RES curtailment brings benefits for the society as a whole** from a more efficient energy system and faster remedy for load shedding.
7. **RES curtailment is a booster for efficiency and innovation – and puts the seeds for the transition towards a RES-dominated system in South Africa.**

In parallel to this positive narrative, **we should pay close attention on the key concerns regarding fairness and who will benefit from it.** This is probably the most subtle yet substantial concern. It may cause a disturbing feeling when private investors (IPPs) are paid for "doing nothing" on the expense of the public during periods of load shedding. Even though there is an undisputed efficiency gain for society as a whole and a benefit for the system operation, a closer look is needed to ensure that the application of the concept for private IPPs does not leave any risks on distortions.

9. Outlook on the transition to higher RES shares: curtailment is here to stay – and it will trigger innovation

South Africa has some of the world's best wind and solar resources, putting the country into an extremely promising position for a full transition towards 100% renewable, highly cost-competitive and secure energy supply. The short-term measures aim for a rapid integration of RES to the existing grid. However, over time and with an increasing share of RES, grid planning and stability as well as market development need to be adjusted. We are aware that Eskom applies great attention and expertise on these mid- to long-term issues. In our experience, a transition towards 100% RES rests on six pillars, all of which should be taken into consideration at Eskom as well: (i) accelerated RES deployment, including space availability, permitting, grid connection; (ii) grid development and expansion, including market development; (iii) energy efficiency; (iv) flexibility on the consumer side, including DSM/DR (demand side management / demand response) of industrial, commercial, and residential customers, (v) sector coupling, with a specific focus on heat and hydrogen, (vi) storage.

What should be noted is that the proposed curtailment framework is fully compatible and brings the seeds of a new "philosophy" of system long-term development towards RES-dominated supply. As shown in the example of the supply for Western Cape, in systems with variable resources a congestion-free grid often means that grid is not optimally utilized. The goal is the optimal use of the system hosting capacity and management of congestions. The investment decision comes by weighing the infrastructure costs against the incremental benefits from reducing congestions (i.e. curtailment, re-dispatching). This Cost-Benefit-Analysis is the state-of-the-art approach used currently for the infrastructure design of systems towards deep decarbonisation.

As opposed to the notion of "wasted energy" through curtailment, it turns out that in fact a **curtailment framework acts as a booster of efficiency and innovation**. The international experience shows two trends in systems that experience curtailment:

1 **Technical and operational excellence to avoid curtailment:** System operators start to deploy approaches and technologies for a better use of available grid capacity. These include grid enhancing technologies to allow higher currents (such as dynamic line rating to allow increasing the thermal limits of assets or reinforcement of conductors), flow controllability to better utilize parallel paths, more flexible approaches on management of N-1 constraints, excellence in system operations. These are all innovative solutions that are employed by the system operator exactly due to the fact that curtailment becomes a direct measure of expected benefits. In this respect, a curtailment framework becomes a booster for innovation for the system operator.

2 **Curtailment as entrepreneurial inspiration: market bounce-back actions:** When areas start experience excess energy and curtailment, a market bounce-back effect is observed. This triggers new business ideas on using the excess energy. These business ideas do not need to be planned ahead yet; they will evolve and be driven by creative entrepreneurs if the regulatory framework allows for it. Examples of such solutions are:

- Power to Heat: ENERTRAG's Nechlin example from Brandenburg/Germany for uptake of otherwise curtailed wind energy to heat up a 1,000 m³ water storage for the local heating system of a village.
- Hydrogen: Massive growth of electrolyser developments in Germany right now, actively seeking grid-friendly sites where curtailment is prevalent. Most recently, the same trend is observed around utility-scale batteries, with developers currently seeking sites for the 100+ MW class of stationary batteries.

- Industrial settlement: Industries locate in areas of RES abundance, actively requesting 100% RES and preferring sites outside of the traditional industrial centers, with space availability and local RES supply (e.g., Tesla mega-factory near Berlin).

10. Next steps and key decisions to be taken: embracing the opportunity of REI4P Bid Window 7

Currently, a window of opportunity seems to open up, given a coincidence of a heightened sense of urgency to resolve the issue of load shedding through the rapid deployment of new RES capacities. In order to achieve this, **two key obstacles** should be removed:

1. **The hosting capacity of the power grid must be increased in the short term.**
2. **The time-consuming REI4P procedure must be shortened.**

The focus of this paper is to address the first obstacle, by the operationalization of a RES curtailment framework. The focus is on immediate actions, namely assessing the readiness to deploy immediately 3-4GW RES capacity, which could be ready in the next 2 years.

A central actor on implementing such a framework is ESKOM. We assessed the readiness of the three main domains of the organization, which should drive this implementation. **Our conclusion is that ESKOM is ready to support the immediate deployment of such RES capacities, relying largely on existing processes**. At the same time, the preparation for the next phase of the RES deployment should start immediately, as such processes will not be sufficient for the further deployment phase (approx. 15GW RES capacity). International experience shows that with higher RES shares, the system operator undergoes a radical transformation, typically leading to a rapid increase in the human resources. Furthermore, RES integration necessitates higher investment in grids, which may lead to need for strategic commitment of higher capital volumes for grid development. In order to embrace these opportunities, the following next steps need to be approved by the respective decision-makers.

ESKOM Executive support for the curtailment framework laid out in this paper. In detail, this includes the following need for action in the respective departments:

1. Roll out a communication campaign to inform stakeholders on the benefits from RES deployment and the role of curtailment
2. Conduct studies to indicate grid hosting capacity to be released in different areas using the curtailment framework
3. Initiate an extensive capacity building program to ensure that ESKOM staff gets training through peer-to-peer exchanges with TSOs operating systems with high RES shares
4. Congestion management process: development of clear operational guidelines on when and who to curtail
5. Clarification of financial rules to manage the curtailment framework: how to remunerate the IPPs for curtailment, mechanisms to share risks with private off-takers (if deemed necessary).
6. Initiate preparation of the organization to manage the system operation with higher RES shares (phase 2): review of resource capacity requirements and processes for forecasting, scheduling and dispatch.
7. Specification and procurement of systems/tools to enable the system operator to implement congestion management with higher penetration of renewables.
8. Review of the Grid code and Scheduling and Dispatch rules to enable this framework
9. Review of the customer connection and quotation processes.

NERSA is the key actor to approve the rollout of the curtailment framework. In line with international best practice, NERSA may confirm the application of RES curtailment in order to maximize the availability of RES generation while minimizing the overall cost to society. This includes the following:

1. Allow grid congestion curtailment costs to be passed through. This is largely in line with the current regulation. However, NERSA should endorse the framework.
2. If necessary, approve a Grid Code amendment process in case the review reveals that changes are needed.

The **IPP Office** is currently preparing the frameworks for REI4P Bid Window 7 and 8. In order to unlock the initial RES potential, the IPP Office may kindly decide to include the curtailment framework into the upcoming Bid Window. In addition to the capacities to be procured under round 7 and 8, the application of the curtailment framework might lead to a “fast-track” option for prequalified RES projects from previous Bid Windows with the opportunity to reconfirm their existing bids and be granted grid access without time consuming reassessment of their projects.

Appendix 1 Overview of allocation of congestion management costs in transmission tariffs in Europe

In the vast majority of countries in Europe congestion management costs are socialized through the transmission tariffs, especially in countries with higher RES shares with more substantiated congestion management volumes. The table below presents the detailed overview of allocation of congestion management costs in the different countries.

Country	System services							
	Tertiary reserve	Congestion Management (internal)	Congestion Management (cross border)	Black – Start	Voltage Control Reactive Power	System Balancing	Losses	Other
Albania	C	N	B/C (estimated)	N	N	N	C	N
Austria	N	C	C	C	C	N	C	C
Belgium	C/B	C	C/B	C	C	N	C (estimated)	C
Bosnia and Herzegovina	C	N	B/C	C	N	C	C	N
Bulgaria	N	N	B/C	C	C	N	C	C
Croatia	C	N	C	C	C	C/B	C	C
Cyprus	C	N	N	C	C	N	C	C
Czech Republic	C	C	C	C	C	C/B	C	N
Denmark	C (estimated)	C/B (estimated)	B/C (estimated)	C (estimated)	C (estimated)	B/C (estimated)	C (estimated)	C (estimated)
Estonia	C	N	C	C	C	N	C	C
Finland	C	C	C	C	C	C	C	C
France	C	C	C	C	C	N	C	C
Germany	C	C	C	C	C	N	C	C
Great Britain	C	C	C	C	C	C	N	C
Greece	N	N	B/C	C	N	N	C (estimated)	C
Hungary	C	N	B/C	C	C	B/C	C	B/C
Iceland	C	N	N	C	C	C	C	N
Ireland	C	C	C	C	C	C	C	C
Italy	C	B/C	B/C	C	C	C	C (estimated)	C (estimated)
Latvia	C	N	N	C	C	C/B	C	N
Lithuania	C	N	N	C	C/B	N	C	N
Luxembourg	C	C	C	C	C	C	C	C
Montenegro	C	N	B/C	N	N	C	C	C
Netherlands	C	C	B/C	C	C	B/C	C	N
North Macedonia	C	N	B/C	C	C	C/B	C	N
Northern Ireland	C	C	C	C	C	C	C	N
Norway	C	B/C	B/C	C	C	N	C	N
Poland	C	C	B/C (estimated)	C	C	C	C	C
Portugal	N	N	B/C	N	N	N	C (estimated)	C
Romania	C	C	N	N	C	N	C	C
Serbia	C	C	C/B	C	C	C	C	C
Slovakia	C	C	N	C	C	N	C	N
Slovenia	C	C	C/B	C	C	N	C	C
Spain	C (estimated)	C (estimated)	C (estimated)	C (estimated)	C (estimated)	C (estimated)	C (estimated)	C
Sweden	N	N	N	C	C	N	C	N
Switzerland	C (estimated)	C (estimated)	B/C (estimated)	C (estimated)	C (estimated)	C (estimated)	C (estimated)	C

Legend:

- C if a given cost item is included in the calculation of the Unit Transmission Tariff.
- C/B if for a given activity there are both costs and benefits/revenues, the costs are higher than benefits, and the difference is included in the calculation of the Unit Transmission Tariff (surplus of costs).
- B/C if for a given activity there are both costs and benefits/revenues, the benefits are higher than costs, and the difference reduces the Unit Transmission Tariff.
- N if a given cost is not considered in the calculation of the Unit Transmission Tariff.
- C or C/B or B/C marked as "estimated" indicate that the cost item is not invoiced by the TSO and estimated values are provided for comparability purposes.

Table 1: Overview of Costs included in the calculation of Unit Transmission Tariffs in Europe (Source: ENTSOE Overview of Transmission Tariffs in Europe: Synthesis 2020).

Who we are: first-hand energy transition experience from (East) Germany, brought by EGI and 50Hertz

Elia Grid International (EGI) is an international consulting company, which offers consultancy services in market development, asset management, power system operations, and security, system and market operations, as well as owner's engineering and investment advisory support both to international clients in the power grid sector and to the Elia Group. It is a full subsidiary of the Elia Group, organized around two transmission system operators (TSOs): Elia in Belgium and 50Hertz in Germany. The unique value proposition of EGI stems from the combination of expertise and experience of two European electricity transmission system operators, enhanced with international and broader industry perspective and insights, as EGI engages staff from different cultural and professional backgrounds. This way, EGI can provide a wide range of comprehensive and specialized consultancy services based on solid industry knowledge, operational expertise and hands-on TSO experience as well as international consulting track-record in all topics related to core processes of a TSO.

50Hertz Transmission GmbH, part of the European Elia Group and a member of the European Network of Transmission System Operators for Electricity (ENTSO-E), is the fully unbundled Transmission System Operator in the North and East of Germany. 50Hertz builds, owns, and operates the highest voltage grid (mostly 380 kV_{AC}, 525 kV_{DC}) with an electrical circuit length of more than 10,000 kilometres, installed generation capacity of > 60 GW (of which ~ 40 GW renewables) and annual power consumption of > 100 TWh. 1,600 employees at 50Hertz ensure the highly reliable electricity supply for 18 million people in seven federal states (Brandenburg, Mecklenburg-Western Pomerania, Saxony, Saxony-Anhalt, and Thuringia, as well as the city states of Berlin and Hamburg). 50Hertz is a frontrunner for the grid integration of volatile renewables, mostly wind and photovoltaics. Already, renewables cover two thirds of the total load in the 50Hertz grid area, and it is our strategic ambition to reach 100% (annual average) by 2032.

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