Re-estimating the Economic Cost of Load Shedding in South Africa

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The original study was commissioned by: Eskom Holdings (SOC) Ltd. in 2020.

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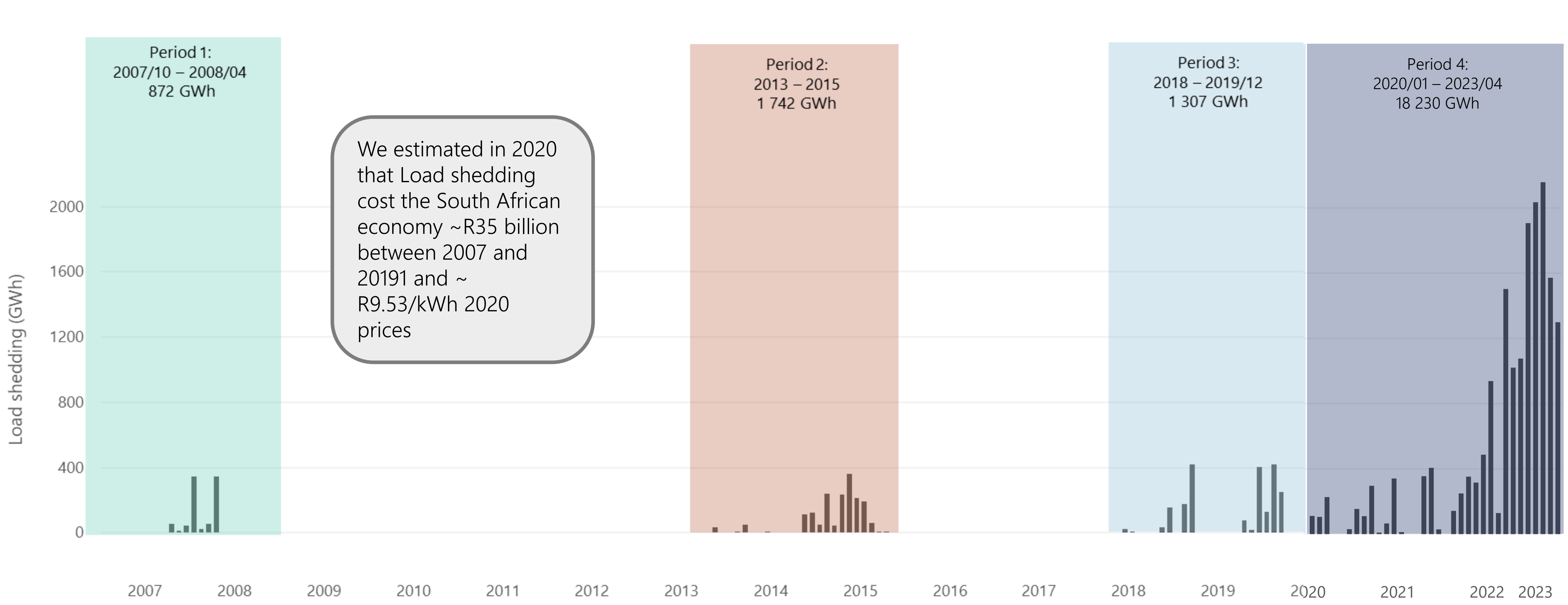
nova economics

Introduction to the study

Introduction to this study

In 2020 Eskom commissioned Nova Economics to provide the utility with reliable and accurate estimates the economic cost of load shedding (CoLS) that had occurred between 2007 to 2019. The objectives of the study was to update a previous estimate produced by Deloitte in 2009, and to explore how different sectors of the economy were impacted by load shedding.



Since 2019 however the frequency and severity of loadshedding increased, and quite dramatically since mid-2022. As such we felt it would be worthwhile re-estimating the relationship between loadshedding and quarterly GDP growth over the period 2003 to 2023 (in R/kWh) and updating our estimates of the total cost.

Source: Nova Economics, based on data provided by the Eskom System Operator on

Background – understanding type of outages & estimating ‘load shedding’ and the associated economic costs

Quantifying the economic impact of two different types of power outages

The literature on power outages distinguishes between two main types of interruptions – infrequent unplanned outages and regular planned outages (Munasinghe and Sanghui, 1988).

Type of outage

Unplanned outages

- **Infrequent, unplanned** occur suddenly
- Usually < 3 hours duration
- Electricity demand temporarily exceeds supply
- Stable reliable power supply, an **adequate reserve margin**
- Very **few customers have a back-up** supply or invest in other mitigation measures
- Occur in both developed and developing countries

Regular planned outages – (a.k.a. Load shedding)

- Regular, planned and unplanned outages
- **Typically scheduled,** but sometimes sudden
- Due to a **structural or long-term shortage** of electricity capacity
- Power system reserve margin is inadequate
- Customers invest in back-up supply or other mitigation measures
- Also referred to as the cost of power shortages
- Usually low and middle-income countries (e.g. Zambia, Nigeria, South Africa, Pakistan, Philippines)

Measure of cost

Cost of unserved energy (CoUE)

- The value (in rand GVA per kWh) that is placed on a unit of energy not supplied due to an unplanned outage of short duration.
- Electricity system planners aim to balance the CoUE and the incremental cost of supplying unserved energy.
- In SA, a methodology was developed to estimate CoUE for use in transmission and distribution network planning (as required by the Distribution Network Code).
- Also referred to as the Value of Lost Load (VoLL)
- **In 2020 the direct COUE was R29.05 GVA/kWh and total (direct & indirect & induced) R101.73 GVA/kWh1**

Cost of load shedding (CoLS)

- The value (in rand GVA per kWh) that is placed on a unit of electricity not delivered due to frequent, recurring, and planned outages
- Accounts for the inherent resilience and adaptive response of end-users (i.e. investing in mitigating measures or inherently more resilient e.g. due to ability to substitute)
- CoLS can be used to assess the relative costs of interventions to reduce the risk of power outages occurring in future
- **In 2020 we estimated the CoLS was R9.53/kWh2**

Source: 1) NERSA (2022) The review of eskom's cost of unserved energy methodology 2)

What are the types socio-economic costs associated with power outages?

Power outages result in both **direct and indirect costs to electricity consumers but also broader economic costs to society.** The net impact on a firm/economy depends on: timing, duration and frequency of the interruptions, reliance on electricity and ability to mitigate/adapt.

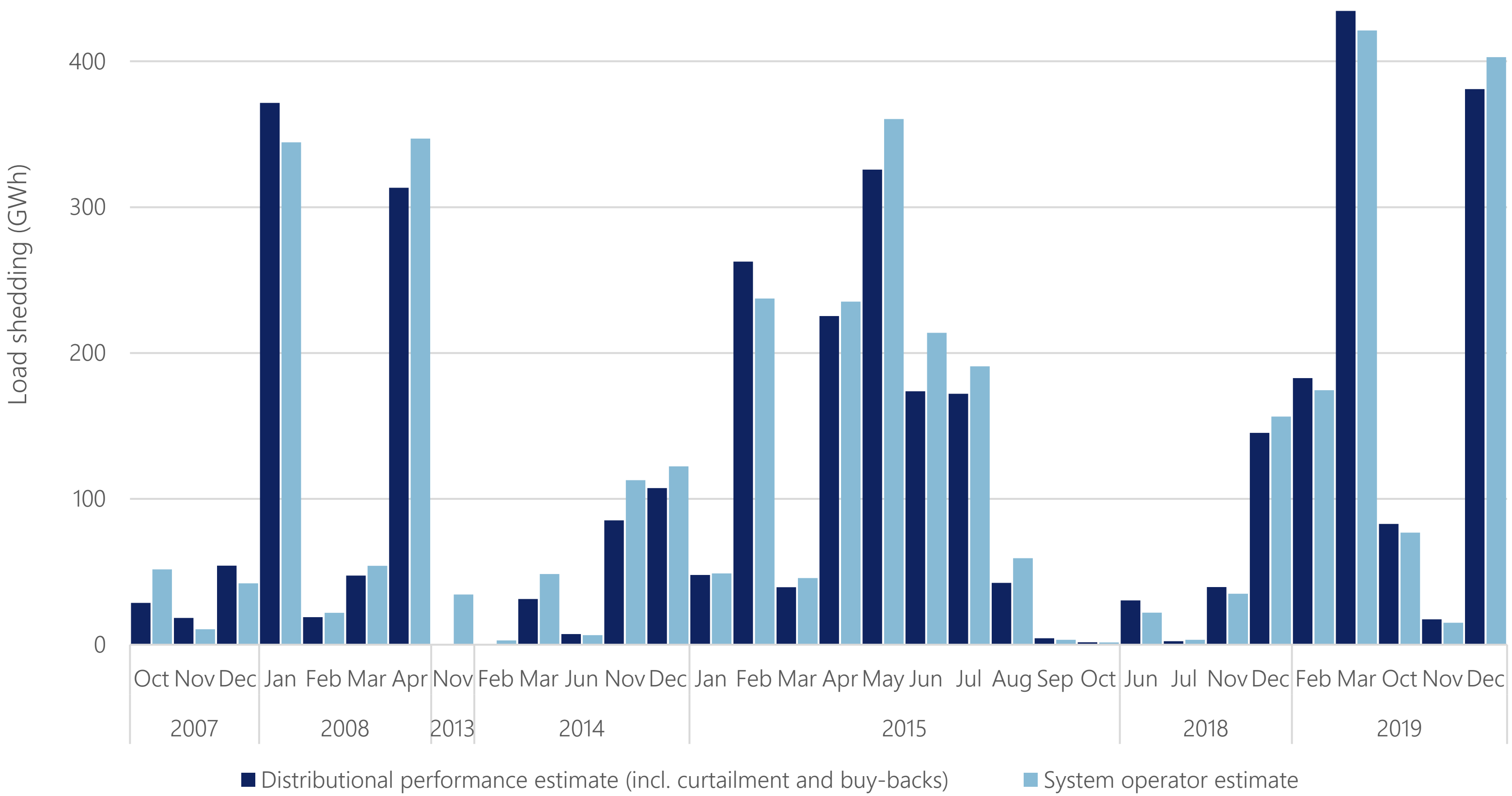
Direct and indirect costs, and resilience measures adopted		
Damages and costs		
Immediate costs		Longer-term costs
Direct costs	Indirect costs	Indirect costs
• Lost production • The opportunity cost of idle resources • Shutdown and restart costs • Spoilage and damage • Inconvenience, nuisance, and stress • Lost leisure	• Cost to customers of impacted firms (e.g. delayed delivery of inputs or services or final goods) • Cost to suppliers of impacted firm (e.g. delayed ordering or purchases of inputs to production as a result of outages)	• Negative impact on consumer, business and investor sentiment leading to loss of domestic and foreign investment in the economy over medium to long-term.

Resilience measures and tactics	
Inherent	Adaptive
• Energy conservation and efficiency • Spreading production over multiple facilities • Recapturing lost production at a later date • Back-up generation and storage • Failsafe equipment that allows proper shutdown procedures to be followed (e.g. universal power supplies)	• Temporarily adopting alternative processes • Substituting inputs • Shifting production to unaffected facilities • Recapturing lost production once the electricity supply is restored

Munasinghe and Sanghui, "Reliability of Electricity Supply, Outage Cost and Value of Service: An Overview. 1988.

Only frequency of loadshedding is observable – so in original study we estimated the amount of load shedding

Two alternative approaches thankfully yielded very similar results, Eskom's estimate of the magnitude of load shedding, provided by the system operator is based on the difference between the day-ahead forecast of the national electricity demand profile and actual demand. We have compared this to the second estimate we derived based on sub-station level data below.



Estimates of load shedding (in GWh)

Top-down estimate:

Eskom's estimate, provided by the Transmission System Operator is derived by taking the difference between **the national day-ahead demand forecast** and actual demand during load shedding, while accounting of the forecast error.

Bottom-up estimate:

We estimated the magnitude based on the frequency and duration of load shedding events by substation multiplied by average monthly sales for that substation . This was then added to power curtailments undertaken by Eskom's key industrial customers (i.e. top customers).

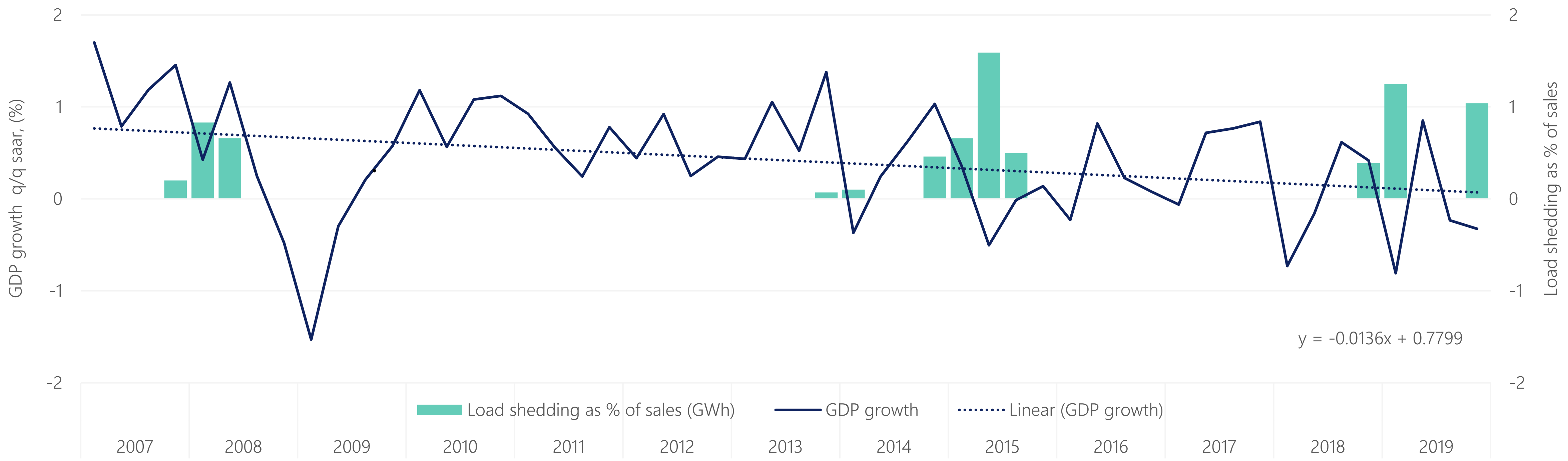
The two estimates of load shedding are similar, both in magnitude and profile. Eskom's system operators' top-down estimate and our bottom-up estimate differed by less than 1% in aggregate over the period considered. For the second study we simply make use of SO estimates available

Methodology and Approach

The initial hypothesis for the original study– based on visual inspection

Our initial hypothesis was that **load shedding was likely to have had a noticeable negative impact on GDP growth in the 16 quarters when it historically occurred.** Since the direct economic impact of load shedding is likely to reflect in the same quarter in which they occur we look at q/q growth..

Total GDP q/q change against load shedding in GWh as a % of total electricity sales



- Simple visual inspection suggested growth in quarter-on-quarter GDP was consistently below trend when load shedding occurred.
- It also appears that more severe episodes of load shedding were associated with a larger decline in growth and that the impact occurs within the same quarter – in other words, the impact does not appear to be lagged.

This suggested that we would expect to find a negative relationship between load shedding episodes and the quarter-on-quarter change in GDP growth if we estimated the relationship econometrically

For the extended period from 2020 to 2023 the relationship between LS and q/q GDP growth is far less clear

The massive variation in GDP in 2020 due to the Covid19 pandemic significantly alters the linear trend in quarterly GDP growth over the period, at the same time there is a significant shift in the frequency and magnitude of loadshedding from 2022.

Total GDP q/q change against load shedding in GWh as a % of total electricity sales

As I will discuss shortly, this presents some serious estimation challenges –the post-Covid observations end up dominating and mess up the pre-covid fit between loadshedding and GDP – the estimated parameters change notably when adding the post COVID-19 observations to the sample,

Methodological approach

Given the initial evidence of a negative relationship between load shedding and LS as % of total electricity sales and q/q GDP, attempt to estimate the CoLS by using standard econometric techniques to estimate the **historical relationship** load shedding and GDP and attempting to control for other influences.

The model and data sources

- We experimented with **two different econometric techniques** – a classical linear regression model (CLRM) and an auto-regressive distributed-lag model (ARDL). The results from **the classic linear regression model** (CLRM) had produced the most consistent estimates of the CoLS for the period 2003 to 2019.

$$y_t = \alpha + \beta_1 LS_t + \gamma_1 X_t + \gamma_2 D_t + \varepsilon_t \quad , \qquad \varepsilon_t \sim N(0,1)$$

- Where y_t is GDP growth (q/q),
- LS_t is load shedding, expressed as the % of sales,
- X_t is a vector of control variables that make up the expenditure side of GDP, and
- D_t is a vector of indicator variables for various significant events, such as the global financial crisis, oil price shock, credit boom, droughts, and heavy rain.
- Only significant control and indicator variables were included.

- The load shedding variable had the most explanatory power when expressed as a percentage of total quarterly electricity sales. This format shows how significant the amount of load shedding was in a given quarter relative to overall electricity demand – which is an input to production.
- We expressed all the GDP aggregates as **quarter-on-quarter changes**, while the load shedding was expressed as GWh 'unserved' as a percentage of total electricity sales. All GDP variables were expressed in percentage change, as they are all $I(1)$ and form a cointegrating vector $CI(1)$.
- We estimated 11 separate single equation regressions, one for total GDP and then a regression for each of the individual sectors of the economy, as reported in the system of national accounts.
- We also created **dummy variables** and included them in the national and industry-level regressions when it was necessary to account for unusual variation in GDP due to the 2007 credit boom and oil price shocks, 2008/9 global financial crisis, Covid19 and in times of drought or heavy rains. For the industry level regressions, we included the subcomponents of GDP that were statistically significant and improved the overall model fit.

Encountered data-related estimation problems once we included the observations in post Covid-19 period

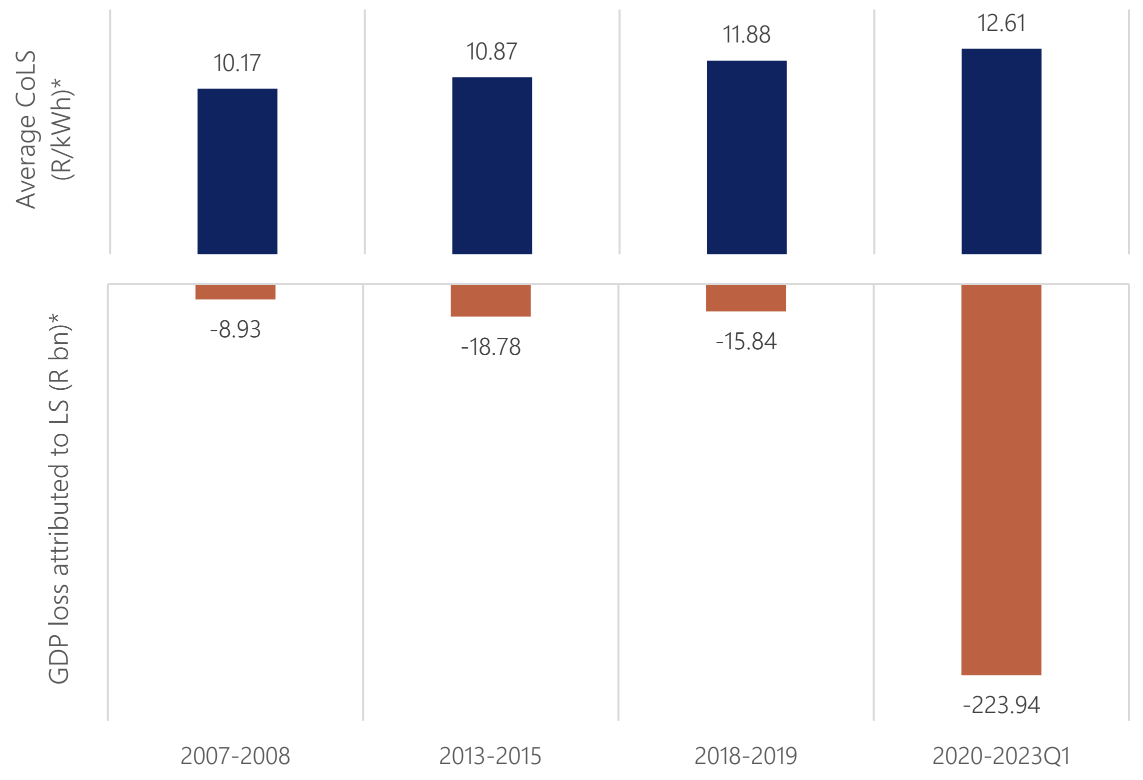
Data issues	Description
① Impact of Covid 19 Shock	• The COVID-19 shock to GDP and its components and is a challenges for time series models, particularly single equation models like we have used. The estimated parameters change notably when we include post-pandemic period (3 years). Yields estimates of the CoLS that were either significant smaller (inconsequential) and some of estimated coefficients were no longer statistically significant.
② Structural break in LS from Q421	• Another complication is that is a structural break in the loadshedding series from 2021Q4. There is a major increase in the frequency and severity of loadshedding from under 2% of total electricity sales to >2% and eventually 14% of sales in 1Q23. This happens just after the Covid19 shock – so the same three-year period.
③ Change in compilation of sectoral GDP	• In August 2021, Stats SA has finalised a comprehensive overhaul of its national accounts. The rebasing and re-benchmarking of gross domestic product (GDP) resulted in an upward revision in the size of the economy, but also changes to the composition of sectoral GDP series – particularly agriculture and manufacturing. While they have incorporated new information, they are only able to back-date to 2012 for Agri GDP. Unable to find relationship between loadshedding and sector GDP with new spliced series.
Way forward	• For total GDP we re-estimated the COLS using rebased and benchmarked GDP but only for the pre-covid19 period Q103 to Q419 – in other words we are assuming underlying relationship between LS and GDP didn't change post-covid. (It might have however). • For sectoral GDP we were unable to produce revised estimates of COLS by based on the new old/new spliced GDP time series. So we have used estimated coefficients from prior GDP series (before benchmarking and rebasing) and again assume relationships have not changed post-covid.

Results

Updated National estimates of the cost of load shedding

We estimate that load shedding cost the South African economy nearly **R43.5 billion** (in 2022 values) over the 12 years from 2007 to 2019 and **R223.94 billion** in the three-year period from 2020.

Estimated CoLS (R/kWh) and total impact of LS on GDP (R bn)*



Putting the economic cost of load shedding into perspective

- To put this into perspective the total cost of load shedding at **R43.5 billion for the between 2007 and 2019 was roughly equivalent** to the impact that the **2008/9 financial crisis** had on GDP growth (it also subtracted a cumulative five percentage points from quarter-on-quarter GDP growth albeit over a much shorter period).
- Between 1Q20 and 1Q23 loadshedding cost the economy and estimated R223.94bn in GVA (2022 prices) and subtracted a cumulative 15.3 percentage points from GDP Growth.
- Our estimates of the CoLS **for the most recent period (2020 to 2023) (is R12.61/kWh) while for the 2018/19 period it was R11.88 /kWh** (total amount of GDP lost/total loadshedding in GWh over the period).
- That said, we were **not able to run separate regressions** for each period (the time series would have been too short), so the coefficient on the LS variable is an average relationship for the 16-year period between 2003 and 2019.

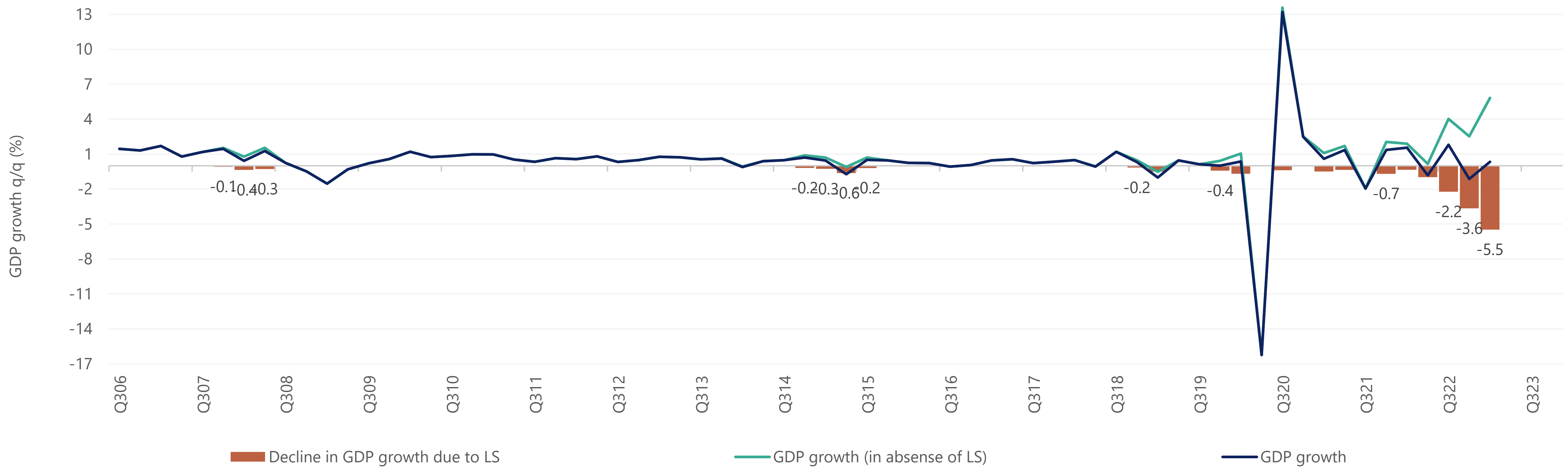
Expressed relative to the load lost, we estimated that the cost of load shedding is between R10.17/kWh and R12.61/kWh (in 2020 prices).

* All values in constant 2020 prices

What would the trend in GDP growth have looked like, in the absence of loadshedding?

Our main estimate of the CoLS was based on a classic linear regression model of the determinants of growth, including load shedding. The estimated parameters show that a **1 percentage point *increase* in load shedding** (as % of electricity sales) was associated with a **0.4 percentage point *decrease* in GDP growth (q/q).**

Proportion of the quarter-on-quarter change in historical GDP growth that was due to load shedding

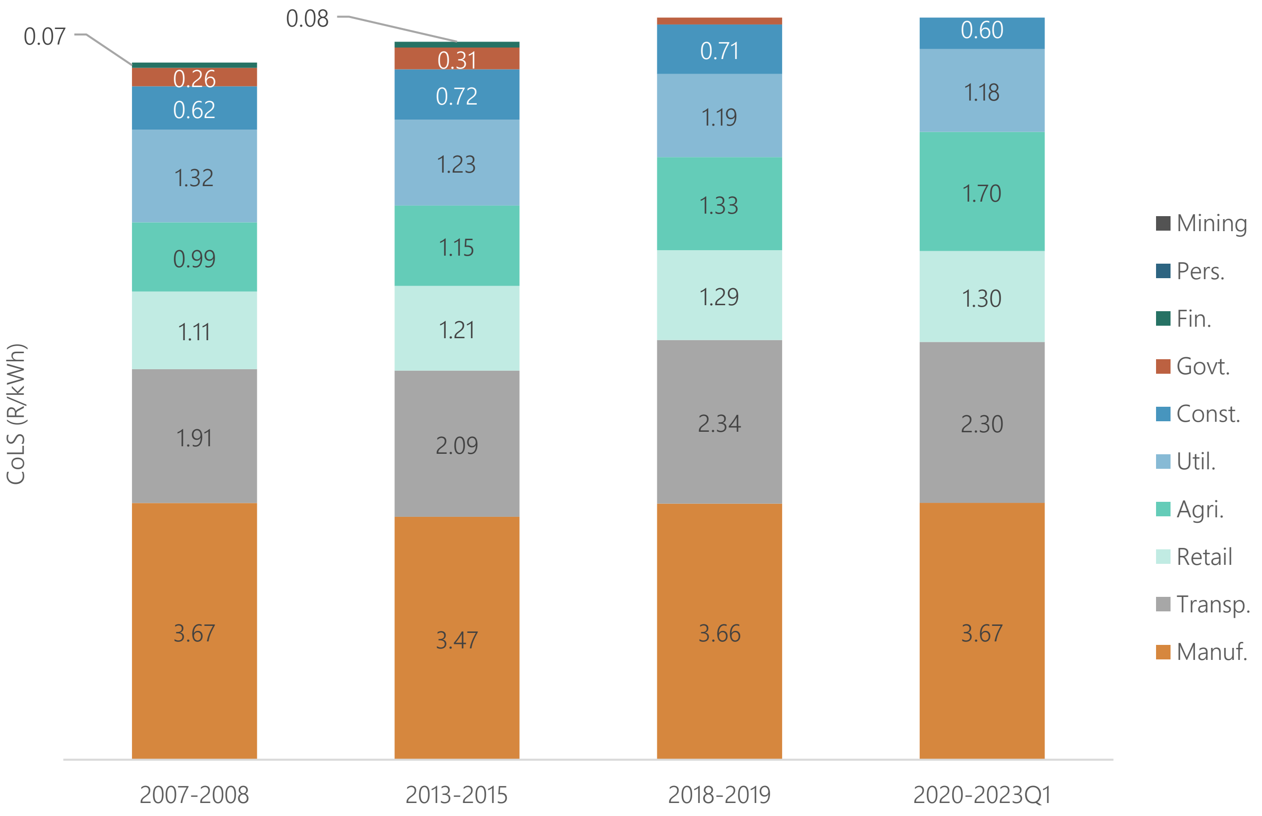


As we illustrate above, our estimates suggest that had it not been for the negative impact of load shedding, South Africa would have been able to maintain a positive GDP growth rate (q/q%) throughout 2015.

The economic cost of load shedding by industry

Our prior sectoral analysis (initial study on previous GDP series prior to rebasing and re-benchmarking) shows that GDP growth **in energy intensive sectors** such as manufacturing and transport are the **worst affected by load shedding**, while the finance sector is largely unaffected by load shedding. Manufacturing has borne 41% of the total cost, or R3.85 out of R9.53 in the latest round of load shedding.

Contribution of each sector to total cost of load shedding (R/kWh)*

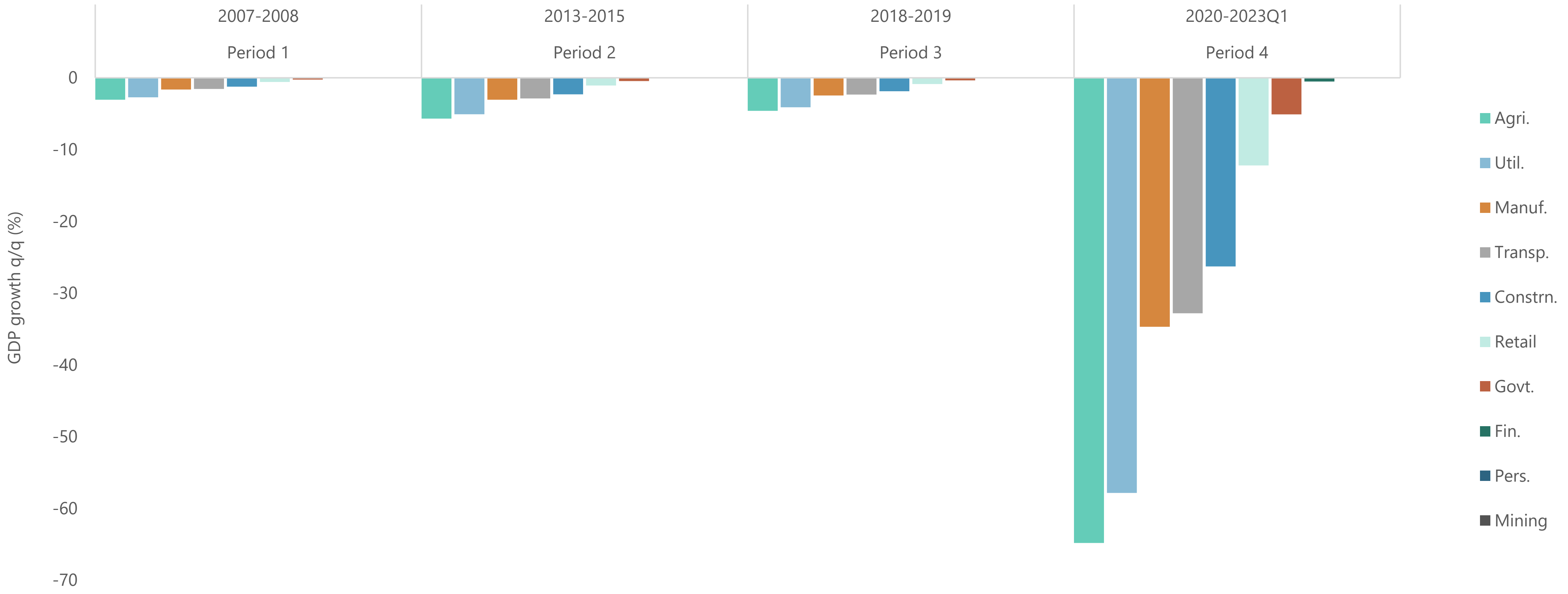


* 2020 constant prices

The costs of load shedding are unevenly distributed across the sectors of the economy

Our estimates show that it was the **energy intensive primary and secondary industries** (i.e. SIC 1: agriculture, SIC 4: utilities, and SIC 3: manufacturing) that were the **worst effected.** By contrast the more service-oriented industries, which are inherently more resilient, were largely unscathed (e.g. :SIC 8 finance, SIC 91: govt, SIC92-96,99: Pers.).

Impact of load shedding on GDP sectoral growth, per load shedding period and by industry*



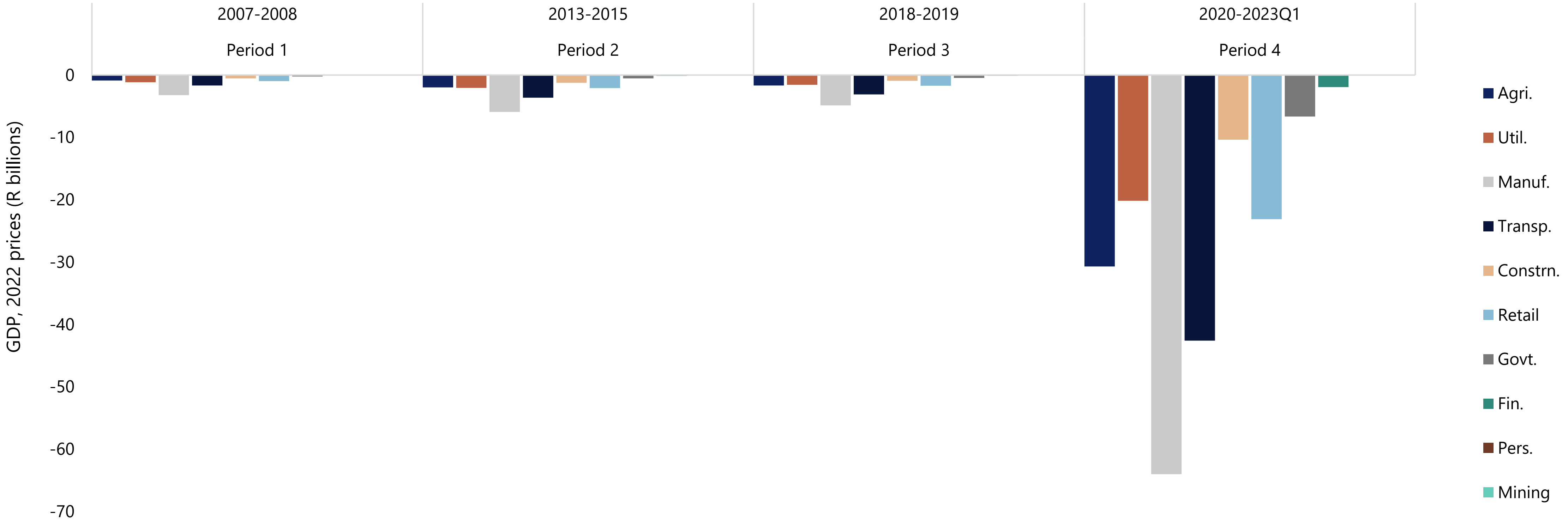
It appears the agricultural sector was the most adversely effected because of its heavily reliance on electricity for irrigation and refrigeration (for the maintenance of the cold-supply-chain critical in preserving fresh produce).

* A reliable estimate of the impact of load shedding on mining sector GDP growth was not obtained.

The manufacturing sector bore the brunt of load shedding in absolute terms

Forty-two percent (R14.4 billion) of the total economic cost of load shedding was shouldered by the **manufacturing** sector (SIC 3). The loss in GDP was greatest during the second period of load shedding, which was the longest and most severe (1 742 GWh of load shedding between November 2013 and October 2015).

Loss in GDP attributed to load shedding, per load shedding period and by industry (constant 2020 prices)*



The finance (SIC 8) and government sectors (SIC91), the two largest contributors to SA's GDP, were relatively unaffected in terms of lost GDP. This confirms that these sectors are inherently resilient and able to adapt when faced with unplanned outages.

* A reliable estimate of the impact of load shedding on mining sector GDP growth was not obtained.

Potential applications

The potential uses of estimates of the CoLS

Estimates of the CoLS provide insights about the distribution and magnitude of the cost of outages that could inform energy sector policy. Measures of the cost of outages may be particularly useful in assessing the relative costs of interventions to mitigate against the future risk of load shedding.

Supply-side and demand-side interventions given persistent outages

Category	Immediate	12-36 months	36 months +
Supply-side interventions	• Running **OCGTs** at higher load factors	• Return mothballed plants to service • Building modular utility scale renewables capacity • Power ships • Co-generation agreements • Postponing scheduled plant maintenance	• Grid extension by way of additional generation plants. • Building modular utility-scale renewables capacity
Demand-side interventions	• Power **buy backs** • Reducing demand from top customers under interruptible and **curtailable** load supply agreements • Emergency **load shedding**.	• Energy-efficiency demand side management • Entering into interruptible load supply agreements	• Energy-efficiency demand side management

Source: Adapted from Deloitte, 2009

The CoLS could be employed in South Africa to assess whether **future investments** in supply or demand side measure to prevent load shedding are **socially optimal**.