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Planning for the future in uncertain times

Cost of Unserved Energy in South Africa

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Abstract

In 2016, NERSA approved a Cost of Unserved Energy methodology as stipulated by the requirements of both the Transmission and Distribution Grid Codes. The methodology utilises a macroeconomic method to provide Cost of Unserved Energy values across a range of economic sectors as well as the residential sector. The development of a COUE methodology based on macro-economic principles and data provides a basis for investment decision-making in South Africa’s power system which is consistent with the macro-economic considerations used in national planning decisions.

NERSA has proposed that the COUE model be used as a basis for COUE for all licensed distributors in South Africa as 1) it is based on a model that has been tested and accepted by NERSA 2) it relieves the need for municipalities having to develop complex economic models and 3) it provides a common basis for economic decision-making across the power system supply chain in South Africa.

1. Introduction

Cost of Unserved Energy (COUE) is used to provide an economic value to the cost of electricity interruptions to electricity customers and the economy as a whole. These values are used to inform a number of investment and refurbishment decisions on the electrical power system, with the aim of optimising the reliability of the network. The benefit of reducing the frequency and duration of electricity interruptions is quantified in economic terms so that business cases for network investment, planning and refurbishment can be appropriately defined and optimal levels of reliability engineered for the needs of the South African economy.

COUE is defined as the value (in rand per kWh) placed on a unit of electricity not supplied due to an unplanned interruption of a short duration (less than three hours). Such unplanned, short duration outage events are to be expected in a well-planned system with adequate reserve margin as a result of random failures of equipment. Typically, a power system planner would balance the total COUE against the cost to supply the energy not served in order to make optimal planning decisions. The method assumes that businesses and households experience the outages as irregular and of low likelihood and short duration; and therefore little or no mitigation is possible or feasible.

Both the South African Grid Code and the Distribution Network Code require a NERSA-approved method of determining Cost of Unserved Energy (COUE) as a key economic parameter for network investment criteria. Additionally, COUE is defined as an input parameter to South Africa's Integrated Resources Plan for future generation investment.

NERSA approved the methodology for COUE in 2015 and the updated COUE levels for 2016, which has since been implemented by Eskom Transmission, Distribution as well as utilised in the Integrated Resource Plan (IRP).

2. Determining Coue

Internationally, several methods are used to determine COUE, primary amongst these are macro-economic methods and customer surveys.

The macro-economic method uses official, published macro-economic data such as gross domestic product (GDP) (and gross value added (GVA)) and household expenditure measures. This method divides the macro-economic indicators by total electricity usage to estimate a cost of interruption per kWh.

The advantages of the macro-economic method include:

- It is feasible and simple to implement as a result of data availability
- It uses official, publicly available data – and is thus, transparent, verifiable and repeatable
- The method is consistent with the System of National Accounting (SNA) methodology of the United Nations
- It enables and supports macro-economic modelling
- It allows for scalability of COUE measures from a national level to higher resolution (e.g. municipal level)
- It provides measures that support the data requirements of reliability planning.

The key disadvantage of the macro-economic method is that it assumes that macro-economic indicators are a reasonable proxy for costs of unserved energy. This is because it is based on macro-economic estimations and no data is collected directly from customers, it is insensitive to variations in costs associated with time-of-day, day in week and time-of-year in which interruption occurs

The survey questionnaire method uses survey questionnaires to collect data from customers on the impact of unserved energy. It is based on the assumption that the customer is in the best position to assess his/her particular costs. Survey questionnaires may either ask customers to estimate what happens in the event of *hypothetical* interruptions (stated preference), or alternative may use revealed preference methods.

The major advantage of customer surveys is that they enable marginal analysis and thus addresses the key weakness of the macro-economic method. These methods should, in principle, provide accurate COUE estimates. In addition:

- These methods could capture variations in costs for differences in time-of-day, day in week and time-of-year in which interruption occurs.
- These methods collect direct feedback from customers.
- These methods enable specific customer populations to be targeted through appropriate sampling techniques.

At the same time the method has, however, several disadvantages.

- Firstly, responses are at risk to bias, especially where stated preference methods are used. Bias may have multiple sources. It is possible that customers may understate their true willingness-to-pay or overstate their damage costs in an attempt to secure discounts on high tariffs.
- The accuracy and repeatability of the survey are highly dependent on survey design and implementation. Customers who experience few interruptions have difficulty estimating impact of interruptions, and therefore data received would be inherently unreliable.
- Customer surveys are expensive and time-consuming to conduct (Dzobo and Gaunt, 2012), especially if scalability to high resolution is required. The time and cost implications of surveys result in extended time periods between updating results. For example, Norway has a long history of using surveys for determining interruption costs. These surveys have been updated once a decade with surveys conducted in 1990-1991, 2000-2001, and another scheduled for 2012 (CEER, 2013). Similarly, in Italy, the only survey conducted was in 2003 and in the Netherlands the surveys were conducted in 2004 and the results updated for economic changes without conducting a survey in 2009 (Nooij et al, 2007).

The combination of disadvantages (bias, expense, difficulties with repeatability) associated with survey questionnaires as well as the international experience of lengthy time gaps between surveys weighed heavily against the use of surveys in South Africa. Since investment decisions are taken in the public interest on an on-going basis it was required the chosen method be **economically sound, repeatable (annually)** and **independently verifiable**.

The macro-economic method was chosen as the preferred COUE estimation method as it met these criteria and in 2016 was accepted by the National Energy Regulator of South Africa (NERSA).

3. COUE Methodology: Total Economic Impact

The COUE method estimates:

1. An Economic COUE for economic sectors that use electricity for production purposes; and
2. A Residential COUE for households that use electricity for various household applications

The Economic COUE, following from the COUE definition, measures the value (in Rand GVA per kWh) placed on unit of electricity not supplied due to an unplanned outage of short duration (less than three hours). For economic activities, Gross Value Added (GVA) for relationship between GVA and Gross Domestic Product (GDP)) is used as an indicator of economic activity. Annual GVA and GDP, by economic sectors, are both officially measured and reported annually by Statistics South Africa. GVA and GDP are both measures of economic output. The relationship is defined as:

GVA + taxes on products - subsidies on products = GDP

As the total aggregates of taxes on products and subsidies on products are only available at the national economy level, GVA is used for measuring gross regional domestic product and other measures of the output of entities smaller than a whole economy.

The Economic COUE is expressed both as direct and total impacts on the economy. Thus, the direct cost of short duration power outages to the economy is measured in terms of production opportunity forgone, as GVA/kWh per economic sector. The direct Economic COUE is disaggregated to 62 ISIC sectors and 257 District and Local Municipalities. The indirect cost of these power outages to the economy is measured as the indirect impact on the economy as a consequence of the changes in sales and expenditure in the whole economy resulting from direct costs. These indirect costs to the economy, i.e. the costs associated with complex cross-linkages in the economy, is also measured in terms of GVA.

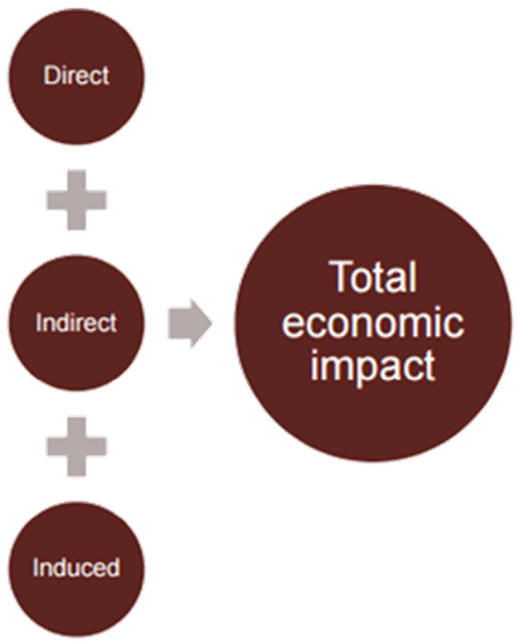

Figure 1: Total Economic Impact

The 1993 System of National Accounts (SNA) requires countries to compile annual Supply & Use tables (SU-tables) as it forms an integrated part of the 1993 SNA. Accordingly, the annual estimates of GVA and its components, as well as output, intermediate consumption expenditure, final consumption expenditure and GDP estimates all have their origin in the annual SU-tables. Stats SA uses the SU-tables framework to derive nominal estimates of GVA and GDP on a detailed, 62-sector, industry and commodity level (Bouwer, 2002).

The supply table shows the origin of the resources of goods and services, and the use table shows the uses of these goods and services and the cost structure of the various industries. As a result, SU-tables report both the GVA generated by and the electricity used by 62 different industries over a 12 month, calendar year accounting period. The electricity is a necessary production input for each of the industries to generate its GVA. The tables are reported in monetary terms and therefore the cost of electricity, as an input into production, is known, for each industry, and how much gross value is added in each industry.

As an analytical tool, the SU-tables are conveniently integrated into macroeconomic models in order to analyse the link and interaction between final demand and industrial output levels.

This type of analysis, which is also known as impact analysis, enables sophisticated economic impact analysis, including productivity analysis. In this way, StatsSA's SU-tables provide the foundation for development of an Input-Output (I-O) model and for analysis of the Total COUE effect. The COUE model adopts the methodology proposed by StatsSA for the construction of an I-O model from the SU-tables, and for analysis of results. Thus, the SU-tables provide a powerful analytical tool as they are conveniently integrated into macroeconomic models in order to analyse the linkages and interaction between final demand, intermediate consumption, GVA and industrial output levels.

The tables further report on all the other inputs from all the other sectors that are used for a specific industry to achieve this GVA. These are called intermediate inputs and explain the inter-industry relationships that exist in the economy.

Consequently, the COUE model uses the SU-tables to construct a single I-O table to establish the linkages and interrelationships between industries, products and other economic variables. In the I-O table the rows represent the outputs and the columns represent the inputs.

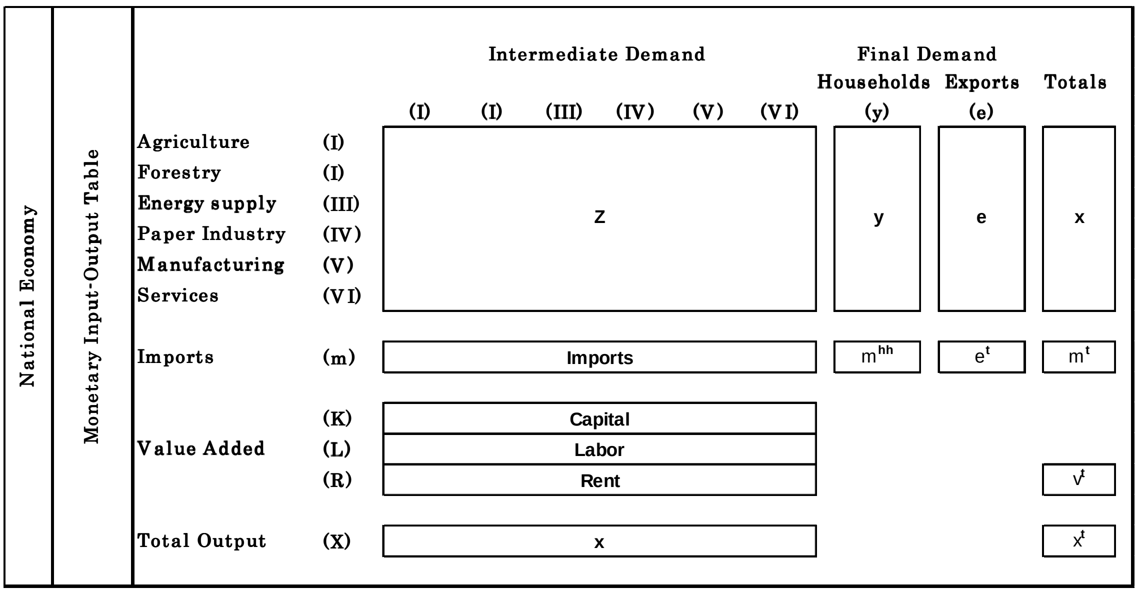

Figure 2: StatsSA Method for constructing I-O Table from Supply and Use Tables (Bouwer, 2002)

This I-O model enables the estimation of both direct and total effects of 1kWh of electricity on the economy. This is achieved through two types of coefficient matrixes: Input coefficients and Inverse coefficients.

Input coefficients are estimated by dividing all the transactions in each column of the I-O table by the total output of each column. These coefficients describe the production input structure for each industry. However, input coefficients will only measure direct production and excludes any spill over effects throughout the rest of the economy. The I-O table enables the derivation of the so-called "Leontief inverse" matrix which reflects not only the direct effects on the production process, but also incorporates the indirect effects on the production process, resulting from a change in demand for a specific product (Leontief, 1966). This method is a well-established method and earned Wassily Leontief the Nobel Prize in Economics in 1973.

The Leontief inverse thus measures all the linkage effects and interrelationships between industries and final consumers and thus also the total impact on the economy. The "Leontief inverse" matrix enables the assessment of a scenario where 1kWh is forgone/or gained in the economy.

The Residential COUE, in turn, is measured as the portion of household expenditure, by South African households, on goods and services that are electricity dependent, expressed as a ratio of residential electricity consumption. Residential lifestyles are increasingly electricity dependent for good and services such as communication, personal care, security, education, household income generation and leisure activities. Short duration power outages results in an opportunity cost of not having or using these goods and services and results in discomfort, nuisance and lost leisure opportunities.

4. Results

The result of utilising the method is that COUE data for electricity investment planning is available on both a municipal level (direct effect) and on a national (direct and total effect). Table 1 lists the COUE for different economic sectors.

COUE: Economic Effect	Direct Effect(R GVA/kWh)	Total Effect (R GVA/kWh)
Agriculture	11.55	42.21
Mining	13.06	54.05
Manufacturing	5.84	54.64
Electricity and water supply	7.70	29.31
Construction	204.10	385.55
Trade	108.65	136.90
Transport and communication	87.29	348.64
Finance	105.77	400.22
Community services	159.39	319.37
General Government	66.62	80.33
Total Economy	**23.81**	**84.16**

The Residential COUE assumes that households receive a utility (benefit) from electrical energy, measured by its expenditure on items that are electricity dependent. This utility is lost during an outage. This does not affect economic production (as in the case of the Economic COUE) but causes discomfort, disruption and nuisance. The Residential COUE is calculated by taking the household expenditure items that depend on electrical energy use, and dividing it by the domestic use of electricity.

COUE: Household Effect	Residential
Total household income (compensation of employees)	1,903,439
Portion of household expenditure on electricity use	14.3%
Household leisure and convenience expenditure (R millions)	272,783
Total residential electricity use (GWh)	40,274
Residential COUE (R HH Expenditure/kWh)	**6.77**

The national aggregate Direct Economic COUE for 2015[1] (at the time of writing these results are not official) is R23.81 GVA/kWh. This number can be interpreted to reflect the weighted average direct economic production lost that can be expected, in an average year, as a result of manifold, short duration, unplanned power outages across the country. This value varies by industry, depending on the energy intensity of the industry.

[1] The Supply and Use Tables are supplied two years later. Therefore the relevant data for the current year is always dated two years earlier e.g. For 2017 the results for 2015 are applicable

The Total Economic COUE for 2015 is R84.16 GVA/kWh. This number can be interpreted as the weighted average total economic production lost that can be expected as a result of manifold, short duration, unplanned power outages across the country.

The Residential COUE for 2015 is R6.77 household expenditure/kWh. This number can be interpreted as the average discomfort caused to households as a result of lost opportunity to use electrical energy, as a result of manifold, short duration, unplanned power outages across the country.

5. Using Cost of Unserved Energy

Nooij et al (2007) identifies two types of decision-making related to interruption cost values, these are 1) to make socially optimal investment decisions and 2) using the values to decide who should be cut off in times of electricity shortages.

Applications of COUE internationally includes transmission planning and investment in Australia (Hicklin, 2010), Canada (Bhavaraju, 2004) and Germany (Praktiknjo, 2011) as well as tariff design in Sweden (Carlsson and Martinsson, 2008), Thailand (Energy Planning and Policy Office Thailand, 2001) and India (TERI,2001). COUE is also used for Generation investment planning and policy decisions in Great Britain (London Economics, 2013) and Spain (Linares and Rey, 2013) and Ireland (Leahy and Tol, 2010).

In the South African context, these values are exclusively used for making socially optimal investment decisions. Both the South African Transmission Grid Code and the Distribution Network Code require a regulator-approved method of determining Cost of Unserved Energy (COUE) as an economic parameter for network investment criteria.

In practice these values are used for different applications with respect to generation, transmission and distribution of electricity in South Africa. In generation planning COUE is used to assess the risk of economic damage (at macro-economic level) as a result of generation capacity inadequacy. This planning is concerned both with constrained economic growth as well as total losses in the economy resulting from interruptions.

Investment in the transmission system in South Africa is primarily based on a deterministic (n-1) criterion. The economic impact of losing a load or not being able to supply a load is considered before a decision is made regarding new investment. COUE is commonly used to conduct comparative analyses to prioritize between investment options.

COUE is also used in the justification of capital expenditure required to implement a project. Least economic cost (Marais, 2006) is then used to justify the project. However, refurbishment projects require COUE, as the level of impact on some refurbishment projects will depend on the customer profile of the individual network.

For electricity distribution COUE is used for load forecasting, reliability based planning and investment decisions. Load forecasting is premised on sub-zone classification and customer class building up from sub-station level. This requires economic impact measurement disaggregated by sub-station and by economic segment. Reliability-based planning uses the COUE values to support capital investment breakeven planning. For the planning of distribution networks COUE is used in evaluating life cycle least economic cost infrastructure investment of various alternatives. The cost of the project to the electricity utility is weighed against the (cost) impact to customers of energy not served if the project is not done.

5.1 Municipalities

In addition to the application of COUE for investment and refurbishment decisions, it could be argued that a need also exists within South Africa's electricity distribution sector (which comprises the vertically integrated national utility, Eskom, as well as municipal utilities) for standardised COUE rates to be used nationally to ensure consistent and optimal decision-making across entities. The need for standardised COUE rates to improve selection and prioritisation of distribution infrastructure projects has been recognised by Cameron and Van De Merwe (2014). This is particularly relevant in the South African context, where approximately half of South Africa's electricity distribution is delegated to municipalities.

The model provides direct economic effect COUE for the 174 municipalities licensed by NERSA, allowing for tailored investment planning based on local circumstances. At the time of writing, NERSA has proposed that the existing COUE model be used as a basis for COUE for all licensed distributors in South Africa and initiated a working group consisting of NERSA, Eskom and municipalities with the aim of implementing this. The underlying reasoning for this proposal is that 1) it is based on a model that has been tested and accepted by NERSA 2) it relieves the need for municipalities (who have limited resources) having to develop complex economic models and 3) it provides a common basis for economic decision-making across the power system supply chain in South Africa.

5.2 Guidelines

The introduction of the methodology and its initial application has shown that guidelines or at least some agreement is required on how to use the available results.

The economic methodology utilised for COUE makes available a range of results that can be utilised in network investment decisions. These are:

- National aggregate total economic effect
- National aggregate direct economic effect
- National sectoral total economic effect (according to 10 economic sectors)
- National sectoral direct economic effect (according to 10 economic sectors)
- Municipal direct economic impact
- Municipal sectoral direct economic effect (according to 10 economic sectors)

At present, practice in Eskom is to use national sectoral total economic COUE for Transmission planning, national aggregate total economic effect for Energy planning (IRP / Generation) and national direct sectoral economic effect for Distribution planning. Both generation and transmission environment have large scale impacts and the use of total effect COUE can be reasonably defended on this basis. The applicability of direct COUE for the distribution environment is much more debatable, particularly when municipalities are taken into account. Significant economic differences exist between large metro municipalities and many of the smaller local municipalities in South Africa. The large metro municipalities are much more integrated into the national economy and interruptions that occur in these environments have indirect economic effects beyond just the area affected. The same is not necessarily the case for smaller municipalities. This does indicate that some differentiation can be proposed for the use of COUE within the distribution environment. A factor that needs to be considered when considering differentiating is that it does run the risk of introducing more complexity for little benefit e.g. Municipal tariffs.

6 Conclusion

A COUE method has been developed that calculates an Economic and Residential COUE. The Economic COUE is based on gross value added (GVA) produced in the economy and the electrical energy consumed to produce that value-add. The direct Economic COUE is also disaggregated by detailed industries as defined by the International Standard Industrial Classification (ISIC) system. The direct COUE effect for 2015 is R23.81/kWh while the total Economic COUE for 2015 is calculated as R84.16 GVA/kWh.

The Residential COUE for 2015 is calculated as R6.77 household expenditure/kWh.

The COUE methodology and its results meets the need for a nationally accepted, transparently determined, standardised set of COUE rates to inform key infrastructure and related investment decisions and provides a process for estimating both Economic and Residential COUE measures that are required by the capital investment criteria as prescribed in the Grid Code. The methodology is based on data sources (inputs) published by nationally recognised institutions and authorities; therefore, the data inputs can be readily updated and the same results or outputs can be reproduced.

NERSA has proposed that the COUE model be used as a basis for COUE for all licensed distributors in South Africa as 1) it is based on a model that has been tested and accepted by NERSA 2) it relieves the need for municipalities (who have limited resources) having to develop complex economic models and 3) it provides a common basis for economic decision-making across the power system supply chain in South Africa.

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