Measuring the impact of utility services for a Smart City infrastructure using an Input-Output approach

B A Rodrigues Filho¹, R F Gonçalves² and M S P Pessôa²
¹National Institute of Metrology, Quality and Technology – Inmetro, São Paulo Office, 1922 Santa Cruz St., São Paulo, SP, Brazil
²Production Engineering Department, Polytechnic School, University of São Paulo, 530 Prof. Luciano Gualberto Av., SP, Brazil
E-mail: bafilho@inmetro.gov.br

Abstract. The Smart City concept has been widely studied and used to justify the implementation of infrastructure and technological solutions such as sensors and software in cities in order to optimize resources and the welfare of citizens. Legal metrology plays an important role in this context since most of the measurement systems in a smart city, such as smart grids are under its regulation. However, these solutions in measurements are expensive and the benefits shall surpass the costs in order apply a technological measurement infrastructure. The present study uses an Input-Output technique in order to evaluate the impact of the utility services, one of services optimized by smart metering system in a Smart City context. The model was applied in the world’s tenth biggest economies. The results show that an improvement of 1% in the water collection, treatment and supply; electricity, gas, steam and air conditioning supply represent USD 68.09 billion. This monetary value can be used as a cost benefit ratio in order to invest in technological infrastructure focused on utilities.

1. Introduction
The world population has experienced a continuous and growing migration process from rural to urban areas. According to the United Nations, in 1950, 30% of world’s population were urban, in 2014, 54% increasing to 66% in 2050 [1]. As a consequence of this migration process, the cities, allied to recent and modern technologies, are investing in solutions to become more liveable areas. Those solutions cover several processes that are part of a city, such as transportation, utilities, disposal treatment and others.

Technologies as Smart Grids, Internet of Things (IoT) and Blockchain have been studied to integrate the processes and ensure the reliability of the protocol, optimizing resources, bringing reliability to measurements, consequently providing the welfare of cities. The concept of a Smart City has also been widely investigated, as well as the real benefits provided by all the technological background. There are several definitions for a Smart City [2], and the majority of them states for optimizing resources using sensors and measurement technologies.

Legal metrology plays an important and decisive role in the context of measurement regarding infrastructural aspects in a smart city. Regulations are applied to the measurement of water, electricity, gas, i.e. the so-called utility services. Although legal metrology does not establish maximum values to measurement uncertainties, it defines the maximum permissible errors for measuring instruments and systems, such as smart metering systems [3]. In utilities, the benefits provide by smart meter systems...
are: the minimization of incorrect meter reads, reduction of number of customer billing inquiries, and validation of exceptional meter reads [4]. However, the implementation these technological solutions are expensive, slow and dependent of several factors as type approval of regulated systems. In order to optimize the efforts of countries, giving guidance in which area the implementation of a smart metering system could generate more benefits, we raise the follow question: in which utility measurement area does a smart metering infrastructure provide more benefits?

In order to answer that question, we applied the Input-Output Method, which allowed to evaluate the measurement of monetary losses in legal metrology [5], to the utility services on the world’s tenth largest economies to understand their impact in a global scenario, considering the interconnected sectors of the economy. We used the monetary indicator as a measurement of benefit, considering the following utilities: water, electricity and gas.

2. Methodology

The Input-Output Model (I-O) is a well-established technique, which allows identifying the interdependence between demand and production. It considers the interconnection sector of the economy, since an input of a sector is an output of another one [6]. For example, electricity is an input of aluminum production, consequently, any deviation in electricity measurement affects the product final price. The I-O is represented in (1), where the production $X$ is represented by the intermediate consumption of the industries $A.X$ and the final demand $Y$.

$$X = A.X + Y \quad (1)$$

The final relationship between the production and the final demand is given in (2), where $(I - A)^{-1}$ is a coefficient matrix, known as the Leontief inverse.

$$X = (I - A)^{-1}.Y \quad (2)$$

The coefficients of $A$ are computed as shown in (3).

$$a_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} \sum_{i=1}^{n} x_{ij} + y_j} \quad (3)$$

Finally, to identify how a deviation in a sector of the economy impacts the entire economy, we introduced a deviation $\delta$, representing the measurement error due to the used measurement system. The less accurate are the measurement systems, the greater are the deviations. Consequently, more technological systems are more accurate. The deviation $\delta$ was applied to the utility services of the world’s tenth biggest economies: water collection, treatment and supply; electricity, gas, steam and air conditioning supply.

A measurement deviation impacts both the intermediate consumption as the final demand, as given in (4), (5) and (6). Where $X^\prime$, $Y^\prime$ and $A^\prime$ represent the matrices when applying the deviation $\delta$.

$$Y^\prime = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ \delta_k.y_k \\ \vdots \\ y_n \end{pmatrix} \quad (4)$$

$$a^\prime_{k,j} = \frac{\delta_k.x_{k,j}}{\sum_{j=1}^{n} \sum_{i=1}^{n} x_{ij} + y_j} \quad (5)$$

$$X^\prime = (I - A^\prime)^{-1}.Y^\prime \quad (6)$$
The final aggregate impact $AGG$ of a deviation in the utilities is shown (7):

$$AGG = \sum_{i=1}^{n} x_i - \sum_{i=1}^{n} x_i$$

(7)

In order to obtain the total impact on entire economy of a country caused by the deviation on measure in an economy sector, we utilize data from the input-output tables of the mentioned countries [7]. The inputs representing electricity, gas, steam and air conditioning supply are aggregate as a single input. In addition, water collection, treatment and supply are aggregate a single one. For simplification, hereinafter we will mention as either electricity or water, for simplification.

3. Results and Discussion
The impact of a 1% deviation in both electricity and water are shown in table 1 and 2. We considered it an incremental value since the relation between deviation and impact is linear, as shown in figure 1. The linear relationship is also maintained for all the simulated data although figure 1 display only three countries, for better visualization.

The annual impact on economy of a 1% deviation represents USD 65.01 billion in electricity and USD 3.08 billion to the studied economies. It is also possible to note that electricity and water have different relative impacts on the economies. For example, Brazil is the third economy affected by water deviation, in contrast to electricity, where the country is eighth. It can be understood based on the strong agricultural production and water-based energy production of the country. This rank position highlights the importance of initiatives in smart grids technologies also in water measurement. Nowadays, the technology investment are mainly focused in energy [6, 7]. In conclusion, we consider that both academia and R&D budget should be aware of water measurement technologies importance.

| Table 1. Incremental aggregation impact of 1% deviation in electricity input in one year. |
|---------------------------------|
| Country | Impact USD (Billion) |
|--------|------------------|
| CHN    | $38.20           |
| USA    | $5.95            |
| GBR    | $4.26            |
| DEU    | $3.37            |
| FRA    | $3.27            |
| JPN    | $3.24            |
| ITA    | $2.94            |
| BRA    | $1.74            |
| IND    | $1.32            |
| CAN    | $0.72            |
| TOTAL  | $65.01           |

| Table 2. Incremental aggregation impact of 1% deviation in water input in one year. |
|---------------------------------|
| Country | Impact USD (Billion) |
|--------|------------------|
| CHN    | $1.04            |
| JPN    | $0.48            |
| BRA    | $0.37            |
| FRA    | $0.27            |
| ITA    | $0.23            |
| USA    | $0.20            |
| DEU    | $0.19            |
| GBR    | $0.18            |
| IND    | $0.12            |
| CAN*   | -                |
| TOTAL  | $3.08            |

*Values not available.

The impact of deviations in the Chinese economy are greater when compared to the other economies, possibly to its industrialization level as well as population. However, China numbers are expressively larger than India’s, to approximately the same population. It suggest that some structural characteristic of economy, as GDP, industrialization, and agricultural production are variables that can be considered.
4. Conclusion

The I-O Model is an important tool, establishing a mathematical relationship between the production and the final demand. Its application also permitted computing the aggregate impact of measurement deviations throughout the economy.

Since water and electricity are basic inputs for both industry and the final demand, representing a vital component for production plants and daily life well fair, these inputs have a significant impact in the economic infrastructure strategically significant for all countries, being strategically significant for all countries. Furthermore, utilities are also under the regulation of legal metrology.

The results showed that an incremental 1% aggregate deviation in measurements altogether represent USD 68.09 billion. Consequently, small improvements due to new and integrate technologies, such as proposed by smart city infrastructure can increase significantly both consume and waste of natural resources. Therefore, there is a great economic interest for development of technologies such as smart grids, not only for electricity, but also for water consumption measurement.

The aggregate impact also demonstrates that each country has their own need, for example, the USA is the second in the electricity rank and Brazil occupies the eighth position and sixth and second, in the water rank, respectively. It represents that improvement in water measurement in Brazil are more economically relevant that in the USA, only considering the economic approach.

Although the present study gives a global overview of the aggregate impact due to measurement deviations, the usage of regional I-O tables can be used as a guide in order to identify regional areas that are prior to the implementation of the smart city technologies, using a cost benefit ratio.

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