Effectiveness and efficiency of urban water access in the Democratic Republic of Congo: a panel directional approach*

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Abstract

In the 2030 Sustainable Development Goals (SDG) of the United Nations, countries are committed to achieving universal and equitable access to safe and affordable drinking water for all. The Democratic Republic of Congo is a paradox as it owns the second-largest basin in the world while more than half of the population has no access to basic drinking water. This fact is our starting point to conduct a performance evaluation exercise of the 11 provinces from 2008 to 2019. Our approach has five distinguished features: we take account of population trends; we use a tailored and complete database of urban centres; we define and decompose flexible indicators, and we use a non-parametric estimation method. Our results show that there is inefficiency and ineffectiveness in urban water access. Overall, larger efficiency–effectiveness differences are over time observed mostly due to a lack of technological change and a resource constraint. We also highlight the role of public policies.

Keywords: water access; data envelopment analysis; effectiveness; efficiency; Luenberger indicator.

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1 Introduction

In 2010, the General Assembly of the United Nations recognized 'the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights' (UN, 2010). It is the only human right inscribed in the 2030 Agenda of the Sustainable Development Goals (SDGs). SDG 6 aims to 'ensure availability and sustainable management of water and sanitation for all' (UN, 2015). In the Democratic Republic of Congo (DRC), access to safe drinking water is a constitutional right (Article 48). Through its major Water Law in 2015, the Congolese Government aims to increase the rate of access to drinking water to 80% by 2030 (SWA, 2020).

High access to safe drinking water is essential for people's living needs. In terms of health, improving access to safe drinking water reduces waterborne diseases (Sy et al., 2017; WHO, 2019). In the DRC, unsafe water is closely related to morbidity and mortality and is one of the top five risk factors associated with death and disability (Dimandja et al., 2022; IHME, 2019; Wembonyama et al., 2007; World Bank, 2017). In developing countries, the low rate of access to water has repercussions on the economic level and education, in particular for women and children to whom the task of collecting water is entrusted. Therefore, a low rate of access to drinking water leads to other types of inequalities in income, employment and education, and between gender (Alou et al., 2015; Dos Santos & Pambe, 2016; OCDE, 2021; Poupeau, 2009; Saïdi, 2001; WWAP, 2019). This implies that improving access to water is revealed as a hub for many of the other SDGs, such as poverty (SDG 1), health (SDG 3), and gender equality (SDG 5).

Significant progress in safe water access has been made worldwide: between 2016 and 2020, the world population with access to safe drinking water at home increased from 70% to 74% (WHO and UNICEF, 2021). However, a closer look shows that, in 2020, one over four people did not have access to safe drinking water at home and almost half of the world's population was without sanitation services. The African situation is even more dramatic. In sub-Saharan Africa, progress remains extremely slow, with only 54% of individuals using safe drinking water, a proportion that drops to 25% in fragile contexts (WHO and UNICEF, 2021). To achieve universal access to safe drinking water by 2030 as stated in SDG 6, many international organisations (UN, 2015; WHO and UNICEF, 2021) argue that urgent efforts are still needed.

In the DRC, significant water resources are available, representing an average annual internal renewable water resource of 900 km^3 (NIS, 2021). Moreover, the Congo Basin is the second largest basin in the world after the Amazon (Callede et al., 2002; Labat et al., 2004).[1] In addition, the DRC has 52% of Africa's surface freshwater reserves and 23% of the continent's renewable water resources (ADF, 2021). Given its comparative advantage in water resources, we may expect that the DRC will perform well and stand out from the regional context. This is not the case: access to water services remains precarious, with access rates well below the Sub-Saharan African average of 54% (WHO and UNICEF, 2021). The World Bank (2017) reports that the DRC had not met the Millennium Development Goal of 2015 about access to water, sanitation and hygiene services.[2] Also, today, more than half of the population (54.1%) has no access to basic drinking water and only 18.4% and 15.8% have access to safely managed water and to basic sanitation services, respectively (World Bank, 2023b).

The problem is therefore not the quantity of water available, but rather the ability to provide water to the population. This observation is the starting point of a long list of empirical studies about the African water utility performances. In the 1990s, several studies have highlighted the poor performances, mostly due to low productivity and disastrous financial results, of the public utilities (World Bank, 1994; Kempe, 1999; Nellis, 1988). To tackle this issue, the African water sector has been privatized or liberalised. This has not stopped the research on the African water sector performances (Boaz et al., 2020; Dos Santos, 2012; Estache & Kouassi, 2002; Jaglin, 2005; Kirkpatrick et al., 2006; Mbuvi et al., 2012; Van Den Beng & Danilenko, 2017; World Bank, 2017; see also Table 12 in the Appendix for a complete literature review). Several dimensions, such as efficiency, and productivity, have been studied, while the impact of organisational and institutional factors have been highlighted.

In this paper, we construct a tailored database and use a new methodology to study the urban access to reliable water performances of the DRC provinces in reaching SDG 6. Our approach presents two main distinguished features. First, we use a unique and complete database for 99 operation centres. Recently, it has been argued that comparing water sector performances across African countries has little interest given the institutional, economic and resource heterogeneity (De Witte & Marques, 2010; Ananda, 2014; Van Den Beng & Danilenko, 2017, Muvaraidzi et al., 2021). A better option is to limit the scope to one country and compare regions, provinces, or utilities. Building on this warning, we use data for operation centres at the province level during the 2008–2019 period. We retain for this study two outcomes: the number of customers connected to the distribution network and the volume of water consumed.

Second, our methodological approach relies on the distinction between two main objectives pursued by the decision-makers: effectiveness and efficiency (Aparicio et al., 2022; Cherchye et al. 2019; Perelman and Walheer, 2020). These two objectives are in direct relation to SDG 6 goals. Effectiveness measures outcome maximization, e.g. to which extent the water access and reliability goal is fulfilled (SDG 6.1), and efficiency measures how far the water utilities are from the best practice (SDG 6.4).[3] Also, we take population trends into account, an important aspect, especially in developing countries, as pointed out in the SDGs.

To measure effectiveness and efficiency over time, we construct new flexible Luenberger indicators, based on directional distance functions, that can be decomposed into several parts to better understand the performance variations over time. Our indicators can be estimated non-parametrically, which represents an advantage as it is difficult to find strong arguments supporting a particular parametric function in our empirical context. Finally, we relate efficiency and effectiveness in a unified approach to highlight the impacts of the resources over time.

The rest of our paper unfolds as follows. In Section 2, we position our contributions in light of the policy context and the literature review, and define our scope. Next, the data we use are discussed in Section 3. The methodology is developed in Sections 4 and 5, and the estimation method is explained in Section 6. Results and policy discussion are given in Section 7, while we conclude in Section 8.

2 Policy context, literature review, and scope

To better contextualize our empirical investigation, we briefly present the policy context and position our contribution in the relevant literature. Next, we discuss the scope of our study.

2.1 Policy context

The legal framework of the management of DRC water resources falls under the 2006 constitution.[4] Before the promulgation of the Water Law in 2015, the governance of the water sector was structurally weak and characterized by a multiplicity of laws and regulations, and institutions with often overlapping and/or conflicting mandates as well as a proliferation of public and private actors operating almost autonomously (UNEP, 2011). Such a new major law reflects the policy's willingness to tackle the low water access issue. To be fair, we point out that the law implementation is not always effective in the institutional framework of the DRC, based on decentralization. As an example, the creation of the Ministry of Water is planned, but to date, it is not yet established. Also, few provinces and decentralized entities dispose of the technical and financial capacities to assume the managing role (MEWR, 2016; Mirindi, 2017). In such a context, water governance and management remain complex.

Moreover, several reforms have been implemented in the direction of improving reliable water access. For example, the first and the second Poverty Reduction and Growth Strategy (DSCRP-I and DSCRP-II) in 2006–2010 and 2011–2015, respectively.[5] The DSCRP-I identifies water sector reform as a priority.[6] Several programs have been implemented, such as the Priority Action Programs and the Medium-Term Expenditure Frameworks, but with much delay and on a smaller scale than expected (Naulet & Biteete, 2014). The DSCRP-II (2011-2015) takes over the water sector as a priority under the 3rd pillar entitled the improvement of access to basic services. For this new cycle, specific targets have been set to optimize investments by strengthening planning for urban and rural sectors, by promoting autonomous systems in small centres and peri-urban areas, through the implementation of decentralization and the establishment of coordination frameworks. All these political orientations were only partially respected (Naulet & Biteete, 2014).

2.2 Literature review

Assessing the performance of the water production and distribution systems is a popular topic in the efficiency literature, probably due to the policy impact and usefulness of such performance evaluation. We found 45 empirical studies starting in 1986. Table 1 presents the papers related to African studies and Table 12, available in the Appendix, gives papers about non-African countries. We make this distinction in light of our empirical framework. We select several features of the papers: authors, region, number of DMUs, estimation method, outcomes, and resources. Also, more recent papers appear at the top.

Both Data Envelopment Analysis (DEA, after Charnes et al., 1978) and Stochastic Frontier Analysis (SFA, after Aigner et al., 1977) have been used as estimation methods, while DEA is more popular. Most of the studies use panel data and focus their attention on one particular country. A potential reason is the need for a homogenous group to perform a fair performance evaluation exercise. Different outputs/outcomes and inputs/resources have been considered even if several variables or indicators are common to many papers: water delivery, water billed, water produced, network length, number of connections, and labour cost.

Amongst all the empirical studies, 10 of them are dedicated to African countries (Table 1). Again, we see that DEA is more popular and that the studies share certain variables. It is also interesting to note that only a few of them study the performance of one particular country. Also, none of them is about the DRC.

A particular focus of the papers about African countries is the effect of privatisation and whether private water utilities better perform than public ones. Estache and Kouassi (2002) indicate that publicly owned water companies exhibited lower efficiency levels compared to privately owned utilities in Africa. They identified governance and institutional factors as significantly influential in explaining performance disparities. In contrast, Kirkpatrick et al. (2006) have not observed statistically significant results for the effect of privatization.

Another level of comparison is the urban vs. the rural water distribution system. Muvaraidzi et al. (2021) found the location and the ratio of metered to unmetered connections to be significant determinants of efficiency for both urban and rural water utilities in South Africa.

Other studies have focussed their investigation on the management of the outcomes and resources, and the determinants of better or worse performances. Mbuvi et al. (2012) reveal that the level of economic development is an important determinant of inefficiencies for 21 African countries. Mande (2015) shows that the participation of an independent regulatory agency or the private sector may improve performance. Mwale (2018) highlighted that repair costs are extremely high and suggests the continued need for investments in water supply infrastructure.

Finally, as proof of the huge interest in performance studies for the water sector, in a World Bank report, Van den Berg & Danilenko (2017) provide a guideline to assist African governments in low- and lower-middle-income countries with the design and implementation of water projects and sector reforms in urban areas. To do so, they run performance evaluation exercises for 119 African utilities. The study suggests that sector reforms in combination with changes in the economic environment in which utilities are operating can help improve the efficiency of water utilities across Africa.

Our study while directly connected with existing literature offers some new features. Up to now, most studies consecrated to water utilities performance in Africa focused on operators' efficiency, by disregarding effectiveness. Next, more than a simple performance evaluation exercise, our empirical study is designed in light of the SDGs and related to the country's policies. Another distinguished feature of our paper is to take population trends into account. Finally, in terms of data and methodological contribution, we use a tailored and complete database of urban centres and we define and decompose flexible indicators.

Table 1: Literature review – African studies

Authors	Region	DMUs	Periods	Method	Outcomes	Resources
Muvaraidzi et al. (2021)	South Africa	77	2010 to 2012 and 2014	DEA	Consumption; Water quality	Total operating cost; Length of main
Banda and Mwaleb (2018)	Malawi	1	2015 to 2016	Ratios	Water revenue; Water produced	Repair cost; Length of network
Van den Berg and Danilenko (2017)	Africa	119	2010 to 2013	DEA	Water billed	Labor; Connections
Mande (2015)	Sub-Saharan countries	17	2000 to 2005	SFA	Water delivered	Labour; Water distribution mains length; Water lost
Diakité and Thomas (2013)	Ivory Coast	145	1998 to 2002	SFA	Water billed; Water loss.	Capital; Electricity; Material; Labour.
Mbuvi et al. (2012)	African	51	2000	DEA	Population served; Water sold	Employees; Network length
Mugisha (2007)	Uganda	15	2000 to 2007	SFA	Connection; Water billed/Water delivered (%)	Staff; Network length; Operating expenses
Kirkpatrick et al. (2006)	Africa countries	14	2000	SFA and DEA	Water distributed; Piped water available	Labour cost; Material cost; Operating and maintenance cost
Estache and Kouassi (2002)	Africa	21	1995 to 1997	SFA	Water production.	Labor; Capital; Material
Akosa et al. (1995)	Ghana	10	–[7]	DEA	Reliability; Utilization; Convenience	Technical; Financial; Economic; Social factor; Institutional and environmental factors.

2.3 Scope

Operationally, the drinking water supply involves two public bodies: the Water Distribution Board (REGIDESO) for urban agglomerations and the National Hydraulic Office (ONHR) for rural and peri-urban areas.[8] The REGIDESO is a former state monopoly in charge of the production and distribution of safe drinking water (vertical integration) for urban and semi-urban areas. The REGIDESO has 99 operating centres partitioned into 11 provinces (see Table 11 in the Appendix). To give some numbers: in 2019, every single connection to the REGIDESO network was shared, on average and depending on provinces, between 25 to 180 inhabitants. At the same time, annual water consumption per capita, including industrial and agricultural usage, varied from 0.5 to 12 m^3. Moreover, even if we observe some disparities between provinces due to the presence of larger cities, all REGIDESO units deserve urban areas and, out of scale of operation differences, they share the same production technology.[9]

The REGIDESO has undergone several institutional changes, the last of which, in 2010, confirmed its transformation into a commercial and industrial company. This reform aimed to restore its financial viability (reduction of operating costs, improvement of billing and collection rates, restructuring of the balance sheet) and to improve its operational performance (reduction of losses, realization of investments). Nevertheless, while transformed into a commercial company, the REGIDESO is still fully state-owned (the sole shareholder to date). The Ministry of Portfolio and the Committee for the Reform of Public Enterprises represent the state as the owner of REGIDESO. Organically, the REGIDESO is placed under the technical supervision of the Ministry of Energy and Hydraulic Resources.

Furthermore, international interventions have enabled the REGIDESO rehabilitation to improve water supply in urban areas. Under the auspices of the World Bank, the largest investment made to date remains the financing by the International Development Association of the Recovery Project, labelled Urban Drinking Water Supply Project (PEMU). In its first phase in 2009, this project aimed to restore the financial balance of REGIDESO through reforms aimed at improving revenue collection and reducing overstaffing as well as through investments in infrastructures focused on the three largest operating centres (Kinshasa, Lubumbashi and Matadi). The second and third phases of the PEMU, in 2016 and 2019, planned to extend the service improvements to three other operating centres (Kisangani, Bukavu and Likasi), and finally to all the REGIDESO centres by 2020. However, the PEMU made progress in Phase 1, but failed to reach the more ambitious Phases 2 and 3 (World Bank, 2017).

In addition, to improve water access in semi-urban centres, the drinking water supply and sanitation project in semi-urban areas (PEASU), which focused on the rehabilitation and extension of water supply infrastructure, has been launched with the support of the African Development Fund. The PEASU had mainly targeted three semi-urban canters: Kasangulu (in the province of Kongo-Central) for its low rate of access to drinking water estimated at 12.5%, Tshikapa (in the province of Kasaï-Occidental) and Lisala (in the province of Equateur) for the absence of drinking water services. In Kasangulu and Lisala, PEASU aimed to extend drinking water production and distribution infrastructure. For Tshikapa, the PEASU focused on the construction of new infrastructure. Ultimately, the PEASU made it possible to increase the total drinking water production capacity from 2,600 to 56,500 m^3/day in the three semi-urban centres. This implies that 100% of the population of Kasangulu and Lisala, estimated at 37,000 and 95,000 inhabitants respectively, have water access. In Tshikapa, nearly 42% of the population was supplied with drinking water (ADF, 2017).

In this paper, we focus our attention on the urban access to reliable water. That is, we measure the performances of the REGIDESO water centres over time. Proceeding in this way, we assume that each water distribution operator in each province is free to give a specific path orientation to its maximization of the bundle of outcomes to reach SDG 6 targets. In light of all national and international policy implementations in the direction of improving reliable water access, we may expect to see a performance improvement. Moreover, it is crucial to provide performance measurements connected with the recent objectives as stated in the SDGs. To this aim, we analyse two scenarios, which correspond to two different operators' objectives. On the one hand, effectiveness, which is the maximization of outcomes without considering resources and, on the other hand, efficiency, corresponds to the case when outcomes are maximized given resources. Finally, by relating effectiveness and efficiency, we highlight the resource impacts. To present and position our approach, we make use of the Design Science Research Methodology (DSRM) introduced by Peffers et al. (2008). The DSRM offers a simple and clear sequence of activities to be followed. The DSRM has been used in efficiency-related contexts by Charles et al. (2019) and Tsolas et al. (2020); ours is given in Table 2.

Table 2: Design Science Research Methodology

DSRM activity	Activity description	Knowledge
Problem identification and motivation	Access to drinking water in urban areas of RDC provinces.	United Nations SDG 6 RDC & Institutional grounds on water utilities Literature review
Define the objectives of a solution	To identify and measure sources of ineffectiveness and their evolution over time.	2008–2019 panel data for 11 water distribution operators in RDC
Design and development	New flexible Luenberger indicators, based on directional distance functions that can be decomposed.	DEA methodology Luenberger indicators
Demonstration	Scarcity of resources appears as the main source of ineffectiveness.	
Evaluation	Comparative analysis shows differences between operators deserving great urban areas and the other.	

3 Data

A major issue for most of the empirical analysis on African water sectors is data availability (Van den Berg and Danilenko, 2017). Our study is not an exception. Data have been collected in two phases. First, we make use of the statistical yearbooks of the DRC (NIS, 2015, 2017, 2021) produced with the financial support of UNDP, the AFDB and the World Bank. We relied also on existing data provided by the Central Bank of the Congo (BCC, 2021). Second, we have completed, checked and corrected data with the REGIDESO. The final sample consists of 99 centres regrouped into 11 provinces as shown in Figure 1 (the list of the centres is provided in Table 12 in the Appendix).[10] After removing missing data, we end up with observations from 2008 to 2019.[11] Finally, to control for urban population trend, we express our variables per the number of inhabitants in the urban agglomerations.[12]

Figure 1: Provinces

Outcomes have to be selected in line with the SDG 6. The main objective is to increase water access for all. This means, at the same time, increasing the number of customers, and raising the water quantity provided. We therefore select two variables to measure the outcomes: the number of customers and the water billed. Note that such a choice is coherent with the literature (see: Table 1 and, in the Appendix, Table 12). Both are expressed per inhabitants in the urban agglomerations to take population change into account. We provide in Figure 2, the minimum, average, median, and maximum of the two outcomes per year.

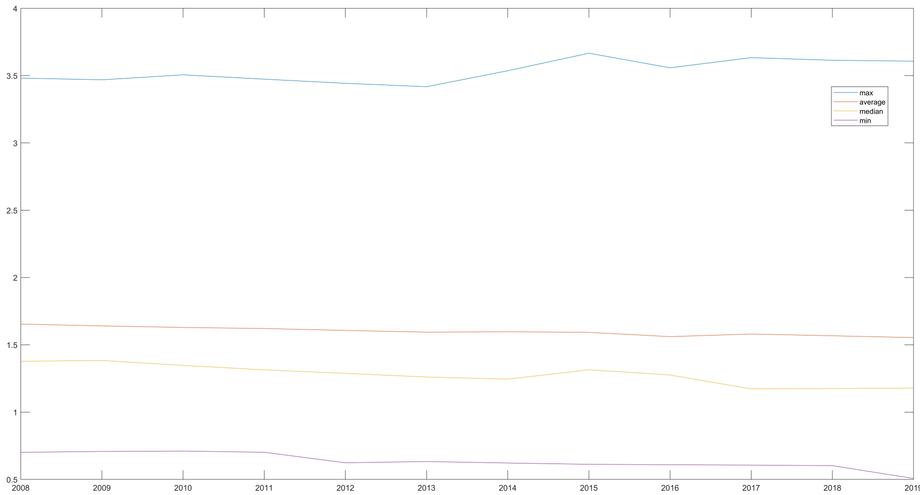
Both outcomes show us a stable situation. The average number of customers per 100 inhabitants is rather stable at around 1.65. A similar trend is observed for the minimum, median, and maximum. For the water billed per 1,000 inhabitants, the average is 4 m^3 per year. Such an average is rather constant. The maximum reaches 12 m^3 (Kongo-Central) and the minimum is 0.05 m^3 (Kasaï-Occidental). Note that the median is always smaller than the average for both outcomes. The average and median volumes are far away from 7.3 m^3 per year which corresponds to a basic access target to cover basic human needs, as recommended by the World Health Organization (WHO, 2003). The maximum is smaller than the WHO's targets of 18.0 m3 and 36.0 m3 per year which correspond to the intermediate and optimal minimum water access needs, respectively.

We continue our presentation of the outcomes by the averages and growths per province in Table 3.

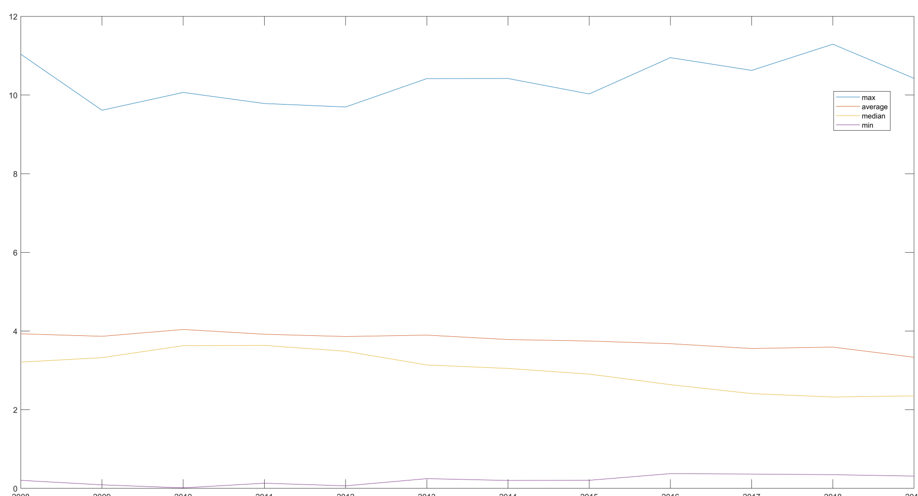
Table 3 suggests huge differences across provinces about the growth rate of the two outcomes. For billed water, we note for example that the province of Kasai-Oriental shows a negative growth rate of -4.52%. Concerning population coverage in terms of the number of customers, we note, for example, an average of 0.636 customers per 100 inhabitants in Maniema v.s. 3.534 in Kongo-Central. Also, interesting patterns can be observed within the same province where the growth rate relating to the number of customers is negative while that relating to the water billed is positive. This is the case for the provinces of Bandundu, Kasaï-Occidental and Maniema. This large difference could be explained by a decrease in the number of connections and therefore could reflect a context of access to safe drinking water outside the home.

To complete our analysis, we consider the resources. This is directly in connection with SGD 6.4 where it is required to improve the resource efficiency in line with the outcomes. Unfortunately, REGIDESO detailed data, by province and year, on physical capital are not available, nor on operating costs. In place of them, we use available detailed information on the number of employees and the quantity of water supplied to the distribution network. In the case of water supplied, the assumption

Figure 2: Outcomes per year



(a) customer number



(b) water billed

Table 3: Descriptive statistics per province (2008-2019)

Province	Statistics	Outcomes		Ressources	
		Customer (number per 100 inhabitants)	Water billed (m^3 per inhabitant)	Employee (number per 10,000 inhabitants)	Water supplied (m^3 per inhabitant)
Bandundu	average	1.265	1.198	0.737	1.651
	growth	-1.41 %	0.64 %	-5.30 %	3.24 %
Équateur	average	1.131	0.531	0.489	0.730
	growth	-2.34 %	-2.98 %	-4.88 %	-2.89 %
Kasaï-Occidental	average	1.194	0.218	0.409	0.288
	growth	-2.06 %	6.89 %	-6.07 %	6.46 %
Kasaï-Oriental	average	0.790	0.474	0.394	0.805
	growth	-2.51 %	-4.52 %	-5.54 %	-1.95 %
Katanga	average	1.364	6.939	0.822	10.359
	growth	-0.37 %	-4.15 %	-5.05 %	-1.73 %
Kinshasa	average	2.396	8.344	2.017	15.534
	growth	-0.37 %	-1.38 %	-4.32 %	-1.78 %
Kongo-Central	average	3.534	10.363	2.640	15.433
	growth	0.30 %	-0.46 %	-4.05 %	0.42 %
Maniema	average	0.636	0.623	0.450	1.018
	growth	-2.31 %	2.25 %	-4.26 %	3.86 %
Nord-Kivu	average	1.643	3.927	0.917	6.878
	growth	2.81 %	0.72 %	-3.88 %	4.11 %
Province-Orientale	average	1.127	3.008	0.645	3.945
	growth	-1.01 %	-2.23 %	-4.55 %	1.17 %
Sud-Kivu	average	2.517	5.807	1.512	9.212
	growth	0.16 %	0.05 %	-4.60 %	1.17 %

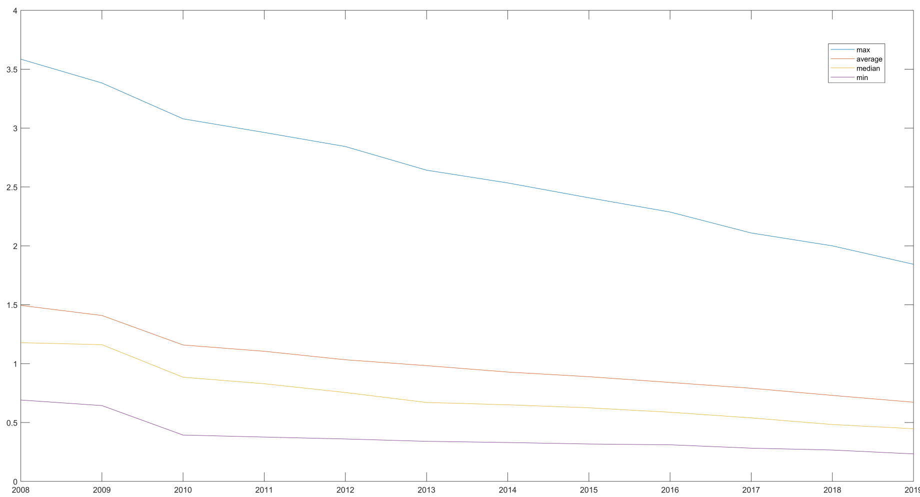
we make is that this variable is a proxy of all the resources, outside labour, which enters the process of water production. Proceeding in this way, we are particularly interested in efficiency measurement corresponding to the way operators use the water resource available (m3 of supplied water) to maximize outcomes; in this case, population covered and water consumption per capita. In other words, water lost in the process of distribution will be reflected by the efficiency score. For a rather similar representation of the water distribution process, see Mbuvi et al. (2012) and Picazo et al. (2009). Again, the resources are expressed per urban inhabitants to consider population trends. As done before for the outcomes, we present the descriptive statistics per year in Figure 3, and per province in Table 3.

The average water supplied is rather stable over the period. This trend is true also for the minimum, median and maximum. At the same time, disparities between provinces are observed. Kasaï-Occidental tops the list with 6.46% while Equateur is at the bottom with a negative growth rate of -2.89%. Three other provinces also show negative growth rates: Kasaï-Oriental (-1.95%), Katanga (-1.73%) and Kinshasa (-1.78%). A surprising pattern is observed for the number of employees with a negative trend. This drastic reduction in staff is the result of a deliberate policy by REGIDESO within the framework of the implementation of phase 1 of the PEMU Project which aimed to restore the financial balance of REGIDESO. To achieve the expected profitability of REGIDESO, the PEMU recommended reducing overstaffing. Through a social recovery plan, REGIDESO had recorded the departure of 1,000 agents. This train of reduction was maintained until the end of 2022 by retirements, dismissal or death without recruitment.

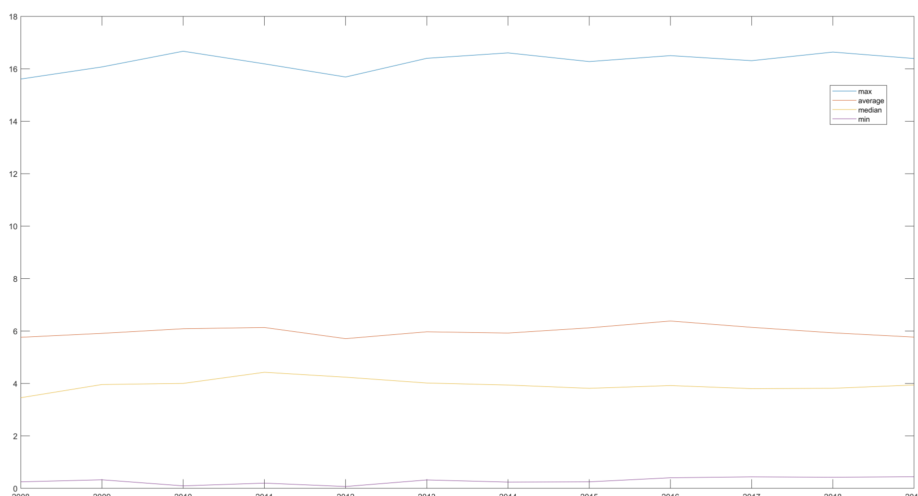
4 Efficiency and effectiveness

The starting point of our analysis is the observation of a panel dataset consisting of n entities during T time periods. We adopt a non-parametric spirit by defining efficiency and effectiveness from two empirical sets constructed from the observed data. The first empirical set, used to define efficiency, contains all possible resource-outcome combinations. The second one, used to define effectiveness, contains the outcome combinations only. That is, the latter set ignores the resource constraint. In a sense, these sets form our non-parametric estimator of the unobserved water generation processes. As there is no guideline about the best parametric functional

Figure 3: Resources per year



(a) worker number



(b) water supplied

form describing that process, it is probably the safest way to proceed. Moreover, as the entities are provinces in our application, we face aggregated data making the parametric choice even harder to defend.

4.1 A production approach

In the production world, entities use certain common technology to transform resources/inputs ($\mathbf{x}_t$) into outcomes/outputs ($\mathbf{y}_t$) at each time period t. A production possibility set can be used to summarize all feasible resource-outcome combinations for every time period. Following the common practice in the literature, we assume that those sets are monotone, convex and satisfy constant returns-to-scale.[13] Formally, the production possibility set at time t is defined as follows:

$$T_t = \left\{ (\mathbf{x}_t, \mathbf{y}_t) \middle| \mathbf{y}_t \leq \sum_{i=1}^{n} \lambda_i \mathbf{y}_{it}, \mathbf{x}_t \geq \sum_{i=1}^{n} \lambda_i \mathbf{x}_{it}, \lambda_i \geq 0 \right\}, \tag{1}$$

In words, T_t is the monotone and convex hull enveloping the observed resource-outcome data at time t. It is the most conservative approximation to the data consistent with a monotone and convex technology.

Two possibilities occur for the entities at each period t: they lie on the frontier of T_t or they are in the set. When the first option is true, we declare such entities as (outcome) efficient; it is not possible to improve the outcomes without increasing the resources. In the second case, entities are inefficient as it is, in principle, possible to increase the outcomes by keeping resources constant. To measure the inefficiency degree, we can use the distance to the production possibility set frontier. A general way to measure such distance is the concept of directional distance function. It is given for a particular entity, defined by its resource-outcome pair $(\mathbf{x}_t, \mathbf{y}_t)$, as follows:

$$e_t(\mathbf{y}_t, \mathbf{x}_t, \mathbf{g}_t) = \max \{ \beta \mid (\mathbf{y}_t + \beta \mathbf{g}_t, \mathbf{x}_t) \in T_t \}. \tag{2}$$

$e_t(\mathbf{y}_t, \mathbf{x}_t, \mathbf{g}_t)$ captures (in)efficiency in the direction of $\mathbf{g}_t$. When $e_t(\mathbf{y}_t, \mathbf{x}_t, \mathbf{g}_t) = 0$, it means that the maximal amount of the outcomes is produced at time t. Greater value of $e_t(\mathbf{y}_t, \mathbf{x}_t, \mathbf{g}_t)$ implies more inefficient behaviour at time t. Outcomes can be improved without increasing the resources.

4.2 A performance approach

In the performance world, resources are ignored and only outcomes matter. In that case, entities face a certain common environment in every time period t to achieve the outcome levels $(\mathbf{y}_t)$. A performance possibility set can be used to define the outcome possibilities at each period t. Keeping the same assumptions as before, it is given at time t as:

$$\mathcal{T}_t = \left\{ (1, \mathbf{y}_t) \middle| \mathbf{y}_t \leq \sum_{i=1}^{n} \lambda_i \mathbf{y}_{it}, 1 \geq \sum_{i=1}^{n} \lambda_i, \lambda_i \geq 0 \right\}, \tag{3}$$

$\mathcal{T}_t$ is a monotone and convex hull but, this time, envelops the observed outcomes at time t only, i.e. it ignores the resource constraints. We immediately appreciate the connection with the production possibility sets defined before. To obtain $\mathcal{T}_t$, it suffices to replace the resources by one in T_t. This exactly reflects the spirit of ignoring the resource constraint.

These sets $\mathcal{T}_t$ allow us to verify whether entities have achieved their optimal outcome values. When this is the case, we declare such entities effective. Ineffectiveness means that it is, in principle, possible to increase the outcomes. As done in the production approach, we use a directional distance function to measure the ineffectiveness degree. It is given for an entity evaluated at $(\mathbf{y}_t)$ by:

$$p_t(\mathbf{y}_t, \mathbf{g}_t) := p_t(\mathbf{y}_t, 1, \mathbf{g}_t) = \min \left\{ \beta \mid (\mathbf{y}_t + \beta \mathbf{g}_t, 1) \in \mathcal{T}_t \right\}. \tag{4}$$

$p_t(\mathbf{y}_t, \mathbf{g}_t)$ captures the maximal possible expansion of the outcomes.[14] When it is zero, it shows that the maximal values have been reached at time t. Greater value reflects greater potential outcome improvement.

4.3 A unified approach

By construction, there is no specific ranking between the inefficiency $e_t(\mathbf{y}_t, \mathbf{x}_t, \mathbf{g}_t)$ and ineffectiveness $p_t(\mathbf{y}_t, \mathbf{g}_t)$ measurements. Nevertheless, important information can be learned by comparing such concepts. We recall here that for both concepts, a value of zero reflects an efficient/effective situation. Strictly positive values mean inefficiency/ineffectiveness. We have to distinguish two cases:

- *Case 1 [unexploited production capacity (UPC)]:* $e_t(\mathbf{y}_t, \mathbf{x}_t, \mathbf{g}_t) > p_t(\mathbf{y}_t, \mathbf{g}_t)$. Inefficiency is larger than ineffectiveness at time t. This means that the outcome result is better when ignoring the resource constraint. In other words, it reflects that the resources are not used optimally. That is, there is unexploited production capacity. Therefore, outcomes could be increased to some extent without requesting more resources.

- *Case 2 [resource constraint (RC)]:* $e_t(\mathbf{y}_t, \mathbf{x}_t, \mathbf{g}_t) < p_t(\mathbf{y}_t, \mathbf{g}_t)$. Ineffectiveness is higher than inefficiency at time t. Ignoring the resources reveals more potential outcome improvement. In other words, resources are fully exploded and therefore more resources are requested to further improve outcomes. That is, resources act as a constraint to further improve the outcomes.

Note that it is of course possible that $e_t(\mathbf{y}_t, \mathbf{x}_t, \mathbf{g}_t) = p_t(\mathbf{y}_t, \mathbf{g}_t)$. In that case, inefficiency equals ineffectiveness at time t. The maximum outcome expansion without constraints exactly equals the maximum outcome expansion with resource constraints. In that situation, that rarely occurs, it is required to check the values of the inefficiency and ineffectiveness scores to better understand the performances.

5 Indicators and decomposition

To capture production and performance changes over time, we rely on indicators. In our particular directional distance function context, we use Luenberger's (1992) indicators (Chambers 2002; Boussemart et al., 2003; Walheer, 2019a).[15] Next, we decompose such indicators into two parts: the first component captures the expansion or shrinkage of the production and performance possibility sets, and the latter indicates how the entities move in those sets. In practice, both components have to be interpreted together to obtain the full picture. In the following, we show how adapted versions of our efficiency and effectiveness measurements can be combined to obtain the indicators and their decomposition.

Our new Luenberger indicators present several new features. First, they are the first to relate efficiency and effectiveness in a simple but coherent way. Next, they offer a certain flexibility to the practitioners as the choice of the directions for the outcomes and resources is free. Also, our indicators are path-independent meaning that it is not required to select a certain time period for the technology and the environment. Finally, our Luenberger indicators can be decomposed into two parts, named the efficiency–effectiveness difference and the technology–environment change. Each component offers new ways to look at the performance change over time.

5.1 Luenberger indicators

To define our indicators, we first have to define time-related versions of our previous definitions of inefficiency and ineffectiveness. Let us consider that we want to compare inefficiency and ineffectiveness between two periods a and b, where $a < b$. The time-related versions are given by:

$$e_b(\mathbf{y}_a, \mathbf{x}_a, \mathbf{g}_a) = \max \left\{\beta \mid (\mathbf{y}_a + \beta\mathbf{g}_a, \mathbf{x}_a) \in T_b\right\}. \tag{5}$$

$$p_b(\mathbf{y}_a, \mathbf{g}_a) := p_b(\mathbf{y}_a, 1, \mathbf{g}_a) = \min \left\{\beta \mid (\mathbf{y}_a + \beta\mathbf{g}_a, 1) \in \mathcal{T}_b\right\}. \tag{6}$$

These measurements give us the inefficiency and ineffectiveness of an entity at period a against the production or performance possibility set of period b. They are thus counterfactual concepts. They have to be interpreted as before but keeping in mind their time-related dimension. Note that when $a = b$, we are back to the definitions of Section 4.

The basic principle of Luenberger's approach is to compare the performances in periods a and b keeping the technology/environment fixed. Two natural candidates emerge: the Luenberger indicator based on the technology and the environment of period a or the one based on the technology and the environment of period b. Adapting the initial definitions to our context gives us the following two indicators:

$$L_a(\mathbf{x}_a, \mathbf{x}_b, \mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b) = [e_a(\mathbf{y}_a, \mathbf{x}_a, \mathbf{g}_a) - p_a(\mathbf{y}_a, \mathbf{g}_a)] - [e_a(\mathbf{y}_b, \mathbf{x}_b, \mathbf{g}_b) - p_a(\mathbf{y}_b, \mathbf{g}_b)]. \tag{7}$$

$$L_b(\mathbf{x}_a, \mathbf{x}_b, \mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b) = [e_b(\mathbf{y}_a, \mathbf{x}_a, \mathbf{g}_a) - p_b(\mathbf{y}_a, \mathbf{g}_a)] - [e_b(\mathbf{y}_b, \mathbf{x}_b, \mathbf{g}_b) - p_b(\mathbf{y}_b, \mathbf{g}_b)]. \tag{8}$$

Both indicators capture change in the difference between efficiency and effectiveness but for a different technology and environment. Putting this differently, they are path-dependent. The status-quo situation is when a Luenberger indicator equals zero meaning the efficiency-effectiveness difference has not moved between a and b. Next, when a Luenberger indicator is larger than zero, this means that the efficiency–effectiveness difference is larger in period a than in b. When it is smaller than zero, it is the opposite situation. Two main reasons explain the Luenberger indicator value.

This will be clarified when discussing its decomposition in the next Section. Finally, we highlight that we rely here on a difference between efficiency and effectiveness only because we rely on a directional distance function and a Luenberger indicator. In other contexts, a ratio might be more appropriate (Aparicio et al., 2022; Cherchye et al. 2019; Perelman and Walheer, 2020).

To avoid an arbitrary choice of time period for the technology and the environment, a commonly used procedure is to take an arithmetic average of the two previous path-dependent Luenberger indicators:

$$L(\mathbf{x}_a, \mathbf{x}_b, \mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b) = \frac{1}{2}\left[L_a(\mathbf{x}_a, \mathbf{x}_b, \mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b) + L_b(\mathbf{x}_a, \mathbf{x}_b, \mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b)\right]. \quad (9)$$

The resulting Luenberger indicator has to be interpreted as the two previous ones but offers the advantage of been path-independent. It is not required to select a specific time period for the technology and the environment.

5.2 Decomposition

A major advantage of the Luenberger indicator is that it can be decomposed into several parts to better understand its value. As discussed before, we select two main components: expansion or shrinkage of the production and performance possibility sets, and the change in the efficiency-effectiveness difference. Formally, we obtain the following decomposition between periods a and b:

$$L(\mathbf{x}_a, \mathbf{x}_b, \mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b) = EED(\mathbf{x}_a, \mathbf{x}_b, \mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b) + TEC(\mathbf{x}_a, \mathbf{x}_b, \mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b). \quad (10)$$

The first component is the change in the efficiency-effectiveness difference. It captures the change in the practice with respect to technology and the environment. It is given as follows:

$$EED(\mathbf{x}_a, \mathbf{x}_b, \mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b) = [e_a(\mathbf{y}_a, \mathbf{x}_a, \mathbf{g}_a) - p_a(\mathbf{y}_a, \mathbf{g}_a)] - [e_b(\mathbf{y}_b, \mathbf{x}_b, \mathbf{g}_b) - p_b(\mathbf{y}_b, \mathbf{g}_b)]. \quad (11)$$

Such indicator can be positive, negative, or zero depending on the (in)efficiency–(in)effectiveness differences in both time periods. To fully understand the reasons for the indicator values, it is required to compare the (in)efficiency–(in)effectiveness difference values in a and b. A detailed analysis of the potential explanations for both cases is given in Table 4. We recall here that UPC and RC mean unexploited production capacity and resource constraint, respectively (see Section 4.3).

Table 4: Efficiency–effectiveness difference

Period a	Period b	EED	possible	explanation
UPC	RC	zero	no	-
UPC	RC	positive	yes	move from UPC to RC
UPC	RC	negative	no	-
UPC	UPC	zero	yes	same UPC
UPC	UPC	positive	yes	UPC is greater in a
UPC	UPC	negative	yes	UPC is greater in b
RC	RC	zero	yes	same RC
RC	RC	positive	yes	RC is greater in b
RC	RC	negative	yes	RC is greater in a
RC	UPC	zero	no	-
RC	UPC	positive	no	-
RC	UPC	negative	yes	move from RC to UPC

Next, the second component in (10) is called the technology–environment change. It captures relative movement in the best practices between the periods a and b. The basic principle is to fix the period of the evaluated entity and change the period of the technology and the environment. Two options are therefore possible:

$$TEC_a(\mathbf{x}_a, \mathbf{y}_a, \mathbf{g}_a) = [e_a(\mathbf{y}_a, \mathbf{x}_a, \mathbf{g}_a) - p_a(\mathbf{y}_a, \mathbf{g}_a)] - [e_b(\mathbf{y}_a, \mathbf{x}_a, \mathbf{g}_a) - p_b(\mathbf{y}_a, \mathbf{g}_a)]. \quad (12)$$

$$TEC_b(\mathbf{x}_b, \mathbf{y}_b, \mathbf{g}_b) = [e_a(\mathbf{y}_b, \mathbf{x}_b, \mathbf{g}_b) - p_a(\mathbf{y}_b, \mathbf{g}_b)] - [e_b(\mathbf{y}_b, \mathbf{x}_b, \mathbf{g}_b) - p_b(\mathbf{y}_b, \mathbf{g}_b)]. \quad (13)$$

To ease the interpretation in terms of technology–environment change, we can reorganize the terms in (12) and (13) to see the technology and environment changes:

$$\begin{aligned} TEC_a(\mathbf{x}_a, \mathbf{y}_a, \mathbf{g}_a) &= [e_a(\mathbf{y}_a, \mathbf{x}_a, \mathbf{g}_a) - e_b(\mathbf{y}_a, \mathbf{x}_a, \mathbf{g}_a)] - [p_a(\mathbf{y}_a, \mathbf{g}_a) - p_b(\mathbf{y}_a, \mathbf{g}_a)] \\ &= TECH_a(\mathbf{x}_a, \mathbf{y}_a, \mathbf{g}_a) - ENV_a(\mathbf{y}_a, \mathbf{g}_a). \end{aligned} \quad (14)$$

$$\begin{aligned} TEC_b(\mathbf{x}_b, \mathbf{y}_b, \mathbf{g}_b) &= [e_a(\mathbf{y}_b, \mathbf{x}_b, \mathbf{g}_b) - e_b(\mathbf{y}_b, \mathbf{x}_b, \mathbf{g}_b)] - [p_a(\mathbf{y}_b, \mathbf{g}_b) - p_b(\mathbf{y}_b, \mathbf{g}_b)] \\ &= TECH_b(\mathbf{x}_b, \mathbf{y}_b, \mathbf{g}_b) - ENV_b(\mathbf{y}_b, \mathbf{g}_a). \end{aligned} \quad (15)$$

The rewritten version highlights the technological change, i.e. movement of the production possibility set frontier, and the environmental change, i.e. movement of the performance possibility set frontier. The different cases are detailed in Table 5. Note that, contrary to the elements in Table 4, those in Table 5 are changes.

Table 5: Technology–environment change

TECH	**ENV**	**TEC**	**possible**	**explanation**
positive	positive	positive	yes	TECH greater than ENV
positive	positive	negative	yes	TECH smaller than ENV
positive	positive	zero	yes	TECH = ENV
negative	negative	positive	yes	TECH smaller than ENV
negative	negative	negative	yes	TECH greater than ENV
negative	negative	zero	yes	TECH = ENV
positive	negative	positive	yes	no clear ranking
positive	negative	negative	no	-
positive	negative	zero	no	-
negative	positive	positive	no	-
negative	positive	negative	yes	no clear ranking
negative	positive	zero	no	-

As done before for the Luenberger indicator, we can obtain a path-independent technology-environment change indicator by taking the arithmetic average of the two previous indicators:

$$TEC(\mathbf{x}_a, \mathbf{x}_b, \mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b) = \frac{1}{2}\left[TEC_a(\mathbf{x}_a, \mathbf{y}_a, \mathbf{g}_a) + TEC_b(\mathbf{x}_b, \mathbf{y}_b, \mathbf{g}_b)\right]. \tag{16}$$

Finally, we highlight that it is also possible to rewrite $EED(\mathbf{x}_a, \mathbf{x}_b, \mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b)$ to obtain a comparison between efficiency and effectiveness changes:

$$\begin{aligned} EED(\mathbf{x}_a, \mathbf{x}_b, \mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b) &= \left[e_a(\mathbf{y}_a, \mathbf{x}_a, \mathbf{g}_a) - e_b(\mathbf{y}_b, \mathbf{x}_b, \mathbf{g}_b)\right] - \left[p_a(\mathbf{y}_a, \mathbf{g}_a) - p_b(\mathbf{y}_b, \mathbf{g}_b)\right] \\ &= EFF(\mathbf{x}_a, \mathbf{x}_b, \mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b) - PERF(\mathbf{y}_a, \mathbf{y}_b, \mathbf{g}_a, \mathbf{g}_b). \end{aligned} \tag{17}$$

The different possibilities are provided in Table 6. This time, the interpretation is done in terms of changes and not per period as in Table 4.

Table 6: Efficiency–effectiveness difference bis

EFF	**PERF**	**EED**	**possible**	**explanation**
positive	positive	zero	yes	EFF=PERF
positive	positive	positive	yes	EFF greater than PERF
positive	positive	negative	yes	EFF smaller than PERF
negative	negative	zero	yes	EFF=PERF
negative	negative	positive	yes	EFF smaller than PERF
negative	negative	negative	yes	EFF greater than PERF
positive	negative	zero	no	-
positive	negative	positive	yes	no clear ranking
positive	negative	negative	no	-
negative	positive	zero	no	-
negative	positive	positive	no	-
negative	positive	negative	yes	no clear ranking

6 Linear programmings

We estimate inefficiency and ineffectiveness using a Data Envelopment Analysis (DEA)-based methodology. DEA, introduced by Charnes et al. (1978), does not assume any functional form for the technology and the environment but rather reconstructs the technology and environment through possible sets using the data while imposing some regularity conditions (here, we assume that the sets are compact and satisfies constant returns-to-scale). DEA is easy to deal with as it only requires solving linear programming using all entities as peers. We point out that DEA is the most used estimation method for empirical works on water utility performances (see Table 12 in the Appendix).

To be fair, DEA presents also some less desirable features. It is sensitive to outliers and measurement errors. To mitigate these shortcuts, we adopt the well-known order-m estimator to compute the potential outputs (Daraio and Simar, 2007; Walheer, 2019b). The basic principle is to compute expected potential outputs obtained with random sub-samples of m peers. Practically, the sampling procedure is repeated B times to obtain the expected potential outputs. In this study, we set $B = 1,000$ and $m = 6$.[16] That is, the linear programming is run for each sub-sample and the estimated inefficiency and ineffectiveness scores are simply the arithmetic average of the sub-sample counterparts.

For an entity evolving at $(\mathbf{y}_a, \mathbf{x}_a)$ and a direction vector $\mathbf{g}_a$, $e_b^s(\mathbf{y}_a, \mathbf{x}_a, \mathbf{g}_a)$ is obtained for sub-sample s by solving the following linear programming:

$$
\begin{aligned}
e_b^s(\mathbf{y}_a, \mathbf{x}_a, \mathbf{g}_a) = \max_{\lambda_1,\ldots,\lambda_n} \beta & \\
& \text{(C-1) } \mathbf{y}_a + \beta \mathbf{g}_a \leq \sum_{j=1}^{n_s} \lambda_j \mathbf{y}_{bj} \\
& \text{(C-2) } \mathbf{x}_a \geq \sum_{j=1}^{n_s} \lambda_j \mathbf{x}_{bj} \\
& \text{(C-3) } \forall j = 1, \ldots, n_s : \lambda_j \geq 0, \\
& \text{(C-4) } \beta \geq 0.
\end{aligned} \tag{18}
$$

To obtain the other inefficiency measurements, it suffices to change the time periods for the evaluated entity, i.e. $(\mathbf{y}_b, \mathbf{x}_b)$ and $\mathbf{g}_b$, and/or the peers, i.e. $(\mathbf{y}_{aj}, \mathbf{x}_{aj})$ for $j = 1, \ldots, n_s$ in (18).

Next, we explain how $p_b(\mathbf{y}_a, \mathbf{g}_a)$ can be computed for an entity evolving at $(\mathbf{y}_a)$. Again, linear programming is used but the resources are not needed. We obtain the following for sub-sample s:

$$
\begin{aligned}
p_b^s(\mathbf{y}_a, \mathbf{g}_a) = \max_{\lambda_1,\ldots,\lambda_n} \beta & \\
& \text{(C-1) } \mathbf{y}_a + \beta \mathbf{g}_a \leq \sum_{j=1}^{n_s} \lambda_j \mathbf{y}_{bj} \\
& \text{(C-2) } 1 \geq \sum_{j=1}^{n_s} \lambda_j \\
& \text{(C-3) } \forall j = 1, \ldots, n_s : \lambda_j \geq 0, \\
& \text{(C-4) } \beta \geq 0.
\end{aligned} \tag{19}
$$

The linear programming in (19) is similar to (18) except that the resources are set to unity. Again, to obtain the three other ineffectiveness measurements, it suffices to change the time periods for the evaluated entity.

Once the linear programmings are solved B times, i.e. one time for each sub-sample s, we obtain our estimator of inefficiency and ineffectiveness that we will use in the following:

$$e_b(\mathbf{y}_a, \mathbf{x}_a, \mathbf{g}_a) = \mathbb{E}\left[e_b^s(\mathbf{y}_a, \mathbf{x}_a, \mathbf{g}_a)\right], \tag{20}$$

$$p_b(\mathbf{y}_a, \mathbf{g}_a) = \mathbb{E}\left[p_b^s(\mathbf{y}_a, \mathbf{g}_a)\right]. \tag{21}$$

The estimated inefficiency and ineffectiveness scores have to be interpreted as the theoretical counterpart: the benchmark value is zero and lower values reflect greater inefficiency/ineffectiveness behaviour.

7 Results

We consider two scenarios (orientations) in direct connection with the SDG 6.[17] In the first one, we consider potential consumer increase only. In SDG 6.1, it is stated that water access should be guaranteed to all. Implicitly, this objective suggests an increase in the number of consumers until the target of universal access is met. In the spirit of SDG 6.1, water utilities must ensure the operation of the network and its expansion at the pace of urbanization in a way to provide reliable water access. In the second scenario, we consider both potential increases in the consumer number and of water billed. This case is in direct relation with SDG 6.4 which targets water access but also requires improving resource use and efficiency.

7.1 Efficiency and effectiveness

As a starting point, we present the average efficiency and effectiveness for our two scenarios in Table 7. We recall that a value of zero represents an efficient/effective situation. Values further from zero indicate inefficiency/ineffectiveness and thus potential outcome increases.

When considering the consumers-only orientation, we see that all the provinces are inefficient and ineffective, except the provinces of Kasaï-Occidental and Katanga which are efficient and Kongo-Central which is effective. Very poor performances are observed in the provinces of Maniema, Kasaï-Oriental, Equateur and Province Orientale in terms of effectiveness. The provinces of Maniema and Kinshasa are the ones with high inefficiency rates of 1.11 and 1.09, respectively. In Kinshasa, as is the case in other inefficient provinces, the main reasons for the poor performance are probably the poor functioning of the water catchment, the recurrent breakdowns of certain equipment at the raw water catchment points, the deterioration of the quality of raw water and multiple shutdowns for instability of electrical current in almost all production units (REGIDESO 2018, 2019). In Kasaï-Occidental, all centres operate with thermal energy to produce drinking water. Even though two of these operating centres have often been out of order, the province has managed to control the consumption of diesel. Just for the year 2019, the increase in production reached 28%, thus contributing to an increase in the number of urban and peri-urban consumers. The efficiency observed in Katanga stems in particular from the improvement of management and especially the increase in the service rate.

For our second scenario, consumers and water billed, it turns out that Katanga and Kasaï-Occidental remain the most effective and efficient provinces. The underperformance observed everywhere else can be explained by the non-achievement of the targeted objectives in water billed. Indeed, as indicated by the REGIDESO, the growth rate of the quantities of drinking water delivered in cubic meters has not achieved the expected objectives (REGIDESO 2017, 2018, 2019). Three main reasons can explain such poor performances. First, the installed capacity exceeded 60% on average, mainly because of the malfunctioning of production units. Second, power cuts for hydroelectric operating centres and the lack of diesel for thermal operating centres. Third, the ratio of inactive points of sale to total points of sale remains very high and shows that the inactive connection rate is over 40%. Although REGIDESO has increased the length of its network, the reality is that in most provinces, the target of 100% availability rate of delivery cube meters has never been achieved.

7.2 Luenberger indicator

Next, we give the results for the Luenberger indicator (LI) and its decomposition into efficiency–effectiveness difference (EED) and technology-environment change (TEC), in Table 8. There, we give the averages per year and we cumulate the indicators over the time periods. In a sense, such cumulative measure gives an overall performance change for the 2008–2019 period. The results reported in Table 8 indicate that, in most cases, the LI indicator is negative highlighting a larger efficiency–effectiveness difference over time. We may interpret our results as REGIDESO's inability to meet the increased demand for drinking water. Most provinces are unable to cover their

Table 7: Inefficiency and ineffectiveness

Province	**consumers only**		**consumers and water billed**	
	inefficiency	ineffectiveness	inefficiency	ineffectiveness
Bandundu	0.52	1.81	0.09	1.65
Équateur	0.27	2.18	0.07	1.96
Kasaï-Occidental	0.00	1.99	0.00	1.81
Kasaï-Oriental	0.41	3.53	0.28	3.04
Katanga	0.00	0.56	0.00	0.49
Kinshasa	1.09	0.25	0.36	0.21
Kongo-Central	0.70	0.00	0.14	0.00
Maniema	1.11	4.61	0.29	4.28
Nord-Kivu	0.39	1.17	0.18	1.04
Province-Orientale	0.08	2.09	0.02	1.92
Sud-Kivu	0.49	0.40	0.18	0.38

urban centres with water access. This is the result of population growth and the fact that a very small number of standpipes on the REGIDESO network over the same period have been installed. The only exceptions are the Bandundu and Kasai-Oriental provinces for the consumer-only scenario and four provinces, Bandundu, Kongo-Central, Province-Orientale and Sud-Kivu for the consumers and water-billed scenario. These better performances can be attributed to rational management of work and effective management of operating centres.

The overall increasing efficiency–effectiveness difference pointed out by the LI results is mainly due to the TEC dimension. Indeed, TEC is overall negative and, in fact, negative for all provinces. A possible reason is the lack of technological change. Despite the rehabilitation of infrastructure, the replacement of old pipes and the rehabilitation of pumping stations during the period under review, all the studies carried out by the World Bank point out the fact that the water sector in the DRC is under-equipped and requires significant investments to achieve the objectives of SDG 6 (World Bank, 2017). Overall, the logistics deficit of the DRC is highlighted by its logistics performance index which is estimated at 2.5 in 2023 on a scale of 1 (=low) to 5 (=high), thus classifying it at the 97th position out of 139 countries (World Bank, 2023a). This score shows that drastic efforts must be made if we want to ensure universal access to water for all Congolese.

EED is positive with two exceptions for the consumers-only direction (Kinshasa and Nord-Kivu) and one exception for the other scenario (Nord-Kivu). The poorer performances observed in the province of North Kivu would be inherent to the succession of armed conflicts that the region has known for more than two decades. Rural populations in search of survival flocked to large urban centres which then experienced a population explosion while the extension of water supply networks did not follow. Moreover, in such a context of instability, the maintenance of existing networks is almost hypothetical; therefore, it follows without a shadow of any doubt a systematic degradation of the pipes of the water network. To better understand the decomposition results, we make use of our roadmaps displayed in Tables 4 and 5.

Table 8: Results per province

Province	LI		EED		TEC	
	average	cumulative	average	cumulative	average	cumulative
consumers only						
Bandundu	0.01	0.13	0.04	0.41	-0.02	-0.27
Équateur	-0.09	-1.02	0.07	0.72	-0.16	-1.74
Kasaï-Occidental	0.00	0.05	0.09	0.97	-0.08	-0.92
Kasaï-Oriental	-0.07	-0.81	0.12	1.37	-0.20	-2.18
Katanga	-0.04	-0.44	0.02	0.21	-0.06	-0.65
Kinshasa	-0.17	-1.92	-0.01	-0.06	-0.17	-1.86
Kongo-Central	-0.11	-1.19	0.00	0.00	-0.11	-1.19
Maniema	-0.16	-1.73	0.08	0.90	-0.24	-2.63
Nord-Kivu	-0.13	-1.38	-0.04	-0.42	-0.09	-0.96
Province-Orientale	-0.01	-0.08	0.02	0.27	-0.03	-0.35
Sud-Kivu	-0.14	-1.56	0.02	0.25	-0.16	-1.81
All	-0.08	-0.90	0.04	0.42	-0.12	-1.32
consumers and water billed						
Bandundu	0.03	0.28	0.05	0.57	-0.03	-0.29
Équateur	-0.03	-0.35	0.08	0.93	-0.12	-1.27
Kasaï-Occidental	-0.02	-0.18	0.09	0.97	-0.10	-1.15
Kasaï-Oriental	-0.03	-0.36	0.12	1.35	-0.16	-1.71
Katanga	-0.02	-0.18	0.11	1.24	-0.13	-1.42
Kinshasa	0.00	-0.05	0.04	0.41	-0.04	-0.45
Kongo-Central	0.01	0.10	0.01	0.16	0.00	-0.05
Maniema	-0.01	-0.16	0.20	2.23	-0.22	-2.39
Nord-Kivu	-0.02	-0.18	-0.04	-0.46	0.02	0.27
Province-Orientale	0.02	0.27	0.04	0.41	-0.01	-0.14
Sud-Kivu	0.00	0.03	0.02	0.17	-0.01	-0.14
All	-0.01	-0.07	0.07	0.73	-0.07	-0.80

We present the results of the decomposition in Tables 9 and 10. In Table 9, using the results of the efficiency-effectiveness difference, we present the resource impact for each period in every province. Two cases are possible: unexploited production capacity (UPC) and resource constraint (RC). For most provinces and all years the RC situation prevails, which means that more resources are requested to further improve outcomes. These results are similar to the recommendations made by the Partnership 'Sanitation and Water for All', according to which achieving the SDG targets will require all partners to adopt new and different ways of working and a considerable increase in available resources (SWA, 2016). It is in the same vein that the Water Law of 2015 ruled on the need to establish new policies and efficient management schemes both at the level of the resource and the public water service to guarantee universal access in the DRC. This being said, there are a few exceptions: Kinshasa and Kongo-Central, under our both scenarios, for which the UPC situation prevails over nearly whole the period, which means that there is a place for improvement in production efficiency.

The results confirm that, overall, universal access to clean water in the DRC remains a major challenge for the majority of provinces, both in terms of the number of consumers served and the quantity of water consumed. As reported in Section 2, the three largest cities, Kinshasa, Matadi (Kongo-Central) and Lumumbashi (Katanga) participated in the first phase of the PEMU project and three others to the second phase, Kisangani (Province-Orientale), Bukavu (Sud-Kivu) and Likasi (Katanga). Without pretending a direct causal relation with the program, it is interesting to note that two of the REGIDESO operators concerned by these first phases, Kinshasa and Kongo-Central are the only ones with an unexploited production capacity. This means that for these provinces to have more resources, water supply or staff, is not a priority. On the contrary, the target must be the efficient management of existing resources.

In Table 10, using the technology–environment change results, we give the largest change for each period and province. It is either technological change (TECH) or environmental change (ENV). As pointed out before, the negative sign of LI is mainly driven by the TEC component. These negative signs indicate that the gap between technology (TECH) and environment (ENV) increased negatively over the period. This being said, we see that technological change is higher than environmental change in some provinces. This is the case of Katanga, Province-Orientale, and Kasaï-Occidental for the consumer-only scenario, and Kongo-Central, Kasaï-Occidental, and Nord-Kivu for the other scenario. These provinces are therefore the most innovative ones. Nevertheless, as the average and cumulative TEC are always negative (as highlighted in Table 8), this implies that while technological change can be higher than environmental change for some years, such positive changes are always countered by negative changes at other time periods. It is therefore crucial to support these better practices to be sure that they last over time.

Table 9: Efficiency–effectiveness difference

Province	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
consumers only												
Bandundu	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Équateur	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Kasaï-Occidental	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Kasaï-Oriental	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Katanga	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Kinshasa	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC
Kongo-Central	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC
Maniema	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Nord-Kivu	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Province-Orientale	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Sud-Kivu	RC	RC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	RC	UPC	RC
consumers and water billed												
Bandundu	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Équateur	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Kasaï-Occidental	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Kasaï-Oriental	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Katanga	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Kinshasa	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	RC	RC	RC	RC
Kongo-Central	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC	UPC
Maniema	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Nord-Kivu	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Province-Orientale	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Sud-Kivu	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC

Table 10: Technology–environment change

Province	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19
consumers only											
Bandundu	ENV	ENV	TECH	ENV	TECH	ENV	ENV	ENV	ENV	ENV	ENV
Équateur	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	TECH	ENV	ENV
Kasaï-Occidental	TECH	ENV	TECH	ENV	ENV	ENV	TECH	TECH	ENV	ENV	ENV
Kasaï-Oriental	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV
Katanga	ENV	ENV	ENV	ENV	ENV	TECH	TECH	TECH	ENV	ENV	TECH
Kinshasa	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV
Kongo-Central	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	TECH
Maniema	TECH	ENV	ENV	ENV	ENV	ENV	TECH	ENV	TECH	ENV	ENV
Nord-Kivu	TECH	ENV	ENV	TECH	ENV	ENV	ENV	ENV	TECH	ENV	ENV
Province-Orientale	ENV	ENV	TECH	ENV	TECH	ENV	ENV	TECH	TECH	ENV	ENV
Sud-Kivu	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV
consumers and water billed											
Bandundu	ENV	ENV	TECH	ENV	TECH	TECH	ENV	TECH	ENV	ENV	ENV
Équateur	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	TECH	TECH	ENV
Kasaï-Occidental	TECH	ENV	TECH	ENV	TECH	ENV	TECH	TECH	ENV	ENV	ENV
Kasaï-Oriental	ENV	TECH	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV	ENV
Katanga	ENV	ENV	ENV	ENV	ENV	ENV	TECH	ENV	ENV	ENV	ENV
Kinshasa	ENV	ENV	ENV	ENV	TECH	ENV	ENV	ENV	ENV	ENV	ENV
Kongo-Central	TECH	ENV	TECH	ENV	TECH	ENV	TECH	ENV	TECH	ENV	TECH
Maniema	TECH	ENV	ENV	ENV	ENV	ENV	TECH	TECH	TECH	ENV	ENV
Nord-Kivu	TECH	ENV	TECH	TECH	ENV	TECH	ENV	ENV	TECH	ENV	ENV
Province-Orientale	TECH	TECH	TECH	ENV	ENV	ENV	ENV	ENV	TECH	ENV	ENV
Sud-Kivu	ENV	ENV	TECH	ENV	TECH	TECH	ENV	TECH	ENV	ENV	ENV

7.3 Policy discussion and robustness checks

We end this part by relating our work to relevant literature and providing policy advice in line with SDG 6. In the 2030 SDG Agenda, countries are committed to achieving universal access to safe and affordable drinking water for all. This is particularly relevant for African countries, like the DRC, where a fast-growing population suffers from water scarcity, either due to no access to water or unreliable water supply. The unified efficiency-effectiveness approach we adopt is particularly well suited to studying countries' performances with the SDG targets and is useful for policy design and orientation.

Overall, our results show a larger efficiency–effectiveness difference over time of a majority of provinces' water operators. In terms of SDG 6.1, universal access to clean water in the DRC remains a major challenge for the majority of provinces, both in terms of the number of consumers served and the quantity of water consumed. Next, in terms of SDG 6.4, most of the provinces are inefficient and ineffective over the period.

Moreover, our results show that resources act as a constraint and that there is a lack of technological change. Despite the rehabilitation of infrastructure, the replacement of old pipes and the rehabilitation of pumping stations, the DRC is under-equipped and requires significant investments to achieve the objectives of SDG 6 (World Bank, 2017). Also, the underperformances observed can be explained by the malfunctioning of production units, power cuts for hydroelectric operating centres, the lack of diesel for thermal operating centres, and the existence of inactive points of sale (REGIDESO 2017, 2018, 2019).

At this point, it is important to point out that better performances are found for some provinces. This is in line with Fuller et al. (2016) who noted substantial inequality in progress toward SDG 6 targets, both between states and within African states. We can attribute the better performances to rational management of work and effective management of operating centres. Also, innovations are found in some cases, but they are not important enough to support technological change in the DRC. It is therefore crucial to support these better practices to be sure that they last over time (e.g. Water Law, PEMU project).

Our results and conclusions are in direct line with the lessons drawn by the World Bank (Van den Bergh and Danilenko, 2017). First, although water utilities in the DRC, in general, underperform there are relatively well-performing utilities (Lesson

1). Second, customer performance is relatively weak even among best-performing utilities (Lesson 2). Finally, turning to policy design and orientation, water coverage in Africa will require large investments that will have to be mostly paid for by public funds (Lesson 4) and the major drivers of water utility performance are linked to efficient use of resources (Lesson 5). This is not the case for the moment: the majority of funding has come from external sources, with around 90% of investments being externally financed. As highlighted by Kirkpatrick et al. (2006), governance and institutional factors are critical in explaining the performance variations among African water utilities.

The challenge for authorities is to make these better practices be adopted by all operators and, at the same time, to find the means to reduce resource constraints in those cases where a shortage of resources was identified. Knowing that for a majority of DRC provinces and the period covered by this study, on average, inhabitants shared with 30 other inhabitants a single water connection to accede to less than 10 m^3 over the year for individual needs, without doubt, there is still room for improvement. Given the slow pace of investment project execution, the conclusions drawn by Nhamo et al. (2019) are increasingly relevant, suggesting that achieving SDG 6 by 2030 is unrealistic for Africa under current conditions.

A last concern is how robust our results are. As explained in Section 6, the order-m estimator has been used to mitigate the potential bias issues. Next, we have tested how our results change when we remove a province or a time period. We have also verified our results using an alternative approach (a Malmquist-Luenberger index). We find very similar findings and our conclusion remains valid. Given the length of our paper and to avoid making it even longer, we have chosen to not show our robustness checks. However, they are available upon request to the authors.

8 Conclusion

The Sustainable Development Goals (SDG) of the United Nations have been designed to foster peace and prosperity for people and the planet. Amongst the 17 goals, the sixth one promotes access to reliable water. Such access, inscribed as a human right, is essential to improve health conditions and reduce inequalities. While significant progress in safe water access has been made worldwide, one in four people did not have access to safe drinking water at home and almost half of the world's population was without sanitation services. The situation is even more dramatic in Africa.

In this paper, we focus our attention on the case of the Democratic Republic of Congo (DRC). This country is somehow a paradox as it owns the second largest basin in the world while more than half of the population has no access to basic drinking water. The problem is not the quantity of water available, but rather the ability to provide water to the population. This proportion drops to less than one over five for safely managed water access, and to basic sanitation services.

This paradoxical situation forms our primary argument to conduct a performance analysis for the DRC connected with SDG 6. To do so, we built a tailored database and used a new methodology. In particular, we studied the urban access to reliable water performances of the 11 DRC provinces from 2008 to 2019 in reaching SDG 6. The methodological approach relies on the distinction between two main objectives pursued by the country's decision-makers: effectiveness and efficiency. To measure effectiveness and efficiency over time, we construct new flexible Luenberger indicators, based on directional distance functions, that can be decomposed into several parts to better understand the performance variations over time.

The results show poor performance in almost all provinces in terms of efficiency and effectiveness of urban water access and a high number of unbilled connections. This is certainly due to the low number of operational centres and the high rate of inactive connections. The negative overall performances observed in all provinces is attributed to the lack of technological change highlighting the low investment in the sector. The challenge for REGIDESO is to strengthen management to improve technical and financial performance. It seems important to increase public investment expenditure in the water sector and to carry out reforms in the sector by clarifying its institutional framework.

We are aware that our study suffers from several limitations due essentially to data availability issues, among them the number of DMUs, eleven provinces, just below Cooper's recommendation of twelve. Even if we are confident in our results, more accurate conclusions will be drawn when complete and detailed data are available for the complete sample of 99 centres operating in RDC provinces. In terms of methodology, our approach can be extended to other types of indicators and indexes (e.g. a Malmquist-Luenberger index) and combined with methods related to the directions for the outcomes and resources. It is also possible to further decompose our Luenberger indicator to obtain more components.

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Appendix

Table 11: Centers

Province	Number	Urban and semi-urban cities
Bandundu	14	Bandundu-Ville, Kikwit, Kenge, Masi Manimba, Idiofa, Gungu, Bulungu, Nioki, Bagata, Bolobo, Mangaï, Mushie, Dibaya-Lubue, Inongo
Équateur	12	Mbandaka, Gbadolite, Kawele, Libenge, Gemena, Lisala, Zongo, Bumba, Basankusu, Boende, Ikela, Bokungu
Kasaï Occidental	10	Kananga, Tshikapa, Demba, Tshimbulu, Ilebo, Dimbelenge, Mutombo-Dibue, Lwiza, Luebo, Mweka
Kasaï Oriental	8	Mbuji-Mayi, Mwene-ditu, Lusambo, Kabinda, Ngandajika, Lodja, Kole, Katanda
Katanga	19	Lubumbashi, Likasi, Kolwezi, Kamina, Kalemie, Kasenga, Dilolo, Sandoa, Kabongo, Malemba-Nkulu, Kongolo, Bukama, Kaniama, Moba, Nyunzu, Pweto, Ankoro, Manono, Kabalo
Kinshasa	1	Kinshasa
Kongo Central	12	Matadi, Boma, Mbanza-Ngungu, Kimpese, Muanda, Inkisi, Kasangulu, Lukala, Lukula, Mfidi-Malele, Tshela, Luozi
Maniema	4	Kindu, Kasongo, Punia, Kabambare
Nord-Kivu	4	Goma, Butembo, Beni, Walikale
Province Orientale	10	Kisangani, Bunia, Isiro, Ubundu, Wamba, irumu, Buta, Watsa, Opala, Aketi,
Sud-Kivu	5	Bukavu, Uvira, Kamituga, Baraka, Kiliba

Table 12: Literature review – non-African studies

Authors	Region	DMUs	Periods	Method	Outcomes	Resources
Cetrulo et al. (2020)	Brasil	77	2010	DEA	Water provided; Customer.	Network length; Operational expenditure; Labor.
Molinos-Senange et al. (2016)	Chile	25	2013	DEA	Water distributed; Customer.	Operating cost; Labor; Network length.
Pointon and Mattews (2016)	England and Wales	10	1997 to 2011	DEA	Water delivered; population served.	Labour; Capital; Other inputs.
Zschille (2015)	Germany	364	2006	DEA	Connection; Water delivery.	Network length; Employee.
Ananda (2014)	Australia	53	2005–2006 to 2010–2011	DEA	Water supplied; Water quality complaint.	Operating expenditure; Length of main.
Romano and Guerrini (2011)	Italy	43	2007	DEA	Water delivered; Population served.	Material cost; Labor; Service and Lease.
Singh et al. (2011)	North India	35	1999	DEA	Net per capita supply; Revenue receipt; Water treated.	Unaccounted for water; Staff; Operation and maintenance expenditure.
Picazo-Tadeo et al. (2009)	Spain	34	2001	DEA	Water delivered; Collected sewage; Treated sewage.	Delivery network; Sewer network; Labour; Ground, surface and purchased water.

Corton and Berg (2009)	Central American region	9	2002 to 2005	DEA and SFA	Water billed; Connection.	Labor; Network length.
Munisamy (2009)	Malaysia	17	2005	DEA	Water delivered; Connection.	Operating cost; Network length.
Renzetti and Dupont (2009)	Canada	64	1996	DEA	Delivery.	Labor ; Material expenditure; Distribution network.
Berg and Lin (2008)	Peru	44	1996 to 1998	DEA and SFA	Water billed; Customer; Coverage; Continuity of service.	Operating cost; Connection; Employee.
Picazo-Tadeo et al. (2008)	Spain	38	2001	DEA	Population served; Water delivered; Treated sewage.	Delivery network; Sewer network; Labour; Operational cost.
Erbetta and Cave (2007)	England and Wales	10	1993 to 2005	DEA	Delivered water; Water connected property; Sewerage connected property; Water waste.	Labour; Operating expenditure; Capital.
García-Sánchez (2006)	Spain	24	1999	DEA	Water supplied; Connection; Analyses performed.	Staff; Treatment plant; Network lenght; Total cost.

Aubert and Reynard (2005)	Wisconsin	211	1998 to 2000	SFA	Volume sold; Customer.	Labour; Energy; Variable cost; Capital.
Coelli and Walding (2005)	Australia	18	1995/96 to 2002/03	DEA	Property connected; Water delivered.	Operating expenditure; Capital.
Lin (2005)	Peru	198	1996 to 2001	SFA	Water billed; Customer	Wage; Capital price.
Tupper and Resende (2004)	Brazil	20	1996 to 2000	DEA	Water produced; Treated sewage; Population served-water; Population served-treated water.	Labour expense; Operational cost; Other operational cost.
Woodbury and Dollery (2004)	Australia	73	1997 to 2000	DEA	Water quality; Service reliability.	Capital; Operating cost.
Ashton (2003)	England and Wales	20	1991 to 1996	SFA	Water supplied.	Staff cost; Non-staff cost; Capital.
Anwandter and Ozuna (2002)	Mexico	110	1995	DEA	Water supply; Primary treatment; Secondary treatment.	Labor; Electricity; Material; Chemical; Outside service; Other cost; Treatment cost.

Estache and Rossi (2002)	Asian and Pacific region countries	50	1995	SFA	Salary; Client; Connection; Daily production; Density; Qualitative treatment.	Operational cost.
Thanassoulis (2002)	England and Wales	10	1994	DEA	Resident population; Area served.	Connection; Lenght of main; Delivery water; Burst.
Antonioli and Fillipini (2001)	Italy	32	1991 to 1995	SFA	Water distributed.	Labour; Capital; Energy.
Ashton (2000a)	England and Wales	10	1989 to 1997	SFA	Connected household.	Labour; Consumable; Capital.
Ashton (2000b)	England and Wales	10	1987 to 1997	SFA	Water supplied	Labour; Other variable cost; Operational asset.
Thanassoulis (2000)	England and Wales	10	1994	DEA	Property; Length of main; Water delivered.	Operating expenditure.
AIDA et al. (1998)	Japan	127	1993	DEA	Operating revenue; Water billed.	Employee; Operating expense; Plant and equipment; Population; Length of pipe.

Cubbin and Tzanidakis (1998)	England and Wales	29	1992 to 1999	DEA	Water delivered; Length of main.	Operating expenditure.
Lambert and Dichev (1993)	United States	271	1989	DEA	Water delivered.	Labor; Energy; Materials; Capital.
Norman and Stoker (1991)	England and Wales	28	1987 to 1988.	DEA	Potable water; Property supplied; Pumping head; Length of main; Average peak.	Manpower cost; Power cost; Chemical cost; Other cost.
Byrnes et al. (1986)	United States	127	1976	DEA	Water distributed.	Ground water; Surface water; Purchased water; Pipeline; Labor; Storage capacity.

Notes

[1]The Amazon drains 163,000 m^3/s over an area of 4,677,000 km^2 at the station of Obidos, while this is an area of 3,475,000 km^2 and a flow of 40,600 m^3/s for the Congo Basin.

[2]The Millennium Development Goals (MDGs), divided into eight quantified social objectives, have been adopted by 189 States and involve state commitments to poverty reduction, development and environmental protection (Gérardin et al., 2016; UN, 2015). The SDGs are an extension of the MDGs as they also apply to developing countries. Jacquemont's dictionary highlights this passage: 'Goals for others become goals for all' (Jacquemot, 2021).

[3]SDG 6.1 and SDG 6.4 are stated as follows: "By 2030, achieve universal and equitable access to safe and affordable drinking water for all" and "By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity".

[4]The constitution establishes the sovereignty of the Congolese state over water (Article 9), the right of Congolese citizens drinking water (Article 48), a universal, just and equitable access to water resources to all Congolese (Article 5), the distribution of powers between the national and the provincial level (Articles 201–206), and exclusive provincial jurisdiction over water production (Article 204).

[5]Other reforms include (i) The national drinking water supply and sanitation plan (PN-AEPA) that aimed at a target of 80% drinking water coverage in rural areas by 2000. This plan, which covered the period from 1991 to 2010, did not achieve the expected objectives. (ii) The national inventory of water and sanitation facilities that should lead to the development of a National Drinking Water Supply and Sanitation Plan in rural and semi-urban areas. Although not implemented, this plan provides useful elements for the development of national and provincial strategies and plans. (iii) The National Public Water Service Policy (PNSPE) drafted under the leadership of the Ministry of Energy and Hydraulic Resources, the PNSPE details the implementation of the Water Law. However, to date, the PNSPE has not yet been approved.

[6]The goals consisted of developing and implementing a national public water and sanitation service policy; enactment of a water law; the reorganization of structures involved in the drinking water sub-sectors in urban and rural areas; the promotion of partnership with the sector.

[7]No specific time period is considered in Akosa et al. (1995). They rather study several projects in the 70s–80s.

[8]The ONHR operates under the supervision of the Ministry of Environment and Rural Development. In addition, in rural and peri-urban areas, through the 'Ecoles et Villages Assainis program' (Healthy Schools and Villages program), several international organizations (including UNICEF, the DRC WASH Consortium, the SWIFT Consortium and IMA Global Health) support the Congolese government in its commitment to guarantee access to water for all. For example, The EVA program (with a budget of USD 350 million) has enabled 7,092,249 people and 1,036,092 schoolchildren to benefit from improved water, hygiene and sanitation in 9,136 villages and 2,546 schools since 2008 (MPH et al., 2018). World Bank (2017) notes that the concentration of funding has been driven by external financing. Approximately 90 per cent of the investments have been externally funded.

In 2015, for example, the government allocated USD 13 million to the water sector compared to approximately USD 85 million for external funds.

[9]Kinshasa, Katanga (Lubumbashi) and Kongo-Central (Matadi) account for 38% of network length, 71% of water service customers and 79% of the turnover (Lumbombo, 2008; REGIDESO, 2019, 2020).

[10]The 2006 Constitution defined the DRC as a unitary, but decentralized state, and the number of provinces has increased from 11 to 26 (Article 2). Nevertheless, we prefer to stay with 11 provinces for two main reasons. First, the new territorial division remains very dependent on many political and structural challenges. Indeed, even though the Water Law offers clarifications in terms of roles and responsibilities in water management, in particular by conferring the prerogatives of project managers and works to the provinces and the Decentralized Territorial Entities (ETD), the autonomy of the provinces is not effective in practice. The big challenge concerns the transfer of project management, which remains partial, the lack of resources of ETDs to fulfil their roles, and the tendency of decentralized state structures to behave as in a unitarist model. In addition, official statistics, in particular those of the National Institute of Statistics (NIS, 2015, 2017, 2021) are still provided to the 11 provinces.

[11]An important point of attention for any performance evaluation exercise is whether the sample size is big enough to obtain fair results. Following Cooper's rule, the minimum number of units to be evaluated is 12 and we have 11. So, we are rather close. Also, it represents the whole population in our context. Moreover, we perform a dynamic analysis so 12 DMUs are involved when computing counterfactual concepts. It is unfortunately impossible to increase the sample size as data collection is challenging and data access is not easy. However, in light of our results, we are confident about our sample selection.

[12]In the absence of a recent and exhaustive census of the total population in the DRC (the latest being carried out in July 1984), the size of the urban population of each province is estimated based on data from the Habitat-III-RDC (MTDUH, 2015) produced by the Ministry of Territorial Development, Urban Planning and Habitat under the auspices of UN-Habitat. The figures presented in the aforementioned report are based on projections made from two sources: the National Institute of Statistics (NIS,1993) and De Saint Moulin (2010). In addition, to calculate the projections for subsequent years, we use the figures relating to the evolution of population growth rates provided by the Habitat-III-RDC report and we make use of a mathematical approach assuming an exponential increase in population size.

[13]In words, monotonicity implies that the outputs and inputs are freely (or strongly) disposable; i.e. producing fewer outputs cannot lead to use more inputs and using more inputs never reduces the outputs. It also implies that marginal rates of substitution/transformation (between inputs, outputs, and inputs and outputs) are nowhere negative or, in other words, there is no congestion. Next, convexity says that convex combinations of feasible netput vectors are themselves also technically feasible. This implies that marginal rates of substitution/transformation (between inputs, output and inputs and outputs) are nowhere increasing.

[14]In the following, $p_t(\mathbf{y}_t, 1, \mathbf{g}_t)$ is replaced by $p_t(\mathbf{y}_t, \mathbf{g}_t)$ for better readability.

[15]Another option is to use a Malmquist-Luenberger indicator. See, for example, Walheer and

Zhang (2018) for a comparison between both approaches. It is fairly straightforward to adapt our methodology to a Malmquist-Luenberger index.

[16]Results do not change when increasing B and barely vary when adapting m.

[17]Formally, in the case of the consumer only scenario, the directional vector is $\mathbf{g} = (\text{number of consumers}, 0)$. For the consumers and water billed scenario, the directional vector is $\mathbf{g} = (\text{number of consumers, water billed})$.