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Energy Consumption and Economic Growth: Empirical Evidence from the Southern African Development Community

Themba Nyasulu^a

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Abstract

Even though the pivotal role that energy plays in catalyzing economic development has received considerable theoretical backing among researchers, conflicting empirical findings from many developing regions across the globe have generated a raging debate about the validity of this thesis. By employing panel causality and cointegration techniques, this paper wades into this debate by examining the energy consumption–economic growth nexus in 15 countries of the Southern African Development Community (SADC) using data from 1990 to 2015. Overall the study finds that a bi-directional/feedback causality relationship exists in the SADC region, suggesting that energy consumption and economic growth are complements in SADC's economic development. Furthermore, energy consumption is found to exert a positive short-run effect on economic growth even though the effect is higher in low-income SADC countries relative to middle-income SADC countries. The study's findings suggest that SADC countries should strengthen the implementation of energy conservation measures, including promotion of energy-saving bulbs, encouraging the use of solar water heaters in residential areas, and promoting commercial energy-efficient lighting. These measures will help to manage demand and allow power and energy savings realized to be channeled to productive sectors and stimulate economic growth in the SADC region.

Keywords: Energy consumption, Economic growth, Panel cointegration and causality, Generalized methods of moments (GMM) approach, SADC

^a United Nations Economic Commission for Africa (UNECA), Addis Ababa, Ethiopia
Corresponding author: Themba.Nyasulu@un.org

Background

Energy is a vital element in the success of an economic development agenda of any country or region across the globe. Lack of access to modern energy services causes poor and marginalized members of the society to waste their precious time doing rudimentary and routine tasks, such as fuelwood collection, that are unproductive, time-consuming, and laborious (SADC 2016). Apart from its importance in daily life, energy is the lifeblood of infrastructural projects that propel the development process both nationally and regionally. Policymakers across the globe have made energy the fulcrum in the attainment of the global development agenda. Indeed, the African Union's Agenda 2063 framework places energy among the crucial infrastructural bedrocks for achieving economic development and regional integration in the continent (UNEP 2017). On the same lines, the United Nations' Millennium Development Goals 2015 considered energy as the missing link in achieving international development. As if this was not enough, the current Sustainable Development Goals (SDGs) also see energy as an important catalyst for socio-economic development. This is why SDG initiatives, such as Sustainable Energy for All (SE4ALL), seek to promote sustainable global development by promoting access to sustainable and environmentally friendly energy services across the earth by 2030 (UNEP 2017).

Given such worldwide publicity, it is not surprising to learn that the relationship between energy consumption and economic growth continues to draw considerable attention among researchers for empirical research and policymaking in many countries, including both developing and developed countries. From a theoretical point of view, there seems to be a consensus among researchers on the pivotal role that energy consumption plays in socio-economic development and technological progress in many developing regions of the world. In fact, the International Energy Agency buttresses this viewpoint by arguing that though not a panacea to socio-economic challenges, energy is a necessary condition for growth

and transformation in the developing world (International Energy Agency 2002). But despite the above theoretical consensus on the vital role that energy plays in fostering economic growth, the same cannot be said about empirical findings, most of which have unearthed conflicting results in many developing countries. Undeniably, the main bone of contention has been the direction of causality between energy consumption and economic growth. Here, the debate has mainly raged on whether consumption of energy services promotes or hinders or does not have any effect on economic growth (Wolde-Rufael 2006). Payne (2010) has classified the causality relationship between energy consumption and economic growth into four categories. First, he identifies the 'growth hypothesis' which envisages a uni-directional relationship running from energy consumption to growth. This suggests that reducing energy consumption can curtail growth over time. Second, there is the 'conservation hypothesis' which exists when a uni-directional Granger causality runs from economic growth to energy consumption. The policy implication of this finding is that a reduction in energy consumption can easily be achieved with minimal effect on economic growth. Third, Payne proposes the 'feedback hypothesis' which stresses on the fact that a bi-directional causation may exist between energy consumption and economic growth. This proposition simply means that much as increased energy consumption may spur growth, economic growth itself may induce more energy demand. The fourth possibility is the 'neutrality hypothesis' which postulates the possibility of no causal relationship between consumption of energy services and economic growth. In this case, energy conservation policies may not affect growth and vice versa.

Predictably, empirical evidence on the subject in question has been mixed across the globe, reflecting the divergence of the aforementioned hypotheses. Among some of the important studies supporting the 'growth hypothesis' include those done by Stern (1993, 2000), Soytaş and Sari (2003), Oh and Lee (2004), Lee and Chang (2005), Wolde-Rufael (2006), Ang (2007), Lee and Chang (2007), Ho and

Siu (2007), Bowden and Payne (2009), and Kumar and Kumar (2013). On the other hand, the 'conservation hypothesis' is supported by the following studies: Kraft and Kraft (1978), Cheng (1998, 1999), Yoo and Kim (2006), Lise and Van Montfort (2007), Karanfil (2008), Ang (2008), Huang, Hwang, and Yang (2008), Zhang and Cheng (2009), Odhiambo (2009), and Kumar, Stauvermann, Patel, *et al.* (2014). Furthermore, the 'neutrality thesis' is validated by empirical works of researchers including Akarca and Long (1980), Yu and Hwang (1984), Cheng (1995), Fatai, Oxley, and Scrimgeour (2002), Halicioglu (2009), Payne (2009), Soytaş and Sari (2009), and Payne (2011). The feedback or bi-directional causality was found by researchers such as Hwang and Gum (1991), Masih and Masih (1996), Hondroyannis, Lolos, and Papapetrou (2002), Paul and Bhattacharya (2004), Ghali and El-Sakka (2004), Mahadevan and Asafu-Adjaye (2007), Erdal, Erdal, and Esengün (2008), Belloumi (2009), Yoo and Kwak (2010), Ouedraogo (2010), and Shahbaz, Tang, and Shabbir (2011). The above disagreement in the empirical findings can be attributed to differences in structural factors within countries (e.g. economic regulations, demographic differences, and relative sizes of economic sectors), differences in sample sizes, variations in econometric approaches (e.g. Ordinary Least Squares or OLS regressions and cointegration) used, and differences in how the level and composition of energy disaggregation is defined within and among different countries. Notwithstanding this, the diversity in empirical results as well as in the potential that energy consumption has to spur economic development in developing regions calls for not only further research on the topic but also the application of new econometric methods for analysing the energy–growth nexus.

It is against this background that this paper investigates a long-run equilibrium and causal relationship between energy consumption and economic growth in the SADC. The SADC region is one of the fastest growing and most important economic regions in Africa. The region covers 16

countries with the combined gross domestic product (GDP) of approximately US\$ 721.8 billion, total population of 345 million, and total electricity installed capacity of 62,343 megawatts as of 2018 (SAPP 2018). Since 1999, the region has been facing acute energy supply challenges characterized by increased duration and incidences of blackouts as power utilities are struggling to meet growing demand. Besides, the region is also experiencing massive deforestation as a result of excessive demand for fuelwood (SADC 2016). But so far, no known empirical study has been attempted in order to examine the energy–growth nexus in the region as a bloc. This study, therefore, argues that given SADC's economic importance in Africa and the increased demand for energy in the aforementioned region, analysing the above relationship is of significance and an important contribution to the literature. In undertaking this endeavour, the study employs the Westerlund cointegration test and the newly developed Dumitrescu–Hurlin panel causality test. Similarly, Arellano–Bond's generalized method of moments (GMM) procedure is performed on the panel in order to not only obtain short-run causality results but also to ensure robustness of the conclusions. The study prefers cointegration to conventional ordinary regression methods because it not only seeks to eliminate the possibility of conducting spurious regression but also to establish long-run equilibrium relationships between the variables. Thus, cointegration allows the analysis to go beyond identifying correlation and unearthing causation (Enders 2004). But more importantly, perhaps, determination of the direction of causality has important policy implications for the SADC region since it can guide policymakers in deciding whether or not to implement energy conservation policies without hampering the region's economic growth aspirations.

The structure of the paper is arranged along the following lines. Section 1 presents a short introductory background to the topic. Furthermore, a description of analytical framework and empirical methodology used in the study is provided in Section 2. The study's

empirical results are discussed in Section 3. Concluding remarks and policy recommendations are given in Section 4.

Analytical framework and methodology of the study

Analytical model

The study utilizes the neoclassical economic growth model in analysing the relationship between energy consumption and economic growth in the SADC region. Given that the neoclassical economic growth model aims at analysing the determinants of long-run economic growth in both developed and developing countries, and SADC being a developing region, it forms a good basis of analysis. On top of this, with energy being an important driver of economic growth powering technological and infrastructural development and boosting efficiency in production in the SADC region, the neoclassical growth model offers a good analytical framework to examine the energy consumption–economic growth nexus in the aforementioned region. The study follows the neoclassical growth model in utilizing a conventional aggregate Cobb–Douglas production function in order to illustrate the contribution of energy to economic growth.

$$Y = AK^\alpha L^\beta \quad (\text{i})$$

where Y is GDP, K is national capital stock, L is labour force, A is total factor productivity (TFP), and α and β are output elasticities with respect to capital and labour inputs, respectively.

Indeed, national output in the SADC region, just like in other developing regions of the world, is principally produced by a combination of labour of workers and tools that workers use in production (e.g. machines, equipment, and buildings [collectively called physical capital]), and technology. For these factors to work efficiently they need energy.

Taking time differentials yields the following growth equation:

$$gY = gA + \alpha gK + \beta gL \quad (\text{ii})$$

In terms of income (GDP) per capita, growth in per capita income (gY_{pc}) implies growth in output (gY) minus growth in population (gN), which translates to growth in the labour force, that is

$$gY_{pc} = gY - gN = gY - gL \quad (\text{iii})$$

Algebraically, this simplifies to

$$\begin{aligned} gY_{pc} &= gA + \alpha gK + \beta gL - gL \\ &= gA + \alpha gK - (1 - \beta)gL \end{aligned} \quad (\text{iv})$$

Because technology changes the way in which factors of production (that is, capital and labour) are combined to produce output, changes in technology can affect the process of economic growth. A crucial aspect of technological change is that it allows an economy to transcend the limitations imposed by diminishing returns from the factors of production (Weil 2014). This shows that economic growth requires technological improvements to continue producing more output efficiently. Energy is an important ingredient in not only powering the present technology to work efficiently but also in technological improvements to improve present technology and create new technology. Without it, research and development efforts, which bring about technological changes, would not be possible. In economic growth theory, energy consumption (ENERG) boosts TFP by enhancing efficiency and powering technology. The positive contribution of energy to TFP is supported by several empirical studies (e.g. Ebohon 1996; Templet 1999; Toman and Jemelkova 2003; Shahbaz and Lean 2012). With this, therefore, we can capture the positive effect of energy on TFP growth in an economy as follows:

$$gA \equiv g\delta(t) \text{ENERG}^\varphi$$

where $\varphi > 0$.

If φ and $\delta(t)$ represent efficiency and technology, respectively, then substituting $gA \equiv g\delta(t) \text{ENERG}^\varphi$ into equation (iv) generates the following econometric model:

$$\begin{aligned} gY_{pc} &= \omega + \delta(t) + \varphi g\text{ENERG} + \alpha gK \\ &\quad - (1 - \beta)gL + \varepsilon_t \end{aligned} \quad (\text{v})$$

where gY_{pc} is growth in income (GDP) per capita, gL is equivalent to growth in population, ω is regression constant, and ε_t is a random disturbance term or the residual term. ε_t represents other important factors that affect economic growth in the SADC region but have not been explicitly captured by our econometric model. These factors may include institutions, human capital, economic policies, and global/international factors such as prices of petroleum and export prices, among others.

In line with standard economic growth theory, it can be expected that $\varphi > 0$, $\alpha > 0$, and $(1-\beta) < 0$.

Data used in the study

As alluded earlier, the study covers 15 countries from the SADC region for the period 1990–2015. These countries are Angola, Botswana, Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe. These countries were chosen largely based on the availability of annual data. All the data are obtained from the World Bank's World Development Indicators 2015 (<http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators>). Furthermore, economic growth is measured by per capita income growth per year ($gDPPC$) and energy consumption is approximated commercial energy use in kilograms of oil equivalent per person as a percentage of the GDP ($gENERG$). But given that there are other important factors such as capital and labour force that affect economic growth as illustrated by the standard neoclassical economic growth theory, omission of these variables may lead to simultaneity bias as is well known in econometric circles (Gujarati and Porter 2009). This being the case, we incorporate capital formation and labour as control variables in the model. Data for growth in capital and labour force, which are measured as annual gross capital formation as percentage of GDP ($gCAP$) and annual growth in working-age population ($gWAP$), respectively, are also obtained from World Development Indicators 2015. The World

Bank takes working-age population aged between 15 and 65 years old. It must also be pointed out that choice of the sample period is based on the fact that the beginnings of SADC as an active economic bloc can be traced to the early 1990s and, as such, economic integration and harmonization of energy policies of member states also began during the same period.

Empirical results

Fisher-type unit root test

Before any analysis can be performed on the panel data, Fisher-type unit root tests need to be conducted in order to remove the possibility of running spurious regression due to non-stationarity of the data. The possible sources of unit roots are that the data series has an infinite variance, which depends on time, and that the effects of its shocks do not dissipate over time. It may also be that the series does not exhibit mean reversion wherein it does not fluctuate around a constant long-run mean. Maddala and Wu (1999) proposed a Fisher-type unit root test (ρ_λ), which is simply derived from combining the p -values of the test statistic for a unit root in each cross-sectional unit. The test begins by letting φ_i to be the p -value from the i th-test such that φ_i are $U[0, 1]$ and $-2\log_{epi}$ independent, and has a χ^2 distribution with 2 degrees of freedom. In the analysis that follows $\rho_\lambda = -2\sum_{i=1}^N \log_{epi}$, the test has a χ^2 distribution with $2N$ degrees of freedom. Furthermore, null and alternative hypotheses for the Fisher-type unit root tests are similar to those of other panel unit root tests. Additionally, by estimating the augmented Dickey–Fuller (ADF) or Phillips–Perron (PP) equation for each panel, an ADF or PP t -statistic for each individual time series can be obtained. This procedure can also be used to calculate not only corresponding p -values (obtained by Monte-Carlo simulation) but also Fisher-test statistics, which can thereafter be compared against appropriate χ^2 critical values. The Fisher test as proposed by Maddala and Wu (1999) has two important advantages that make it superior to other panel unit root tests. The first advantage is that it can easily be executed

in unison with any other panel unit-root test on a single time-series. Moreover, this test is unlike other panel unit-root test, does not require a balanced panel, and as such the value of T can vary with cross-sections. Table 1 presents results of the Fisher-type panel unit-root tests based on the PP framework.

From the above table it can be deciphered that the majority of the series are non-stationary (that is, have unit roots) in levels. The possible sources of unit roots are that the data series has an infinite variance, which depends on time, and that the effects of its shocks do not dissipate over time. It may also be that the series does not exhibit mean reversion, wherein it does not fluctuate around a constant long-run mean. After first differencing, all the series become stationary, that is, integrated of order one, $I(1)$, and this eliminates unit roots.

Westerlund cointegration test

The next step after removing unit roots from the panel is the determination of cointegration or long-run relationship between variables. Westerlund (2007) developed four panel-based cointegration tests to detect the presence of a long-run equilibrium relationship between variables. The basic idea behind the test is to examine the absence of cointegration by proving that an error correction mechanism (ECM) exists for either the panel as a whole or for individual panel members. A typical depiction of the error

correction model is illustrated in a situation where all the variables are in levels, that is, integrated of order one, $I(1)$ as follows:

$$\Delta y_{it} = \omega_i + \alpha_{i1} \Delta y_{it-1} + \alpha_{i2} \Delta y_{it-2} + \dots + \alpha_{ip} \Delta y_{it-p} + \beta_{i0} \Delta x_{it} + \beta_{i1} \Delta x_{it-1} + \dots + \beta_{ip} \Delta x_{it-i} + a_i (y_{it-1} - \beta_{i1} x_{it-1}) + \varepsilon_{it}$$

α_i gives an estimate of the speed of error correction or adjustment towards the long-run equilibrium $y_{it} = -(\beta_i/\alpha_i) \times x_{it}$ for the i th series. Furthermore, G_a and G_t are simply test statistics that assess the null hypothesis $H_0: \alpha_i = 0$ for all i against an alternative hypothesis $H_1: \alpha_i < 0$ for at least one i . In addition, P_a and P_t are test statistics which pool information across all the available cross-sectional units with an aim of testing $H_0: \alpha_i = 0$ for all i against $H_1: \alpha_i < 0$ for all i members. On the other hand, rejection of H_0 indicates that cointegration is available for the panel as a whole. An important advantage of the Westerlund test relative to other cointegration tests is that it is not only flexible but also enables heterogeneous specification of both the long- and the short-run facets of the ECM. Additionally, the aforementioned test also works well with both balanced and unbalanced panel data. This method is well suited to the available data that the study will use for SADC. The dataset is unbalanced with some countries having no observations in some years.

Against this background, the study utilizes the Westerlund test in order to determine the existence of a long-run equilibrium relationship (i.e. cointegration) between energy consumption

Table 1 Fisher-type unit root tests

Method	Variables (in levels)	Test statistic (<i>p</i> -value)	Variables (first differenced)	Test statistic (<i>p</i> -value)
Fisher-type (Phillips–Perron)	<i>gGDPPC</i>	−6.1166 (0.0000)	$\Delta gGDPPC$	−15.3956 (0.0000)
	<i>gWAP</i>	0.2886 (0.6135)	$\Delta gWAP$	−5.0551 (0.0000)
	<i>gCAP</i>	−12.4998 (0.0000)	$\Delta gCAP$	−10.6602 (0.0000)
	<i>gENERG</i>	0.3754 (0.6463)	$\Delta gENERG$	−10.6591 (0.0000)

Source: Author's own analysis using Stata

and per capita income growth. Results of the Westerlund panel cointegration method are given in Table 2.

From the above table it can be clearly visualized that there is no cointegration between energy consumption and per capita income growth in both low- and middle-income countries. This simply indicates that no long-run equilibrium relationship exists between the aforementioned variables. For instance, electricity demand in the SADC region has been on the rise for the past two decades so much so that since 2008 the demand has outstripped the supply resulting in electricity blackouts throughout the region. The SADC Energy Monitor 2017 estimates that regionally electricity demand has been growing at an average rate of 3% per annum (SADC 2017). On the other hand, economic growth rate in the SADC region has been fluctuating. The African Development Bank observes that despite SADC's economic size, its GDP growth has been sluggish, falling from 4% in 2010 to about 1.2% in 2018, with projected growth of around 2.2% in 2019 and 2.8% in 2020, lower than in other African regions (The African Development Bank 2019). This suggests that energy consumption and economic growth do not always move together overtime in the SADC region hence no long-run equilibrium relation between the two variables exists. However, even in the absence of cointegration, Granger causality can still be performed on the panel using vector auto-regression method (Hurlin and Venet 2008; Dumitrescu and Hurlin 2012).

Generalized methods of moments procedure

Successful conduction of cointegration enables the study to undertake causality tests. In order to test for short-run causality, the GMM estimation procedure as outlined by Arellano and Bond (1991) is applied to the panel data for 15 SADC member states using annual observations for each country. Similarly, the SADC countries are grouped into low- and middle-income categories according to the World Bank income classification as illustrated in the Appendix. This categorization assists in determining whether differences in income levels affect the energy–growth nexus in the SADC region. The estimated system is of the following form as determined by the analytical framework in Section ‘Analytical Model’.

$$\Delta GDPPC_{it} = \sum_{j=1}^m \gamma_{1j} \Delta GDPPC_{it-j} + \sum_{j=1}^m \gamma_{2j} \Delta gENERG_{it-j} + \sum_{j=1}^m \gamma_{3j} \Delta gCAP_{it-j} + \sum_{j=1}^m \gamma_{4j} \Delta gLAB_{it-j} + \Delta \varepsilon_t$$

$$\Delta gENERG_{it} = \sum_{j=1}^m \delta_{1j} \Delta gENERG_{it-j} + \sum_{j=1}^m \delta_{2j} \Delta gGDPPC_{it-j} + \sum_{j=1}^m \delta_{3j} \Delta gCAP_{it-j} + \sum_{j=1}^m \delta_{4j} \Delta gLAB_{it-j} + \Delta \varepsilon_t$$

As already alluded to, *gENERG* denotes energy consumption growth, *gGDPPC* represents growth in GDP per capita, *gCAP* is growth in capital stock, and *gLAB* is labour force growth, which is equivalent to growth in working-age population

Table 2 Westerlund error correction mechanism panel cointegration test results

Low-income SADC countries				Middle-income SADC countries		
H_0 : no cointegration				H_0 : no cointegration		
Statistic	Value	Z-value	p-value	Value	Z-value	p-value
G_t	−2.334	−2.609	0.005	−1.993	−2.394	0.008
G_a	−2.534	0.558	0.712	−1.249	1.375	0.915
P_t	−2.322	−1.115	0.133	−1.420	−0.145	0.442
P_a	−1.255	−0.158	0.437	−1.149	−0.104	0.459

SADC: Southern African Development Community

Source: Author's own analysis using Stata

(*gWAP*). Furthermore, $i = 1, 2, 3, \dots, 15$ represents countries, and $t = 1, 2, 3, \dots, 26$ captures the number of years. Results of the GMM estimation procedure are reported in Table 3.

In low-income SADC countries a unit percentage increase in energy consumption results in a 7.39% increase in the level of per capita income growth and the result is statistically important at all levels of significance (10%, 5%, and 1%). This indicates that in the short run, energy consumption is a strong contributor to economic growth. This finding seems to render support to the fact that energy is one of the key enablers of sustainable development in southern Africa and that intermittent power shortages have been experienced across the region for the past decade and, if not permanently addressed, could hinder the regional road map towards higher industrial production and economic growth (EPF and SAIIA 2015). Furthermore, a 1% expansion in capital formation triggers a 0.128% surge in income growth, but the result is only significant at 10% level. This is supported by neoclassical economic theory predictions that physical capital accumulation boosts economic growth. However, the smaller

statistical significance could be a reflection of low saving rates in many low-income SADC countries such as Malawi, Tanzania, Mozambique, Democratic Republic of Congo, and Zimbabwe, which limit capital accumulation and, thus, lower economic growth rates (UNECA 2018). On the other hand, working-age population growth results in the decline in per capita income growth at 10% significance level. Rapid population growth rates common in many SADC countries reduce the amount of physical accumulation/investment since a sizeable percentage of national resources is spent on taking care of increased social needs or a rising population rather than on productive investments. Also, lagged values of per capita income have an insignificant effect on the present economic growth in the short run. This suggests that economic growth from previous period is not an important determinant on current growth.

Now turning to middle-income SADC member states, a 1% surge in energy consumption generates a corresponding 0.988% increase in economic growth and the result is statistically significant at 5% level. This suggests that energy consumption is an important driver

Table 3 Generalized methods of moments short-run effects results for low- and middle-income Southern African Development Community countries from 1990 to 2015

Dependent variable: GDP per capita growth		
Independent variables	Low-income SADC countries	Middle-income SADC countries
$gGDPPC_{t-1}$	-0.024 (0.083)	-0.161 (0.191)
$gCAP$	0.128* (0.098)	0.553* (0.119)
$gWAP$	-4.678* (2.658)	-2.164** (0.885)
$gENERG$	7.386*** (2.500)	0.988** (0.120)
Constant	-38.527*** (13.032)	-5.235 (21.555)

* $p < 0.01$

** $p < 0.05$

*** $p < 0.001$

SADC: Southern African Development Community

Note: Standard errors are in parentheses

of economic growth in the aforementioned countries. In many middle-income countries that are mineral dependent, such as South Africa, Botswana, Namibia, and Zambia, power shortages have played a significant role in reducing mineral production (which is mostly energy intensive) in the last five years thereby leading to slower economic growth rates (AfDB 2019). Likewise, the study finds that capital formation has a positive effect on the level of economic growth even though the result shows statistical significance at only 10% level. This is supported by an economic theory that suggests that high investment increases physical capital accumulation, which in the end boosts economic growth. However, a working-age population growth of 1% generates 2.194% decrease in per capita income in the short run. Thus, rapid population growth necessitates governments to spend more on social needs rather than on productive investments, which can boost growth. Furthermore, lagged values of per capita income have a negative, albeit insignificant effect on economic growth at all levels of significance in these middle-income SADC economies. This suggests that economic growth from previous periods is not an important driver of current growth in middle-income SADC countries.

Direction of causality: Dumitrescu–Hurlin Granger causality test

Having examined unit roots and cointegration, it is important to determine the direction of causality of the energy consumption–economic growth nexus in the SADC region. Establishing the direction of causality issue is more important than ever before in this present age where there are concerns regarding the contribution of energy and growth to global warming and climate change. SADC countries, just like other developing nations across the globe, are struggling to find the right policy balance that optimizes energy consumption levels thereby reducing pollution levels (i.e. carbon dioxide emissions) but at the same time encourages real income growth. Therefore, determining the direction of causality can certainly help to solve this jigsaw puzzle. If

causality is found to run from energy consumption to per capita income growth, then this indicates that a shortage of energy will have detrimental impact on economic growth. But, if there is reverse causality running from growth to energy consumption then energy conservation policies will encourage income growth over time. In order to accomplish the same in the SADC region, we employ Dumitrescu–Hurlin (2012) causality tests on a panel of low- and middle-income SADC countries. The typical Dumitrescu–Hurlin method for testing panel causality can be illustrated using the following regression equation:

$$y_{i,t} = \varphi_i + \sum_{k=1}^k \vartheta_{ik} y_{i,t-k} + \sum_{k=1}^k \pi_{ik} x_{i,t-k} + \varepsilon_{i,t}$$

where $x_{i,t}$ and $y_{i,t}$ are the observations of the two variables that do not have unit roots (i.e. stationary variables) for individual i in period t . Furthermore, even though the coefficients (ϑ and π) may vary across individual panel but they do not vary over time. This fact is illustrated by the i subscripts attached to the coefficients. Apart from requiring the balanced panel data, the Dumitrescu–Hurlin test also assumes the lag-length order K to be identical for each and every individual. Just like in the conventional Granger causality test (1969), the Dumitrescu–Hurlin procedure is also a potent method for determining the existence of significant causal effects of past values of an independent variable (x) on the present value of a dependent variable (y) (Dumitrescu and Hurlin 2012).

Table 4 presents the results of the Dumitrescu–Hurlin causality tests for low- and middle-income SADC countries. The optimal lag length in both the groups of the countries is 3 as selected by Akaike information criteria.

It is clear from the above table that a feedback or bi-directional relationship exists between energy consumption and per capita income growth in both low- and middle-income SADC countries. This suggests that increase in the growth rate of per capita incomes may demand increased utilization of energy supply, but at the same time, more energy use may induce an expansion in per capita incomes over a

Table 4 Dumitrescu–Hurlin panel Granger causality tests for low- and middle-income Southern African Development Community countries

Null hypothesis (H_0)	Optimal lags chosen by AIC	Test statistics		p -value	Conclusion
		W-Stat	Z-bar Stat		
<i>Low-income SADC countries</i>	3				
$gENERGD_1$ does not Granger-cause $gGDPPCD_1$		12.6221	3.8233	0.0001	Reject H_0
$gGDPPCD_1$ does not Granger-cause $gENERGD_1$	3	116.8218	63.9830	0.0000	Reject H_0
<i>Middle-income SADC countries</i>					
$gENERGD_1$ does not Granger-cause $gGDPPCD_1$	3	79.5216	51.9876	0.0000	Reject H_0
$gGDPPCD_1$ does not Granger-cause $gENERGD_1$	3	81.5135	53.3961	0.0000	Reject H_0

D1 represents first-differenced series

AIC: Akaike information criteria; SADC: Southern African Development Community

Source: Author's own analysis using Stata

period in both low- and middle-income SADC member states. In this case, one can conclude that energy consumption and economic growth are complementary to each other in the aforementioned countries. The policy implication of this finding is that it may be prudent for SADC countries to vigorously pursue demand-side management (DSM) measures and energy-efficiency initiatives to reduce demand and allow power and energy savings realized to be channeled to productive sectors and stimulate economic growth. These DSM and energy-efficiency measures include replacement of incandescent bulbs with compact fluorescent lamps (CFLs), commercial lighting (CL), and solar water heater geysers (SWH).

The Sargan test for over-identifying restrictions

The study proceeds to perform the Sargan test for over-identifying restrictions on the panel data. Basically, this is a test to determine whether the instrumental variables used in the analysis are

valid. The null hypothesis the test examines is that the instrumental variables are not correlated with the residuals and can, therefore, be applied in estimation. The Sargan statistic follows a chi-square distribution if the null hypothesis holds. In Table 5 it can be seen that when lagged values of the variables are employed as instruments, the Sargan test accepts the null hypothesis that the instruments used in the model are valid. With Stata software it is shown that the Prob > χ^2 value is greater than the p value (0.05).

Table 5 Sargan test for over-identifying restrictions

H_0 : Over-identifying restrictions are valid	
Chi ² (52)	52.32119
Prob > χ^2	0.4614

Source: Author's own analysis using Stata

Wooldridge test for autocorrelation

Finally, the study checks for autocorrelation in the panel models for low- and middle-income SADC countries in order to ensure robustness of the results. Indeed, given that autocorrelation or serial

correlation in panel–data models biases standard errors and causes inefficiencies in the estimated regression results, it is important to detect serial correlation in the error term and remedy it if possible (Drukker 2003). A standard procedure for testing for panel data autocorrelation is the Wooldridge (2002) test, which is applicable under general OLS conditions and is easy to perform. In Stata, this test is computed by simply comparing the computed F -value against the p -value (0.05). If the former value is greater than the latter, the null hypothesis of no autocorrelation is accepted and vice versa. Wooldridge test results for the two panel models, which are presented in Table 6, clearly indicate that there is no autocorrelation in both the models.

Table 6 Wooldridge test for autocorrelation

Low-income SADC countries		Middle-income SADC countries	
H_0 : No first-order autocorrelation		H_0 : No first-order autocorrelation	
$F(1, 3)$	5.665	$F(1, 4)$	2.295
Prob > F	0.0976	Prob > F	0.2043

SADC: Southern African Development Community

Source: Author's own analysis using Stata

Summary and concluding remarks

The study was principally aimed at examining the relationship between energy consumption and economic growth in the SADC region during the period 1990–2015. In this endeavour, the study utilized the neoclassical economic growth model to analyse the economic growth–energy consensus in the SADC region. Given that the model aims at analysing the determinants of long-run economic growth in both developed and developing countries and SADC being a developing region, it forms a good basis of analysis. Moreover, with energy being an important driver of economic growth and powering technological and infrastructural development and boosting production efficiency in the SADC region, the neoclassical growth model offers a good analytical framework to examine the energy consumption–economic

growth nexus in the aforementioned region. Furthermore, the period under consideration 1990–2015 provides a good time period to examine long-run economic growth. Following the neoclassical framework, energy in combination with traditional economic growth-generating factors such as capital and labour, formed the study's theoretical foundation. Furthermore, panel cointegration and causality procedures were employed as the main empirical methods for analysing time-series properties of the variables in question.

Based on the empirical results, the study concludes that there exists no long-run equilibrium association (i.e. cointegration) between energy consumption and per capita income growth in both low- and middle-income SADC countries. Nevertheless, in the short run, a positive and statistically significant relationship was found between the two variables. But more importantly, perhaps, a bi-directional/feedback relationship between energy consumption and economic growth was also detected in both low- and middle-income SADC member states. This suggests that increased levels of economic growth boost demand for energy in the SADC countries. Likewise, an increase in energy consumption drives aggregate per capita income growth over time. Additionally, working-age population growth (representing labour force growth) and capital formation have negative and positive significant effects, respectively, on per capita income growth in the region.

The study's findings suggest important policy implications for the region. The first policy implication is that in view of the bi-directional causality finding, it may be prudent for SADC countries to vigorously pursue DSM measures and energy-efficiency initiatives in order to reduce demand and allow power and energy savings realized to be channelled to productive sectors and stimulate economic growth. These DSM and energy-efficiency measures, which include replacement of incandescent bulbs with CFLs, CL, and SWH, are already in place in many SADC countries such as Zimbabwe, Zambia, Malawi, and South Africa even though

the measures vary from one country to another depending on the magnitude of the imbalance between energy demand and energy supply (SADC 2018).

Furthermore, SADC countries need to increase their efforts aimed at encouraging their firms and industries to adopt clean technologies, such as solar photovoltaics (PVs) and wind energy technologies, which ensure energy efficiency and reduce pollution. SADC countries such as Botswana, Malawi, Namibia, Swaziland, Tanzania, and Zimbabwe are developing large-scale solar PV projects while South Africa continues to be a leader in wind technology in the SADC region. These clean technologies have the potential to promote sustainable energy consumption and drive environmentally friendly economic growth in the region. If SADC governments implement subsidies and other economic incentives to suppliers and manufacturers of clean energy technologies, then this will stimulate the uptake of renewable energy products and technologies that promote 'green' economic growth. Such measures include making it compulsory for the electricity industry to purchase renewable energy or supply a certain proportion of their energy from renewable sources as well as the development of guaranteed markets.

The empirical results also reveal that it may not be prudent for both low- and middle-income SADC countries to adopt and, indeed, implement similar energy conservation measures such as promotion of energy-saving or fluorescent lights and encouraging the use of SWHs in residential areas and promoting commercial energy-efficient lighting (SADC 2016). Instead of taking a one-size-fits-all approach each member country should adopt energy conservation strategies that suit its own peculiar socio-economic and environmental characteristics.

Still on the empirical side, the bi-directional causality also suggests that researchers interested in analysing the energy consumption–growth nexus in the aforementioned region need to be cautious when employing single-equation

methods in their assessment and making forecasts and inferences on the same. Indeed, the possible endogeneity existing between the variables that has been exposed by the panel Granger causality tests clearly reveals that reliance on single-equation methods may generate misleading empirical results and, hence, bad policy prescriptions on both energy and economic development.

But all in all, it is worth noting that the above recommendations on the direction of causality provided in this discussion are only suggestive. It may be worthwhile for researchers and policymakers to conduct further research on the topic in question. Further research can concentrate on empirically ascertaining other important factors such as energy prices that affect the energy consumption–economic growth nexus in the region and may also be responsible for the observed disparity in the causality effects between low- and middle-income SADC countries.

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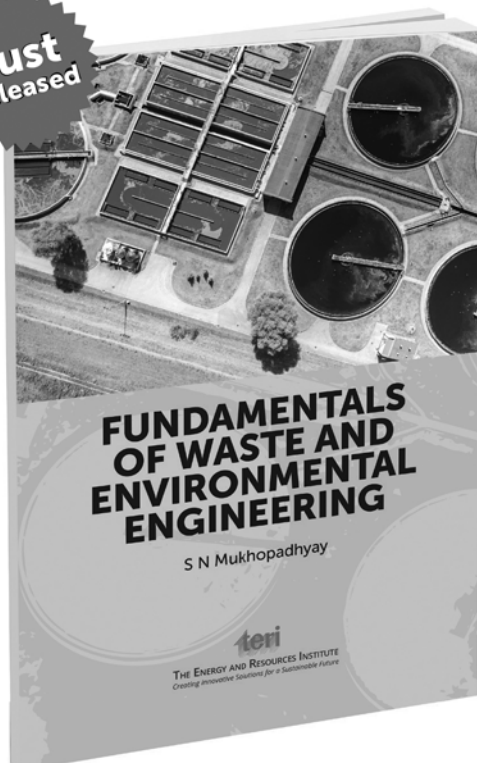
Appendix

Low-income SADC countries	Middle-income SADC countries
Democratic Republic of Congo Malawi Tanzania Mozambique Madagascar Zimbabwe	Angola Botswana Lesotho Mauritius Namibia Seychelles South Africa Swaziland Zambia

SADC: Southern African Development Community

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Assessing the Impact and Cost-Effectiveness of Electric Vehicle Subsidy in India

Aravind Harikumar^{a,*} and Palak Thakur^a

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Introduction
FAME-II
Methodology and Assumptions
Impact of FAME-II
Cost-effectiveness of EV Subsidy
Allocation
Conclusion
References

ABSTRACT

The paper assesses the potential impact of the national electric vehicle (EV) subsidy scheme and the cost-effectiveness of the allocation of the subsidy for different vehicular segments in reducing carbon dioxide equivalent emissions. The results show that even though the impacts are positive, most of the allocated subsidy is spent on switching the most-efficient mode into electric.

Keywords: Electric vehicles, Subsidy, Cost-effectiveness, Carbon emissions, E-mobility, Sustainable mobility

^a The Energy and Resources Institute (TERI), New Delhi, India

* Corresponding author: h.aravind@teri.res.in

Introduction

The world is undergoing a major transition with respect to the automobile sector. With the global advent of electric mobility, India is also not behind with its strong policies and schemes supporting the shift to clean technologies. The road map for this paradigm shift to electric mobility was laid with the National Electric Mobility Mission Plan 2020, which has a vision of facilitating sales of 6–7 million units of electric vehicles (EVs) in India by 2020 (DHI 2012). In order to execute the plan, FAME (Faster Adoption and Manufacture of Hybrid and Electric Vehicles) India scheme was launched by the Ministry of Heavy Industries and Public Enterprises in 2015. The aim of the scheme was to incentivize the production and promotion of hybrid and EVs (DHI 2015). The scheme was a success with the demand incentives being completely utilized and the scheme being extended till March 2019 with additional outlay (PIB 2018). The Department of Heavy Industries (DHI) recently launched FAME-II with ten times the financial resources allocated in FAME-I for faster adoption of EVs (DHI 2019). Similar to FAME-I, a major chunk of the ₹ 10,000 crore allocated under FAME-II is for demand incentives for EVs. The subsidy scheme has varied fund allocations for vehicular segments of two wheelers (2W), three wheelers (3W), four wheelers (4W), and buses. This paper critically analyses the FAME-II scheme, with the following two objectives:

1. Quantify the benefits of FAME- II scheme in terms of savings of air pollutants and carbon dioxide (CO₂).
2. Assessing the cost-effectiveness of the allocation of FAME subsidy among different vehicular segments in reducing CO₂ equivalent emissions.

This paper is divided into four sections. The first section briefly describes the FAME-II scheme, how it has changed from the first phase, the allocation of funds among different vehicular segments, and the parameters for selection of the eligible vehicle models and their subsidy levels. The second section explains the methodology followed in this paper for quantifying the benefits

of FAME-II and assessing the cost-effectiveness of the subsidy allocation in different vehicular segments. The third section quantifies the amount of potential savings in terms of reduction in vehicular exhaust emissions including carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), methane (CH₄), ammonia (NH₃), and particulate matter (PM) from deployment of all the eligible vehicles under FAME-II. This section also quantifies the overall expected benefits in terms of CO₂ equivalent units. The fourth section attempts to assess the cost-effectiveness of the overall subsidy allocation for different vehicular segments in reducing CO₂ equivalent emissions. In simpler terms, this section will assess if the subsidy allocated for a particular vehicular segment is worth the monetized savings of CO₂ equivalent vehicle exhaust emissions. The fifth section concludes the results and recommends alternative decisions for increasing the benefits and effectiveness of the FAME-II scheme.

FAME-II

In this section, the subsidy schemes, FAME-I and FAME-II, are being discussed. Figure 1 briefly indicates the allocation of the budget under various heads.

The FAME-I scheme was launched in 2015 for a period of 3 years with an overall budget of ₹ 795 crore. It was later extended up to March 2019 with an additional allocation of ₹ 100 crore.

FAME-I was offering variant-wise subsidy for market creation under the demand incentive to 2W (with both more than and less than 250 W), 3W (L5 category), 4W (M1 category), light commercial vehicle (LCV) (N1 category), and buses (M3 category)¹. Mild hybrids, strong hybrids, plug-in hybrids, and pure electric technologies were covered under the scheme with highest subsidy being allocated to the pure EVs. The subsidy was given to both advanced and conventional battery vehicles. The retrofitted vehicles under the categories M1, M2, and N1 were also given subsidy within FAME-I.

¹ The vehicle categories are as per Central Motor Vehicle Rules (ARAI 2016)

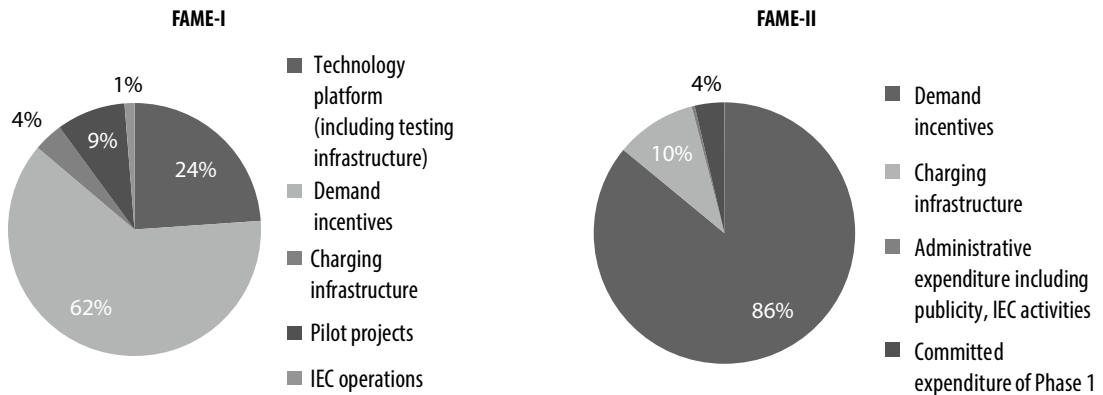


Figure 1 Fund allocation under FAME-I and FAME-II

The demand incentive was proposed in two levels: Level 1 and Level 2, with Level 2 being the improved fuel consumption. In principal, Level 2 incentive was around 120% of Level 1 incentive. The utilization of FAME-I subsidy was limited to major urban agglomerations with million-plus population, state capitals, northeastern cities, and smart cities.

Other than higher allocation for demand incentives, there has been a considerable change in the FAME-II scheme with respect to the type of vehicles included and subsidy mechanism for the same. See Figure 3. The FAME-II scheme plans to spend an overall sum of ₹ 10,000 crore, of which 86% will be allocated for demand incentives. The scheme is committed to pure electric segments such as electric buses, electric 3W (including e-rickshaw), electric 2W except the 4W category, which covers electric and plug-in hybrid and strong hybrid. Unlike FAME-I, which offered variant-wise subsidy, FAME-II provides uniform incentive of ₹ 10,000/kWh to all the vehicles (including pure hybrid EV and strong hybrid) except buses. For buses, the uniform maximum demand incentive of ₹ 20,000/kWh has been allocated. However, there is a limit on the number of vehicles eligible for incentives in each vehicular segment. The DHI targets to subsidize 10 lakh electric 2W, 5 lakh electric 3W, 35,000 electric cars, 20,000 strong hybrid cars (SH 4W), and 7090 hybrid/electric buses (see Figure 2). There

is also cap on maximum incentive per vehicle. The cap on incentive of buses will be 40% of the cost of vehicle and 20% for all other categories. The target of the FAME subsidy is to bring down the cost of battery and accordingly demand incentive is based on battery capacity. However, the FAME-II incentive is limited to vehicles with advanced batteries only. This means that many of the electric 2W (low-speed conventional battery) sold in the initial phase of FAME-I are not eligible in FAME-II. Additionally, FAME-II also proposes to provide funds for one slow charger per electric bus and one fast charger for every 10 electric buses. It also provides flexibility of funding 100% charging infrastructure depending upon the proposed project.

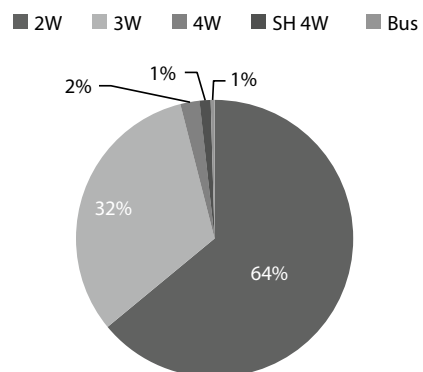


Figure 2 Vehicles targeted under FAME-II

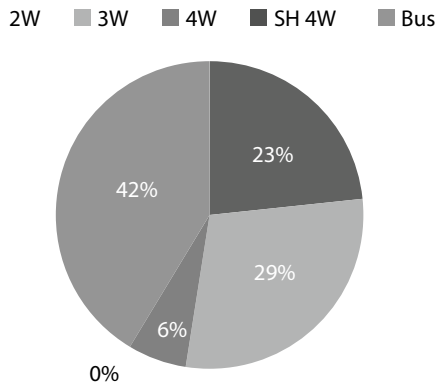


Figure 3 Segment-wise fund allocation in FAME-II

Methodology and assumptions

The impact of FAME-II is quantified by calculating the conventional vehicle kilometres replaced by EV kilometres. The paper attempts to understand the effectiveness of each subsidy segment in reducing carbon emissions with an assumption that all the eligible vehicles under FAME-II are deployed by 2022. The assessment of overall savings in terms of equivalent emissions is done assuming there is no modal shift due to the subsidy as it is a scheme for faster adoption of a cleaner technology and not a cleaner mode. The emissions saved are estimated based on the standards/limits prescribed under BS VI notification by Automotive Research Association of India (ARAI 2018). The paper has quantified the impact of FAME-II assuming that EVs are replacing BS VI compliant vehicles. The impact is estimated over the lifetime of the replaced vehicle. The methodology used for estimating greenhouse gas (GHG) emissions is in line with the refined guidelines on national GHG inventories by Intergovernmental Panel on Climate Change (IPCC 2019).

Vehicle operational assumptions

Let i be the set of all vehicular segments, such that $i = \{2 \text{ wheeler}, 3 \text{ wheeler}, 4 \text{ wheeler}, \text{buses}\}$. Similarly, let j be the set of fuel types, such that

$j = \{\text{petrol, diesel, CNG, LPG}\}$. Let L_i be the lifetime of vehicle in years and D_i be the average distance covered per day. Table 1 summarizes the assumption made on daily operations and lifetime of vehicles eligible under FAME-II.

Table 1 Vehicle operational assumptions

Vehicular segment (i)	Lifetime in years (L_i)	Distance per day (D_i)
2 Wheelers	15	30
3 Wheelers	20	120
Commercial 4 Wheelers	20	266
Buses	15	200

Fuel-efficiency assumptions

Let E_{ij} denote the average fuel efficiency in kilometre per litre for an individual vehicle of fuel type ' j ' in vehicular segment ' i '. Table 2 shows the assumption regarding the efficiency of different mode–fuel pairs considered in the assessment.

Table 2 Fuel-efficiency assumptions

Fuel type (j)	Vehicle type (i)	Fuel efficiency (E_{ij}) km/l
Petrol	2 Wheelers	60
Petrol	3 Wheelers	35
CNG	3 Wheelers	49
LPG	3 Wheelers	28
Diesel	3 Wheelers	18
Petrol	4 Wheelers	18
Diesel	4 Wheelers	18
CNG	4 Wheelers	30
LPG	4 Wheelers	12
Diesel	Bus	4
CNG	Bus	3

CO₂ emission factors

CO₂ equivalent emissions are often used for accounting GHG emissions as per IPCC guidelines. This paper uses recent India-specific emission factors from fuel consumption in transport (WRI 2015). Let C_j denote the CO₂ emissions in kilograms per litre consumption of fuel type ' j '. Table 3 shows the values taken in assessing the kilograms of CO₂ released into the atmosphere from the vehicle exhausts for every unit of fuel consumed in India.

Table 3 Carbon dioxide emission factors

Fuel type (j)	CO ₂ equivalent emissions factors kg/l (C_j)
Diesel (WRI 2015)	2.60
Petrol (WRI 2015)	2.30
CNG (WRI 2015)	3.01
LPG (ARAI 2006)	1.64

Vehicular kilometres saved

Let V_{ij} denote the number of vehicles in a section by fuel type of a vehicular segment, for example, the number of petrol-powered two wheelers. Hence, $\sum_{j=1}^n V_{ij}$ is the total number of vehicles in vehicular segment ' i ' and $\sum_{i=1}^n V_{ij}$ is the total number of vehicles of fuel type ' j '.

$$VKM_{ij} = \frac{V_{ij}}{\sum_{j=1}^n V_{ij}} \times D_i \times 365 \times L_i$$

The above equation gives the conventional VKM saved from the vehicles operating on fuel type ' j ' in vehicular segment ' i '.

Fuel consumption saved (in litres)

Fuel saved was estimated from the vehicular kilometres saved. The total vehicle kilometres saved by a vehicle divided by the efficiency of that vehicle will give the fuel consumption saved by the vehicle.

$$\text{Fuel saved}_{ij} = \frac{VKM_{ij}}{E_{ij}}$$

The above equation gives the fuel saved for each vehicle or ' ij ' category.

$$\text{Total fuel saved}_j = \sum_{i=1}^n \text{Fuel saved}_{ij}$$

The above equation gives each type of fuel saved. In other words, the above equation will show how many litres each were saved of petrol, diesel, CNG, and LPG.

CO₂ kg saved

From the estimate quantity of each fuel-type saved, the expected savings of CO₂ kilograms were calculated.

$$\text{Total CO}_2 \text{ kg saved} = \sum_{j=1}^n (C_j \times \text{Total fuel saved}_j)$$

Similarly, by summing across the CO₂ emissions saved from all fuel types for each vehicular segment, the benefit from each segment is calculated. Dividing the incentive allocation by the CO₂ saved gives the incentive per kilogram of CO₂ saved.

Impact of FAME-II

Epidemiological and toxicological studies indicate a number of negative health outcomes due to exposure to vehicular emissions, including mortality, respiratory morbidity, symptoms like asthma, cardiovascular morbidity, and cancer (Heinrich, Schwarze, Stilianakis, *et al.* 2005). The arrival of hybrid and EVs in the road transport sector is expected to reduce the negative effects of air pollution and subsequently the health risk to urban citizens. This paper assesses the potential impact of FAME-II if it successfully leads to the sale of the target number of EVs in the 3-year period. The projected vehicular kilometres saved from each subsidy segment

was used for calculating the potential reduction in pollutants including CO, HC, NO_x, CH₄, NH₃, and PM. Figure 4 displays the kilograms of expected pollution avoided by each vehicular segment eligible in FAME-II.

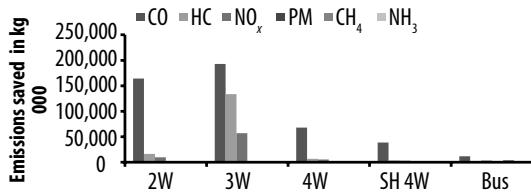


Figure 4 Exhaust emissions saved from FAME-II

A total of 75% of the expected saved is due to uptake of electric 2Ws and 3Ws. The expected uptake of electric 3Ws will also be responsible for 82% of the hydrocarbon emissions saved. The major contribution to reduction of CO, HC, and NO_x has been from the expected uptake of electric 3W. The adoption of electric 2W is also expected to reduce CO, HC, and NO_x emissions by 164 million kg, 16 million kg, and 10 million kg, respectively. The major savings from the eligible 7090 buses will be in terms of reduced PM, CH₄, and NH₃ emissions from vehicle exhausts. As the emissions expected to be reduced by electrification of each vehicular segment cannot be summed across the pollutants, it is difficult to ascertain from these results the cost-effectiveness of EV subsidy allocation for various segments in reducing pollution. Further, the pollutants also have varied effects on human health subject to various other factors (Heinrich, Schwarze, Stilianakis, *et al.* 2005). Hence, from the vehicle kilometres saved from conventional fuels, this paper also estimates the savings of equivalent emissions from the FAME-II scheme.

Our results show an estimated savings of 67.79 million tonne of gross CO₂ from successful utilization of the allocated demand incentives offered for EVs by the Government of India, as shown in Figure 5. The major chunk (61%) of the emissions to be saved is expected to come from the 3W segment and the least savings (8%) are expected from buses. This is in contrast to

the funds allocated for buses in the scheme. A segment that has been allocated 42% of the funds will save only 8% of the expected CO₂ equivalent savings from the entire scheme.

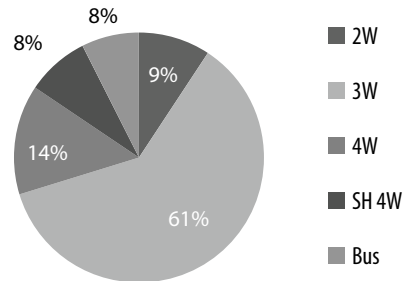


Figure 5 Carbon dioxide saved from FAME-II

The country-level social cost of CO₂ for India is the highest in the world at US\$86/tonne CO₂ (Ricke, Drouet, Caldeira, *et al.* 2018). The social cost of carbon is the economic harm to the society from the release of 1 tonne of CO₂ into the atmosphere. Taking this value, the expected 67.79 million tonne CO₂ saved from the FAME-II scheme will generate social cost savings of approximately US\$5.8 billion or ₹ 40,530 crore.² In other words, the allocation of ₹ 10,000 crore FAME-II is expected to save ₹ 40,530 crore worth of CO₂ emissions from vehicles. The social cost for CO₂ per kilogram in India is derived to be approximately ₹ 5.98, as can be seen in Figure 6. That is, for every kilogram of CO₂ emitted in India, there is a social cost of ₹ 5.98. In the form of demand incentives, the FAME-II scheme on an average is expected to spend just ₹ 1.26/kg of CO₂ saved. For each Indian rupee spent on demand incentives for EVs, there is an expected savings of ₹ 4.74 in terms of CO₂ equivalent emissions reduced from conventional vehicles. This clearly indicates that allocating subsidy for EVs is a positive decision in reducing CO₂ emissions. However, the saving of CO₂ from each vehicular segment is disproportionate to the fund allocated for it. The bus segment, which has been allocated the highest proportion of the fund, has the lowest amount of expected contribution in CO₂ savings.

² Assuming ₹ 69.52 as the value of 1 US\$

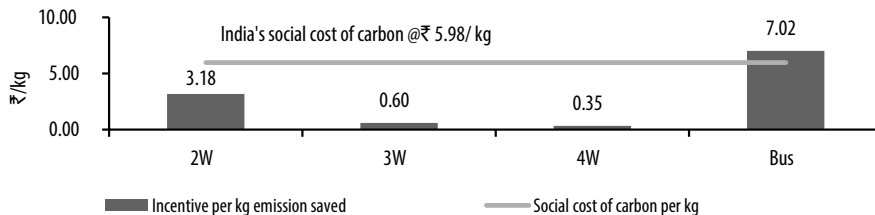


Figure 6 Cost-effectiveness of electric vehicles subsidy

Cost-effectiveness of EV subsidy allocation

The varied impact from different vehicular segments led us to further investigate and understand the effectiveness of the demand incentives to reduce carbon emissions. From the allocation of demand incentives and expected savings of CO₂ equivalent emissions, we easily derived the incentive offered for each vehicular segment for each kilogram of CO₂ saved. As discussed in the previous section, India's social cost of carbon could be converted to ₹ 5.98/kg of CO₂. The same has been plotted as horizontal line in Figure 6. The bar graph (Figure 6) shows the results and buses are the most expensive in terms of subsidy spent per kilogram of CO₂ saved. It can be deduced that the cost-effectiveness of EV subsidy in terms of CO₂ saved is the least in electric buses. When compared with India's country-level social cost of carbon, it becomes clear that the subsidy offered for buses is, in fact, not cost-effective. Through the EV subsidy, the Government of India is spending ₹ 7.02/kg of CO₂ saved from buses in contrast to ₹ 0.35, ₹ 0.60, and ₹ 3.18 for electric 4W, 3W, and 2W, respectively. The line ($y = 5.98$) in the following bar graph draws the limit for achieving cost-effectiveness of EV subsidy at a unit kilogram level. It shows that except buses, all vehicular segments targeted in FAME-II are cost-effective. The four-wheeler segment shows to be the most cost-effective mainly because of the low overall subsidy allocated.³ However, the adoption of electric 4W

is significantly slower in India compared to 3W and 2W, and hence our assumption that all the demand incentive will be utilized has a bias in favour of electric 4W. The electric 2W and 3W, which are eligible for the incentives, are much more likely to be deployed by 2022 than the eligible 4W (TERI 2018). What emerges here is that even though the FAME-II scheme appears effective in its overall expenditure, it is not cost-effective in its planned demand incentive for electric buses. In fact, the scheme offers twice the incentive per kilowatt-hour (kWh) for electric buses in comparison to 2W, 3W, and 4W. The large expected CO₂ savings from the electric 3W segment masks the inadequate cost-effectiveness of the subsidy offered to electric buses.

The inadequate cost-effectiveness of hybrid and electric buses in developing countries has been discussed before in the literature (Guerrero 2014). The quantitative assessment in a World Bank report showed that in order to tackle the problem of urban air pollution, hybrid and electric buses are an expensive solution (Guerrero 2014). The report recommends that the resources required to subsidize hybrid and electric buses may be better utilized in improving existing diesel bus systems, which in most developing countries have major liquidity problems. A more efficient allocation of resources to mitigate urban air pollution and congestion would be to reduce car usage.

³ The four wheeler segment includes savings from both targeted electric and strong hybrid four wheelers. Each strong hybrid four wheeler is eligible for an approximate subsidy of just ₹ 1300.

To consider this argument in India's context, consider a typical urban commuter who must travel 50 km in a day. Such an urban commuter will emit 6 kg of CO₂ if he or she commutes by a diesel engine car in contrast to just 0.9 kg and 0.8 kg when commuting by a CNG and diesel bus, respectively. Table 4 shows our results ranked based on daily emission by the passenger, contingent on occupancy factors. Diesel-operated 4W came out to be the most polluting option for an Indian urban commuter. Diesel appears less polluting than petrol for a passenger when assessed in terms of CO₂ equivalent emissions. However, globally, diesel is discouraged as pollutants from diesel exhaust emissions have higher risks for human health (Kagawa 2002). Also, the higher fuel efficiency of diesel reduces its CO₂ emissions per unit fuel consumed. The passenger considered in the model will emit lesser CO₂ if he or she commutes by petrol-

powered 2W (1.5 kg) than when travelling by petrol- (2.7 kg) or diesel-powered (6 kg) 3W. There is no dispute that all EVs emit 0 kg of CO₂, but the point here is that when the commuter chooses a diesel bus over his or her personal diesel car, he or she reduces her emissions by 5.2 kg of CO₂ and when he or she chooses an electric bus over a diesel bus, she saves just 0.8 kg of CO₂. The heavy subsidy offered for buses in FAME-II attempts to save this '0.8 kg' of CO₂.

If we compare based on emissions per passenger kilometre, bus is the most efficient mode of transport. Spending millions on improving efficiency of the most-efficient mode of transport is irrational. There have been numerous studies published in India citing the inadequacy, inefficiency, and financial inoperability of bus systems in Indian cities (Pucher 2004). Despite various government missions and schemes such as JNNURM (Jawaharlal Nehru National Urban

Table 4 Carbon dioxide emissions per passenger

Vehicle type	Fuel type	Fuel efficiency ^a	Occupancy ^b	Daily CO ₂ per passenger (kg/50 pkm)
3 Wheeler	Diesel	15	1.2	6.0
4 Wheeler	Diesel	18	1.2	6.0
4 Wheeler	LPG	12	1.2	5.7
4 Wheeler	Petrol	18	1.2	5.3
4 Wheeler	CNG	30	1.2	4.2
3 Wheeler	Petrol	35	1.2	2.7
3 Wheeler	CNG	49	1.2	2.6
3 Wheeler	LPG	12	1.2	2.4
2 Wheeler	Petrol	60	1.4	1.5
Bus	CNG	3	40	0.9
Bus	Diesel	4	40	0.8

^a The fuel efficiency factors have been taken from the TERI emissions model (Paladugula, Kholod, Chaturvedi, *et al.* 2018).

^b The average occupancy value, except buses, has been taken from the TERI emissions model (Paladugula, Kholod, Chaturvedi, *et al.* 2018).

Renewal Mission), AMRUT (Atal Mission for Rejuvenation and Urban Transformation), and smart cities, the fund allocation for bus transport in Indian cities is still inadequate. The bus fleet per thousand populations in Delhi is lowest in comparison to the other global metropolitan cities in the world (Jeelani 2019). Amidst this acute shortage of buses, the Government of National Capital Territory of Delhi (GNCT-D) plans on deploying over 1000 electric buses (Anand 2018). FAME-I provided a subsidy of approximately 60 lakhs to a diesel hybrid bus by OEM Volvo, which is claimed to be 25–30% more fuel efficient than a diesel bus. Deployment of this bus by a bus system in India instead of a diesel variant will probably save 30% of 0.8 kg for 40 passengers for a 50-km trip. With the same purchase price, approximately three CNG buses could be purchased (Gupta 2018). Considering the two additional buses capture commuters from CNG-operated 3W, this purchase decision would save 1.7 kg/passenger for additional 80 commuters. The later choice discussed has significantly larger savings of CO₂.

The CO₂ equivalent emissions saved are a lot more when these resources are utilized for purchase of CNG buses.⁴ According to Table 4, the maximum gain would be in converting diesel-operated 3W into electric. This would save 6 kg CO₂ per passenger for every 50 km. For higher cost-effectiveness of the subsidy in reducing CO₂ emissions, the policy must target vehicular segments that are the highest polluters per passenger kilometre and not per vehicle kilometre. Following the later approach will lead to massive expenditures and miniscule impact levels on the urban air quality. Unfortunately, this is precisely what Indian policies are doing. Rather than converting the most polluting to electric, as seen in top of Table 4, the scheme is spending

twice the subsidy to convert the least polluting to electric (as seen in the bottom of Table 4).

Conclusion

This paper had the dual objective of quantifying the impact of FAME-II and assessing the cost-effectiveness of the segment-wise allocation of incentives in reducing CO₂ equivalent emissions. The impact was quantified in terms of savings of air pollutants and also CO₂ equivalent savings. The above section attempted to economically assess the cost-effectiveness of the allocation of FAME-II subsidy to the vehicular segments of 2W, 3W, 4W, and buses. It was found that except electric buses, the EV subsidy offered to all other segments was cost-effective.

The paper also showed that buses which are allotted 42% of the demand incentives are expected to contribute to only 8% of the expected CO₂ savings from the entire FAME-II. The above section discussed the CO₂ emissions by a commuter travelling 50 km by different modes. Table 4 displays the ranking of different vehicles based on CO₂ emissions per passenger kilometre. The rankings from the top to bottom of the table are of least efficient to most efficient modes. Even though the buses have high emissions per vehicle kilometre, they have very low emissions per passenger kilometre, which is why they settle at the bottom of Table 4. The paper attempts to highlight the irrationality in spending a major amount of money for incentivizing the most-efficient mode (buses) to become even more efficient. There are two types of shift towards sustainable mobility that may be induced in commuters which are modal shift and technological shift. Sustainable modal shift is when the commuter switches to a cleaner mode of transport like shifting from using a car to using a bus. The EV subsidy scheme discussed here does not intend to induce any direct modal shift. The EV subsidy targets to induce a technological shift, where the commuters would not change their mode of transport, but switch to a cleaner technology option of the same mode. For example, the EV subsidy intends to induce a switch from petrol car to electric car and not

⁴ This paper does not suggest diesel buses because even though they emit lesser CO₂ than CNG buses in terms of CO₂, the exposure to their emissions carry higher risk to human health.

a switch from petrol car to electric bus. In such cases of technological transitions, the focus must be on switching least efficient modes into electric. In the case of promoting switching to EVs, the priority vehicular segments must be decided based through the lens of emissions per passenger kilometre and not merely through emission per vehicular kilometre.

It is recognized that there may be factors other than CO₂ that govern the basis of subsidy levels for segments of vehicles. Without challenging those factors, this paper draws the conclusion that reducing urban air pollution as a purpose is not adequately served by the FAME subsidy of electric buses. At best, the subsidy serves as a help for public bus undertakings to make a symbolic move towards electric transport. Each electric/hybrid bus is eligible for subsidy of approximately 5 million. For the same amount, 100 electric 3W could be subsidized. These 100 electric 3W would cater to seven times the number of passengers and would save four times the carbon from each of those passengers. The deployment of electric 3W will also generate higher employment and attempt to solve the woes of last mile connectivity in urban India. Figure 7 shows two alternative scenarios where the number of eligible electric/hybrid buses in FAME-II is reduced by 10% and 50% to be reallocated to subsidize 14% and 71% more electric 3W, respectively. The scenarios are expected to save 8% and 39% more than the current allocation in FAME-II. A total of 61% of the expected savings from current allocation in FAME-II is to come from electric 3W. The deployment of electric 3W will also generate higher employment and attempt to solve the woes

of last mile connectivity in urban India.

In conclusion, this paper criticizes the allocation of higher incentives for electric/hybrid buses in FAME-II and urges reconsideration of the same for the sake of sustainable mobility and clean air in India.

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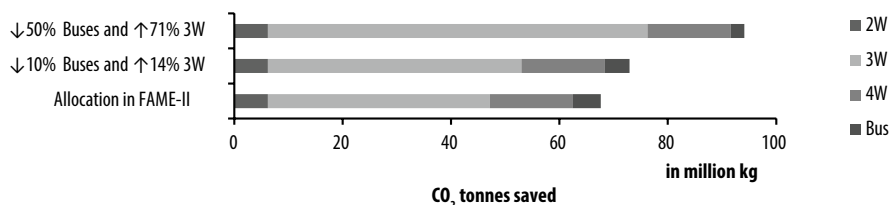
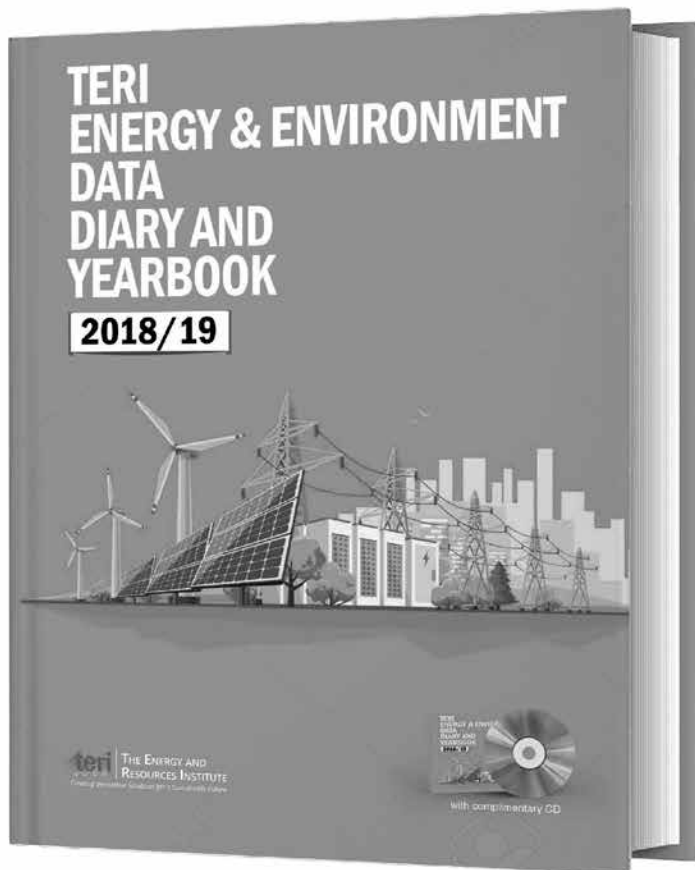


Figure 7 Impact of reallocation in FAME-II

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A Conceptual Lens for Introducing Retail Competition in Indian Power Sector

Atul Agrawal^{a,*} and D P Kothari^b

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Background
Global Experience in Retail
Competition
Challenges in Indian Power Sector
and Foreseen Benefit from Retail
Competition
Research Objective and Methodology
Development of Conceptual Lens
Conceptual Lens
Conclusion
References

ABSTRACT

The power sector reforms in India have received major thrust in the reform agenda of the state budgets. Owing to the lack of competition and existence of major challenges, the Government of India made significant institutional and legal changes and the most important legislation in this direction was the Electricity Act 2003. The act aimed to bring a paradigm shift in the sector by encouraging competition. Though the act enforced the shift of the Indian power sector from vertically integrated monopoly to wholesale competition model, inefficiencies and losses still plague the sector. It is expected that introduction of globally practiced retail competition may address the existing challenges. Literature review suggests that formulation of a conceptual lens is necessary in order to provide comprehensive understanding of retail introduction in the Indian scenario. Therefore, we have developed a conceptual lens by using Vygotsky's sociocultural theory of conceptualization. The formulated conceptual lens suggests a road map that may be referred to by policymakers for introducing retail competition in the Indian power sector.

Keywords: Indian power sector, Electricity Act 2003, Retail competition, Conceptual lens

^a Research Officer, Central Electricity Regulatory Commission, Ministry of Power, New Delhi, India

^b Professor and Ex-Vice Chancellor, VIT, Vellore and Ex-Director, IIT Delhi, India

* Corresponding author: india_atulagrawal@live.com

Background

India's power sector is the backbone of the Indian economy (Ghosh 2012). The country's economic growth depends on power availability and consumption pattern of electricity (Omer, Ghosh, Kaushik, *et al.* 2013). Since the first step of the reforms, taken way back in 1991, many alternative restructuring paths have been tried by the government towards structural changes, but very little has been attained in line with the goals of the reforms. The sector is continuously performing poorly. Energy deficit and peak shortage are still major challenges (Bhattacharyya 2007). The major players in the sector are government owned (Rao 2002). Informal control of the state governments on the Indian state electricity boards (SEBs) is more powerful than the formal control of regulatory commission (Lal 2006). SEBs in India are loss-making organizations. The cost, at which power is purchased, has been rising continuously. There are signs of further weakening of the ability of SEBs to pay and sign for power purchase agreements (Carstairs and Ehrhardt 1995). In order to meet the social objectives, the government-owned utilities are neglecting efficiency in the sector. Hence, the power system in India is continuously delivering unsatisfactory results (Thakura and Deshmukh 2006).

Even after 14 years of the initiation of the reforms, the sector is unable to match the gap between demand and supply (Thakura and Deshmukh 2006). The gap between the average revenue realization and the average cost of supply is increasing continuously in the Indian power distribution sector (Kiran, Sairam, and Santosh 2013). The gap between the average revenue and the average cost was 20% in 2011. The main reason for widening of the gap is a continuous increment in the power purchase cost (Khurana and Banerjee 2015).

The mounting AT&C losses are hampering the viability of the power sector (Tripathy and Thakur 2012). The national average of AT&C losses

stands at 25.38%, which is quite high (PFC 2016). AT&C losses can only be reduced to a certain extent. They cannot be removed completely (Dasgupta and Atmanand 2013).

A sharp fall has been witnessed in the financial health of the SEBs (Rao 2002). The total loss of the utilities was ₹ 75,297 crore in 2010-11, ₹ 102,411 crore in 2011-12, and ₹ 105,070 crore in 2012-13. This clearly tells that financial losses of the utilities have been increasing significantly over the years (PFC 2014). The loss-making power sector has been continuously supported through substantial borrowings from financial institutions. The total debt of the sector rose to ₹ 3.5 trillion (~US\$77 billion) in 2011, which is equivalent to 5% of India's gross domestic product (Khurana and Banerjee 2015).

Due to poor performance of the sector, the finances of SEBs have reached an alarming level. Hence, it has become imperative that a solution is found (Karmacharya 2012). Inefficiencies are continuously having a detrimental effect on the economic growth of India (Navani, Sharma, and Sapra 2012). However, efforts are being made to reform the sector and increase the operational and financial performance (Edvardsen and Førsund 2003).

Low performance of Electricity Act 2003

With the enactment of the Electricity Act 2003 a paradigm shift was expected in the Indian power sector (Tripathy and Thakur 2012). The Electricity Act 2003 attempted to set a milestone in the history of the Indian power sector reforms. Provision of the act had a significant impact on structural changes and policy-related issues of power generation, transmission, and distribution (Agrawal, Kumar, and Rao 2017). The Electricity Act 2003 encourages power generation from a captive power plant and introduces the provision of open access. A two-level regulatory system (state-level and central-level regulatory bodies) was retained by the act. It tries to move away from the single-buyer model and increases competition

in electricity generation (Joseph 2010). The act helped the Indian power sector, though some uncertainties and issues remained that need to be addressed including the dominance of some power-generation companies, which may lead to increase in tariff (Thakur, Kaushik, Deshmukh, *et al.* 2004). In recent years, reduction in the overall AT&C losses has been witnessed. Demand-side management and energy audit are the fields that further require attention of power managers for proper planning (Bajaj and Sharma 2006). Future reforms should focus on consumer satisfaction, tariff, pricing, theft, and corruption (Sharma, Chandramohan, and Balasubramanian 2005). In the absence of global standard practices, implementation of reforms in the distribution sector is a difficult task and hence a substitute institutional structure may be practiced in the power sector (Dossani 2004). The present conditions for future reforms are suitable to establish the retail marketplace in the Indian power sector (E&Y 2016).

Global experience in retail competition

Globally, reforms in the electricity market involve various forms of unbundling of previously state-owned vertically integrated utilities. Retail competition is present in countries that had introduced competition in electricity generation. While many countries are allowing large and industrial consumers to choose the supplier of electricity, there are countries which are giving the same freedom to medium and residential consumers also. By 2000, New Zealand, the United Kingdom, Norway, Sweden, Germany, and some states of the USA and Australia implemented full retail competition. The European directive, 2001 mandates the implementation of retail competition in all the nations of the European Union. The centralized objective of the retail competition is the removal of monopoly in distribution business by introducing competition in electricity supply (Littlechild 2002). Table 1 shows the competitive metrics for retail markets globally.

The first country to introduce competition in electricity industry was the United Kingdom

Table 1 Global competitive metrics for retail markets (ranking of selected retail electricity markets)

Country, province, state or territory	RED index score 2003	World rank 2003
England, UK	88	1
New Zealand	75	2
Texas, USA	69	3
Pennsylvania, USA	67	4
Maine, USA	64	5
Alberta, Canada	61	6
New York, USA	60	7
Columbia, USA	54	8
Michigan, USA	52	9
Maryland, USA	52	9
Victoria, Australia	50	11
New Jersey, USA	50	11

(Woolf 1994). New Zealand's market design also provide fundamental design elements, which ensure competition (Hogan 2001). These countries' retail markets rank higher than other countries as shown in competitive metrics.

Challenges in Indian power sector and foreseen benefit from retail competition

Financial losses of the power sector increased to ₹ 29,773 crore from 2011 to 2013 (PFC 2016). From 2003 to 2011, there was an increase in debt burden on DISCOMs by 27% (Agrawal and Tripathi 2019). Though AT&C losses have shown an upwards trend, the increase was not as expected. The AT&C losses reduced by 1.75% from 2011 to 2013 (PFC 2014). The average revenue and average cost gap increased by ₹ 33,109 crore between 2010 and 2013 (PFC 2016). There is an increment of 70% in the average cost of power from 2003 to 2011 (Agrawal and Tripathi 2019). As the average cost increased, it directly affected the tariff. Thus, there was an increase of ₹ 1.74 in the average per unit tariff for sale of electricity in India from 2007

to 2014. With the tariffs increasing, and despite claims of better facility, the customer satisfaction surveys conducted by the Government of India from time to time have been disappointing.

This clearly points out that the expectations from the first phase of the reforms were not achieved and the results of the second phase have subset the euphoria. So, to address the problem, global experience suggests retail competition as the way forward for the Indian power sector.

Research objective and methodology

Literatures suggest that retail competition be introduced in the Indian power marketplace in order to address the issue of local inefficiencies. However, there is dearth of scholarly articles suggesting a blueprint to introduce the same. In view of the above, the research gap of the study can be stated as: 'A comprehensive study could not be found, which suggests a conceptual lens for introducing retail competition in the Indian power sector'. In line with the research gap, the research objective of the study can be formulated as: 'To formulate a conceptual lens to introduce retail competition in the Indian power sector'.

This research work uses a qualitative paradigm to develop a conceptual lens for the introduction of retail competition in the Indian power sector. The qualitative researchers think conceptually via examination of the empirical and methodological qualitative literature (Vygotsky 1934).

Vygotsky's theory of conceptualization

Conceptual lens is a network of linked concepts that provide a comprehensive understanding of a phenomenon (Jabareen 2009). The conceptual lens is constructed and not founded. But structure- and coherence-wise, it is something that a researcher builds and not something that already exists. The concept of conceptual lens is rooted in Vygotsky's sociocultural theory. Vygotsky (1934, 1986) presented the following three main classifications of pre-conceptual

thoughts: (i) formation of syncretic groups; (ii) grouping according to complexes; and (iii) creation of potential concepts. This classification bore similarity with open, axial, and selective coding of thoughts, respectively, as suggested by Strauss and Corbin (1998).

Development of conceptual lens

Till date, there are two key documents that discuss the introduction of retail competition in the Indian scenario: (i) Standing Committee on Energy (2014-15) Fourth Report on Electricity (Amendment) Bill, 2014 and (ii) introducing competition in retail electricity supply in India 2013, Forum of Regulators. We studied these documents in detail to make conceptual lens based on Indian regulations. Study of these documents familiarized us with the ground realities of the retail regulations in India.

Generation of core concept

Through the study of 'Fourth Report of Standing Committee on Energy (2014-15) on Electricity (Amendment) Bill, 2014', 516 codes and 49 categories were generated while through the study of 'FOR Report – Introducing competition in retail electricity supply in India', 178 codes and 20 categories were developed. These categories were combined and refined further by identifying an association, that is, in total, 69 identified categories were refined and reduced to 32. These 32 refined categories developed 13 initial themes, which were further minimized to 5 core themes through data reduction. These themes and refined categories helped in conceptualizing the introduction of retail competition in the Indian scenario.

Conceptual lens

The conceptual lens as shown in Figure 1 gives a road map for introducing retail competition in India by separating carriage and content. The description of conceptual lens and steps suggested by it to develop retail competition in India are as follows:

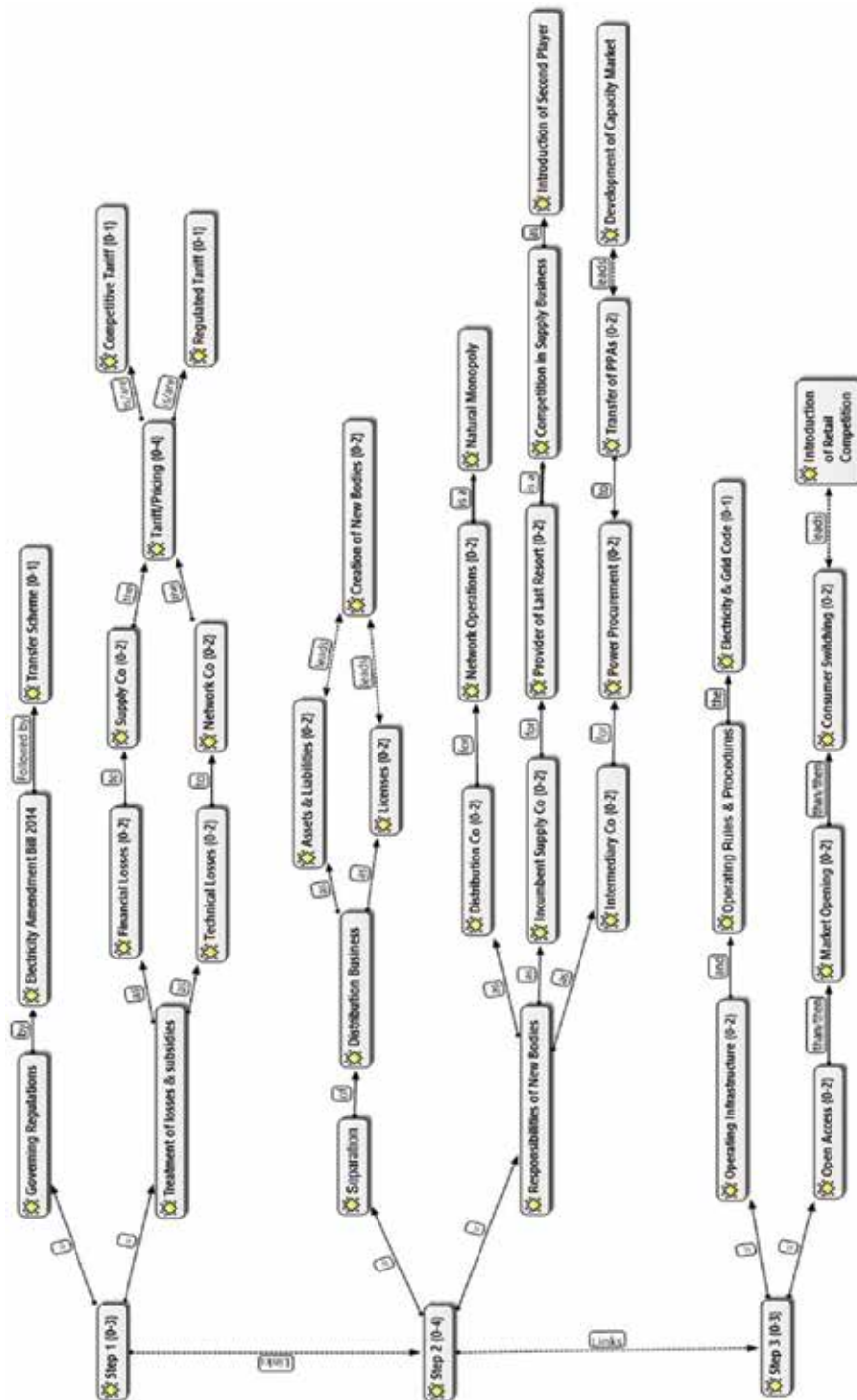


Figure 1 Conceptual lens for introduction of retail competition in India

Step 1: Governing regulations

- **Electricity Amendment Bill 2014:** Present regulations of the Indian power sector are not sufficient to introduce retail competition. These regulations need to be amended. Presently, the power sector is regulated by the Electricity Act 2003, which does not have the provision of separation of the distribution business. Hence, Standing Committee on Energy came up with Electricity Amendment Bill 2014 to amend the preliminary act. But the bill is still pending in the Lok Sabha. Thus, enactment of this bill is necessary in order to provide a regulatory platform for a retail introduction.
- **Transfer scheme:** After the enactment of Electricity Amendment Bill 2014, respective states need to come up with 'Transfer Scheme' as described in Section 131(4A) of Electricity Amendment Bill 2014. The scheme shall ensure fair division of assets, liabilities, and proceedings among the newly formed entities. Division and transfer of accounts and present employees shall be done through this scheme only.
- **Treatment of losses and subsidies:** Provision for the treatment of losses and subsidies shall be described in respective regulations. All the commercial losses shall be allocated to supply company while the technical losses shall be allocated to the distribution company. Proper segregation of financial losses into technical and commercial losses shall be done for the same purpose. Cross-subsidies need to be gradually eliminated for the success of retail competition.

Step 2: Unbundling of carriage and content business

- **Separation of distribution business:** After the introduction of proper governing regulations, the distribution business shall be unbundled into carriage business and content

business. Newly formed businesses will need to take separate licenses. Assets and liabilities shall be captured by the new businesses based on the transfer scheme.

- **Assigning responsibilities to new bodies:** After the separation, newly formed companies shall be distribution (network) company, incumbent supply (content) company, and intermediary company. The companies shall be responsible for network operation and maintenance, providing electricity to end consumer and for the power procurement arrangements, respectively. All the existing power purchase agreements shall be transferred to an intermediary company, which shall help in developing the capacity market. Network business shall have natural monopoly while the supply business shall be made competitive by introducing the second player in the market. Incumbent supply company shall work as the provider of last resort.

Step 3: Operating infrastructure and open access

- **Operating infrastructure:** Operating infrastructure of power market shall be strengthened. Operating rules and procedure for the grid and consumer operations shall be fixed simultaneously. Various responsibilities, metering infrastructure, universal service obligation, connection/disconnection, and investigation powers shall be defined in the electricity code.
- **Open access and market opening:** After the introduction of second supply licensee in the area, facility of open access shall be provided in which consumers will be able to choose their power supplier. The open access shall be provided as per the standard operating rules of different consumer categories. The market will be opened up for each consumer category in a phased manner. The consumers shall have the freedom to switch the supplier.

The particulars described above shall lead to the introduction of retail competition in India. Consumer satisfaction shall be the key to the success of the retail competition.

Conclusion

The research objective of this study is to develop a conceptual lens for the introduction of retail competition in the Indian power sector. The idea of conceptual lens is rooted in Vygotsky's Sociocultural Theory of 1934 and 1986. The developed conceptual lens suggests that separation of carriage business and content business from existing power distribution business is a pre-requisite. Carriage business shall continue as a natural monopoly while the much needed second player will be introduced in content business. Introduction of parallel player in content business intends to shift market structure from monopoly to oligopoly, although adequate governing regulations are necessary to administer the market transformation. In retail scenario, consumers will be able to choose their power supplier, which will ultimately lead to consumer satisfaction. The retail competition is also expected to increase sectoral efficiency. Foreseen profitable power sector in retail scenario shall receive new techno-commercial upgradation to provide quality and reliable power to the end consumers.

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Energy Demand and Supply Outlook in Cote d'Ivoire: A Study of Sustainable Portfolios

Yessoh Gaudens Thecle Edjoukou^{a,*}, Bangzhu Zhu^b, Minxing Jiang^b, and Akadje Jean Roland Edjoukou^c

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Socio-economic facts
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ABSTRACT

Energy access in developing countries is a real challenge, although the availability of modern, reliable, and efficient energy services is a capital driver for economic development. In Cote d'Ivoire, the electrification rate was only 38% in 2014, and solid biofuels (charcoal and fuelwood) contributed 63% of the total fuel consumption in 2015. This paper focuses on forecasting energy demand and supply for Cote d'Ivoire in the short term (2015–2030) and identifying possible energy policy paths. ARIMA (autoregressive integrated moving average), Holt–Winters forecasting, and LEAP (long-range energy alternative planning system) are used in our analysis. The results show that the forecasts for total energy demand have higher values when the LEAP model is used than with the other two. As LEAP includes population growth trends, it is believed to give the best estimates. However, the results for the scenarios considered here clearly show that the requirements of the sustainable energy policy for all will not be met in Cote d'Ivoire by 2030. Policy recommendations are therefore made to allow the energy policy to be streamlined.

Keywords: Energy forecasting, Energy demand, Sustainable Energy for All, Cote d'Ivoire

^a School of Management, Jinan University, Guangzhou 510632, People's Republic of China

^b Business School, Nanjing University of Information Science and Technology, Nanjing 210044, People's Republic of China

^c School of Accounting, Dongbei University of Finance and Economics, Dalian, People's Republic of China

* Corresponding author: yedjoukou@yahoo.fr

Introduction

After a decade of political upheaval between 1999 and 2010 in Cote d'Ivoire, one of the major challenges for the country involves the development of basic social services, such as universal access to clean energy and water, education, and better healthcare.

This political instability created a marked downwards trend in living conditions, and poverty in the country is characterized by limited revenues and correspondingly weak access to modern energy services. Another feature of this poverty is the massive reliance on solid biofuels (charcoal and fuelwood) for basic energy needs. The total rate of access to electricity was 77% in 2014, accounting for only 34% of households in the same year. In response to this issue of energy access, which is relevant throughout West Africa, the members of the Economic Community of West African States (ECOWAS) decided in 2006 to implement 'the white book'—a policy designed to increase the access of West African citizens to modern energy services rate to 50% by 2015 and improve their living conditions in general (Republic of Cote d'Ivoire 2012).

'The white book' policy was implemented with the help of the United Nations Development Programme. In addition to the central objective as mentioned earlier, the policy had three specific goals: (i) reinforcement of regional integration to maximize the exchange of experiences especially in the field of energy; (ii) promotion of harmonized legal and institutionalized setting emphasizing access to modern energy services as one of the top national priorities to ensure human development and achieve the Millennium Development Goals (MDGs); and (iii) establishment of energy policies stressing poverty alleviation and the achievement of MDGs in line with national politics. These energy programmes focus on providing revenues-generating income, modernization of basic social services (health, education), and improvement of women's living conditions.

In 2012, the 'white book policy' was implemented via a national programme for

investment in energy services in Cote d'Ivoire, with more or less the same objectives. In the same year, the aim of Sustainable Energy for All was adopted.

Issues relating to future energy supplies have been intensely discussed worldwide. A long-term forecast for energy supply and demand in Taiwan was carried out using the LEAP model (Yophy, Jeffrey, and Chieh-Yu 2011). In Turkey, primary energy consumption for the period 2005–2020 was forecasted using the ARIMA model and cyclic analysis (Ediger and Tatildil 2002 and Ediger and Akar 2007), and energy demand forecast models have been reviewed (Suganthi and Samuel 2012). Although the literature on this topic is far less abundant in Africa, an examination of the alternative energy policy options for the region for the period 2015–2040 has been conducted using the LEAP model (Ouedraogo 2017).

The aim of the present study is not only to forecast energy demand in Cote d'Ivoire for the short term (2015–2030) and analyse the supply outlook, especially in the power sector, but also to simulate future energy policy options, including issues relating to greenhouse gas emissions. Policy recommendations are proposed based on the results of this analysis.

Energy status

Energy access

Energy is essential for most human activities, and access to modern, reliable, and efficient energy services, therefore, appears to be a prerequisite for any economic and social advancement.

In Cote d'Ivoire, solid biomass (firewood and charcoal) accounts for more than 70% of the total energy used by households to meet their basic needs in terms of cooking and heating (World Bank 2018a). In addition, a noticeable gap is observed between rural and urban areas; modern cooking energy sources such as electricity and liquefied petroleum gas are only available in urban areas, and, particularly, in large cities where the purchasing power of individuals is relatively high. People in rural areas rely mostly

on solid biomass, as this is both cheaper and the most widely available source of energy to them.

The power sector in Cote d'Ivoire follows this pattern. In 2014, 77% of the population were living in electrified areas (Republic of Cote d'Ivoire 2016); the rate of access to electricity that is one of the highest in West Africa. However, the national electrification rate was estimated to be 38%, with only 34% of households having access to electricity (Republic of Cote d'Ivoire 2016). These figures clearly indicate that people living in electrified zones are unevenly distributed across the territory. The bulk of people with access to electricity live in cities, and in rural areas and outside cities the access rate is much lower.

Many rural communities do not currently have access to basic social services, such as proper healthcare, education, and clean water, because there is no electricity. In addition, petroleum products such as liquefied petroleum gas are also very scarce in these areas. The reasons for this are threefold: they are unaffordable to most people; the rural markets are irregularly supplied; and there are geographic limitations on the supply network.

This limited access to modern, reliable energy services is a major hindrance to economic and social progress, and traps rural residents in constant poverty with no possibility of escaping. These people, therefore, rely on traditional solid biomass, with its range of negative effects including indoor air pollution. Their health and quality of life are poor, and this is especially true for women and children, who spend long hours collecting wood and cooking.

In this context, the Ivorian government has initiated many programmes to improve the situation and increase the rate of electrification. Although an investment programme for energy access in Cote d'Ivoire was adopted for the period 2012–2015 (Republic of Cote d'Ivoire 2012), this ambitious project had unsatisfying results, mainly due to lack of financial resources.

Energy resources

Cote d'Ivoire is relatively well endowed with natural resources. In terms of fossil fuels, the country has proven oil reserves of 100 million barrels and gas reserves of 1 trillion ft³ (US Energy Information Administration 2017), and is a net oil exporter. However, it imports crude oil and refines in its national refinery. The majority of its oil and gas assets are located offshore. In 2017, daily oil production in the country reached 34,000 barrels per day, and production of natural gas was 216 million ft³/day (Ivorian Press Agency 2018). The overall economy is highly dependent on carbon-based energy, and sectors such as transport and industry are heavy consumers of petroleum-related products. More than 80% of the electricity produced in 2015 originated from thermal power plants, which mainly use natural gas and substitute fuels such as heavy fuel oil or distillate diesel oil (International Energy Agency 2018). This dependence on petroleum products adversely influences the national economy due to the constant fluctuation in oil prices in the international market. The population has experienced upwards trends in the prices of both petroleum products, such as gasoline, and basic food items, which are linked to oil via the transport sector.

Nevertheless, Cote d'Ivoire does have tremendous potential in terms of development of renewable energies. One such form of energy that is widely utilized is solid biomass, which accounts for more than 70% of household fuel choices. Although this creates a great deal of pressure on forest resources and biodiversity, and harms people's health, its use is expected to increase due to population growth. However, clean sources of renewable energy such as hydropower and solar energy are receiving a high level of attention and investment in the country. The hydropower potential, which is currently unused, is estimated at 7000 MW, 1847 MW of which is commercially exploitable (Ivorian Electricity Company 2017). Solar energy is abundant, with average solar

radiation varying from 4 to 6 kWh/m²/day and a daily sunshine duration of 6 hours (Koua, Koffi, Gbaha, *et al.* 2014), but this is not yet widely disseminated. In 2014, renewable energy sources (mainly hydropower) accounted for 20% of the electricity use (Koua, Koffi, Gbaha, *et al.* 2014).

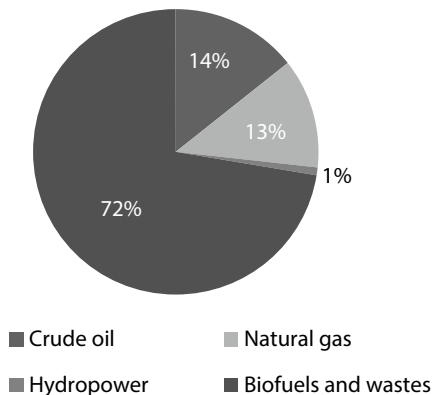


Figure 1 Energy supply by fuel in 2015

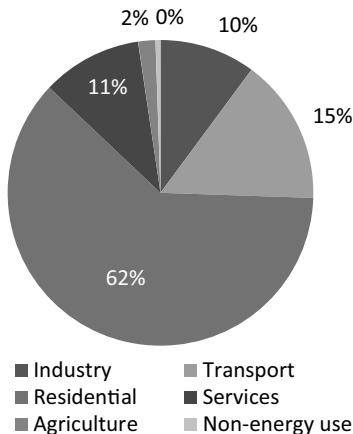


Figure 2 Energy consumption by different sectors in 2015

Supply and demand

In 2015, the total primary energy supply reached 12.98 Mtoe (million tonnes of oil equivalent) with the proportions of crude oil, natural gas, hydropower, and solid biomass and wastes being 14%, 13%, 1%, and 72% (International Energy Agency 2018), respectively (Figure 1).

By the end of 2017, the capacity for electricity production amounted to 1899 MW, which was supplied by hydropower (879 MW) and thermal plants (1020 MW). Over the last decade, most of the electricity production in the country has originated from thermal sources. In 2017, 9796 GWh of electricity was produced, with 79% coming from thermal plants and the remainder from hydropower (Ivorian Electricity Company 2018). The total energy demand was estimated to be 6.78 Mtoe in 2015, of which the residential sector was the largest energy consumer at 4.17 Mtoe (International Energy Agency 2018) (Figures 2, 3, and 4), while the national electricity consumption was 8721 GWh.

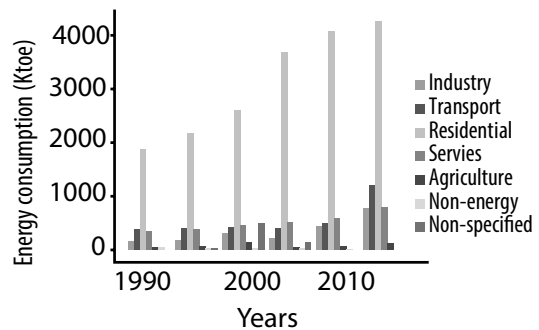


Figure 3 Total energy demand by different sectors

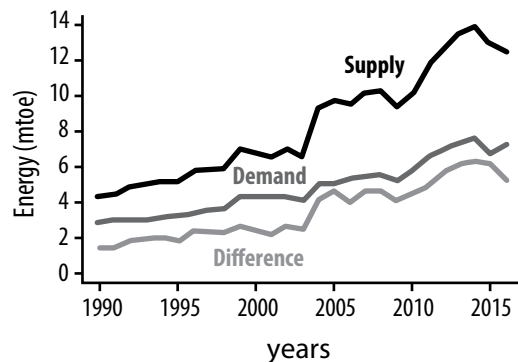


Figure 4 Energy demand, supply, and their difference

Socio-economic facts

Economy

Since 2012, following a decade of political turmoil, the Ivorian economy has shown good performance, marked by a steady increase in the gross domestic product (GDP) and a substantial reduction in poverty. The economy reached a growth rate of 7.6% in 2017, and the same order of magnitude is expected in the next few years. For the period 2016–2020, the government initiated a national development plan to turn the country into a middle-income state. The poverty rate dropped slightly, from 51% to 46%, between 2011 and 2015 (World Bank 2018b).

However, this glowing portrait overlooks a number of weaknesses. In 2016, the country ranked 171st of 188 countries in the United Nations Human Development Index, and the growth observed over the last few years has mostly been driven by the public sector. Public domestic debt and external debt have both grown, the first from 16.9% to 18.9% of the GDP between 2012 and 2016, and the latter from 22.2% to 28.5% between 2015 and 2017 (International Monetary Fund 2017). Poor management of public finances and the high reliance on foreign investment funds were the main causes of this. In addition, political stability appears increasingly fragile in the run-up to the 2020 presidential election.

Demographic trend

In 2016, the estimated Ivorian population was 23.7 million, with around 55% living in cities and the remainder in the countryside. The population growth rate has been stagnant at 2.5% annually over the last 5 years, and the fertility rate was approximately five births per woman the same year. The population is, therefore, growing steadily, and posing new challenges in terms of access to modern energy services, clean water, basic healthcare, and education infrastructure.

Modelling approach

Energy models can be divided into various categories based on the analytical approach used

(i.e. top–down or bottom–up), or the purpose of the analysis (i.e. forecasting, exploring, or scenario analysis) (Ouedraogo 2017). In addition, due to the specific challenges associated with energy modelling in developing countries (e.g. reliance on traditional energies, large informal sector), hybrid models combining the benefits of top–down and bottom–up methodologies work best (Ouedraogo 2017).

Although LEAP is not a hybrid model, it combines the features of bottom–up and top–down approaches (Song, Lee, Maken, *et al.* 2007) in (Ouedraogo 2017). LEAP is a software tool for energy policy analysis and climate change mitigation assessment that was developed at the Stockholm Environment Institute. It is a scenario-based modelling tool that allows different future paths to be assessed in terms of their energy requirements, their costs, and their environmental impacts (LEAP 2018). It is used for long-term predictions and has low initial data requirements. This key feature makes it highly suitable for energy modelling in developing countries such as Cote d'Ivoire, where detailed energy data are not available. In addition, the technology and environmental database is an interesting characteristic that allows the user to record the pollution levels from any fuel utilized on the demand side. Another important aspect is that the software is available free of charge to students for a one-year period, thus allowing for broader dissemination and learning. For these reasons, LEAP was chosen in this study as the best tool for exploring scenarios portraying various energy policy targets for the period 2015–2030. The last year of the study corresponds to the final phase of the Sustainable Energy for All policy, which was initiated in 2012 by the United Nations as part of the MDGs.

Furthermore, to define the range of magnitude of the results and for comparison, several other statistical models are used in addition to LEAP, including the ARIMA model, the Holt–Winters exponential smoothing method, and regression models. Detailed information for each of those models will be provided in the following paragraphs.

Data

The bulk of the data used for this paper comes from the following two main sources: (i) international organizations such as the World Bank (World Bank 2018a), the International Energy Agency (International Energy Agency 2018), and the United States Energy Information Administration (US Energy Information Administration 2017) and (ii) Ivorian national institutions such as the regulatory body for the electricity sector (ANARE) (ANARE 2017), the Ivorian national electricity company (CIE) (Ivorian Electricity Company 2018), and the Ivorian national refinery (SIR) (Ivorian Refining Company 2018b). The data are yearly time series of energy consumption and supply by sector and fuel type, and broadly cover the period 1980–2017 with a slight difference in the time frameworks between the sources.

The LEAP–Cote d'Ivoire model takes into account the final energy consumption by sector and fuel type, and the transformation modes. The sectors include residential, industry, transport, services, non-specified, and non-energy use, while the transformation modes encompass the transmission and distribution of electricity, electricity generation, oil refining, and charcoal production. The main elements of the model are population growth, increase in the proportion of renewable energy, and improvements in energy efficiency. The study covers the period 2015–2030.

Statistical models

ARIMA model : The ARIMA model is a mixed time-series model with an autoregressive part (AR) and a moving average part (MA). It is only valid for stationary time series. A brief description of this is given here.

An ARMA (p, q) process, which is an autoregressive moving average, is defined as follows: $X_t = \phi_1 X_{t-1} + \phi_2 X_{t-2} + \dots + \phi_p X_{t-p} + Z_t + \beta_1 Z_{t-1} + \dots + \beta_q Z_{t-q}$ (Shumway and Stoffer 2011).

This can be written using a backshift operator as

$$\phi(B) X_t = \beta(B) Z_t$$

where

$$\beta(B) = \beta_0 + \beta_1 B + \dots + \beta_q B^q$$

$$\phi(B) = 1 - \phi_1 B - \phi_2 B^2 - \dots - \phi_p B^p$$

- Z is a complex variable
- The roots of the polynomials $\beta(z)$ and $\phi(z)$ lie outside the unit circle
- The ARMA (p) process is stationary and invertible.

Since real datasets are always non-stationary, the data trend needs to be removed. Thus, we introduce a difference operator

$$\nabla = 1 - B$$

A process X_t is an autoregressive integrated moving average of order (p, d, q) if

$$Y_t \sim \text{ARMA}(p, q) \longrightarrow X_t \sim \text{ARIMA}(p, d, q)$$

$$Y_t := \nabla^d X_t = (1 - B)^d X_t$$

In this study, the ARIMA technique is employed to estimate the total energy demand and the energy demand by fuel and sector type. R Studio software was used as a platform. The modelling procedure is as follows. First, time-series data are plotted to determine the overall trend. Differencing is then executed if the plot exhibits no stationarity. In the case of an obvious variation in the variance, a log-return transformation is performed. At this stage, a Ljung-Box Q-statistic test is done to evaluate the autocorrelation of the transformed data. If the p -value is lower than 0.05, an ARIMA model can be fitted to the transformed data. The autocorrelation function (ACF) and the partial autocorrelation are plotted to estimate the orders

of the MA(q) and AR(p) processes, respectively. Several models are considered, and the final model is chosen based on the lowest Akaike criterion, the lowest sum of squared errors, and the parsimony principle, which states that the simplest explanation that fits the evidence should be chosen (i.e. the sum of the total parameters of the model should be the lowest possible value) (Coursera 2018). ARIMA has been widely used in energy demand forecasting, including ARIMA forecasting of primary energy demand fulfilled by fuel in Turkey (Ediger and Akar 2007).

Holt–Winters exponential smoothing:

This method is simple, has low data storage requirements, and is easily automated. It also has the benefit of incorporating changes in trends and seasonal patterns (Goodwin 2018). In this study, we use the following parameters that make the double exponential technique:

- The level with parameters 'alpha' (α)
- The trend with parameters 'beta' (β)

There is no apparent seasonality in the datasets. The double exponential equation can be written as follows:

(Double exponential) forecast = Smoothed value + Correction including trend information

The equations for the next step in the forecast are as follows:

$\hat{x}_{n+1} = \text{level}_n + \text{trend}_n$ with:

$\text{level}_n = \alpha x_n + (1-\alpha)(\text{level}_{n-1} + \text{trend}_{n-1})$

$\text{trend}_n = \beta \times (\text{level}_n - \text{level}_{n-1}) + (1-\beta)\text{trend}_{n-1}$

R Studio is used to find both the optimal values of α and β and the forecast values for the total energy demand and the energy demand by fuel and sector type.

Regression model: In a regression analysis, a relationship is established between an explanatory variable and a response variable. The coefficient of correlation between both the variables is an indicator of the quality of the relationship. A high coefficient of correlation signifies that the response variable can be predicted based on the predictor or explanatory variable. The population is the variable with the highest coefficient of correlation with

respect to energy demand (Figure 5). In this study, the energy demand by sector used in the LEAP model is therefore estimated with a polynomial regression model, using population as a predictor. A polynomial regression model between a predictor X and a response variable Y can be simply defined by the following equation:

$$Y = \beta_0 + \beta_1 X + \beta_2 X^2 + \dots + \beta_h X^h + \varepsilon$$

where h is the degree of the polynomial and ε is the standard error.

The data were analysed using R Studio. For each sector, the best model was chosen based on the following features:

- A high correlation of coefficient (adjusted R-squared value)
- A high statistical significance given by an analysis of variance. The p value must be lower than 0.05.

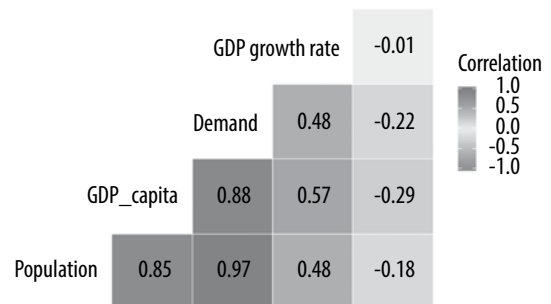


Figure 5 Correlation matrix plot

LEAP model

The LEAP–Cote d'Ivoire model uses the final energy demand of the various sectors. In each sector, the final energy consumption data are grouped by fuel type. The five key sectors — residential, industry, transport, services, and agriculture — are used, and two further categories — non-specified and non-energy use — are added. For the residential sector, the activity level was organized by household. The model encompasses transformation modules on the supply side, which are charcoal production, oil refining, electricity generation, and transmission and distribution. The key assumptions include the population and

population growth rate, which is estimated as 2.5% over the study period. Population is the key parameter that has the highest correlation with energy demand (Figure 5).

Scenario design: Five alternative energy paths are considered in line with SE4All. Twenty years after the Rio Conference on Environment and Development in 1992, the UN proclaimed 2012 the International Year of Sustainable Development, and set new goals for 2030. SE4All was a policy initiated in 1992 by the UN, which was followed up in 2012 with a new set of objectives. It involves several states, private sector companies, and non-governmental organizations. Its goals are universal access to modern and reliable energy services, the doubling of energy-efficiency actions, and the doubling of the proportion of renewable energy sources in the total energy supply.

Reference scenario: This is the baseline scenario, which is characterized by an increase in the energy demand in the major sectors, especially for electricity, and a more or less steady increase in the population growth rate. Here, general actions in relation to improving energy access improvement are modelled, particularly in the power sector. The following aspects are included in the model:

- The electricity demand increases to 9.5% on an average in all the sectors (Republic of Cote d'Ivoire 2016)
- Two thermal plants with 627 MW production capacity are constructed by 2020 (Ivorian Electricity Company 2017)
- Two coal plants are constructed by 2020 with a total production capacity of 700 MW (Ivorian Electricity Company 2017)
- LPG demand reaches 1.2 million tonnes by 2030 (Republic of Cote d'Ivoire 2016)
- There is a gradual increase in the final energy demand by sector, based upon the population growth rate

- The electricity production outlook by 2030 is estimated based upon the production capacity of each plant type

In addition to the reference scenario, three further scenarios are investigated.

Renewable scenario: The renewable energy sources in Cote d'Ivoire mainly include hydropower, solid biofuels (firewood and charcoal), and solar energy. This scenario models both the capacity for electricity production and the outlook. Capacity figures are derived from officially planned projects, while electricity production is estimated based on the capacity increase. According to the national programme for renewable sources of energy that set the targets for SE4All, renewable energy sources should account for 34% by 2020 and 42% by 2030 (with the proportions of hydropower, solid biofuel, and solar energy being 26%, 15%, and 1%, respectively) (Republic of Cote d'Ivoire, ECOWASE 2016). No other specific plans have been made for the dissemination of renewable energy sources in other sectors such as biofuels for transport.

Energy access improvement scenario

The following two key parameters are taken into account in this model: the percentage of households with access to electricity, and the percentage of households using clean cooking methods such as LPG. The first parameter is expected to reach 100% by 2020. With regard to clean cooking technology, the rate of LPG use is projected to be 67% by 2030 (Republic of Cote d'Ivoire 2016). In October 2014, the Ivorian government initiated the 'Electricity for All' policy, which aims to connect additional 200,000 households to the national electricity grid above the usual 50,000 that are connected annually, over a 10-year period (Ivorian Electricity Company 2018). It was also decided to pursue the liquefied petroleum gas policy launched in 1994, and to promote the use of improved cooking stoves (Republic of Cote d'Ivoire, ECOWASE 2016).

Energy-efficiency scenario: Efforts in energy efficiency actions should trigger the following energy savings that are modelled:

- Electricity transmission and distribution losses are expected to drastically decrease from 22% in 2015 to 3.23% in 2030
- Charcoal production efficiency is expected to rise to 20% and that of charcoal produced by efficient combustion to 16% by 2030

- The residential sector is expected to save 84 Gwh of electricity and 2100 ktoe (thousand tonnes of oil equivalents) from cooking using efficient bulbs and improved cooking stoves. For the transport and industry sectors, the figures may reach 172 and 93 ktoe, respectively.

Compound scenario: This scenario combines the use of renewable energy with increased energy efficiency.

Table 1 Total energy demand in million tonnes of oil equivalent

Models	2016	2018	2020	2022	2024	2026	2028	2030	AGR(%)
Holt–Winters	7.69	8.26	8.82	9.39	9.95	10.51	11.08	11.64	2.99
ARIMA	7.28	7.76	8.32	8.92	9.57	10.26	11.01	11.81	3.55

AGR: Annual growth rate; ARIMA: Autoregressive integrated moving average

Table 2 Additional energy demand in million tonnes of oil equivalent

Model	2016	2018	2020	2022	2024	2026	2028	2030
Holt–Winters	0.12	0.08	0.03	−0.01	−0.06	−0.10	−0.14	−0.19

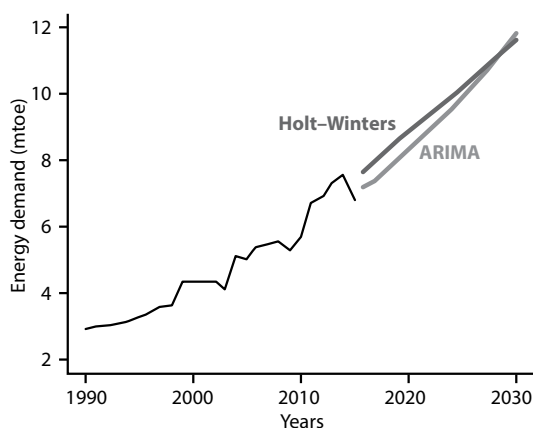


Figure 6 Energy demand predictions by autoregressive integrated moving average and Holt–Winters

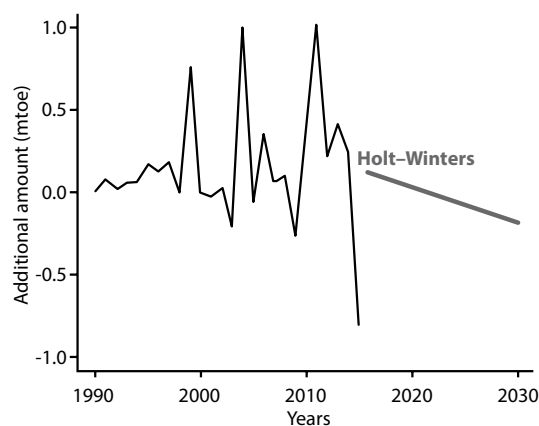


Figure 7 Additional energy forecasts using Holt–Winters method

Results and discussion

Energy consumption

Demand-side results: Using the Holt–Winters and ARIMA methods, the total energy demand is forecast to reach 11.64 and 11.85 Mtoe, respectively, in 2030 (Figure 6 and Table 1). The average annual growth rates (AGR) are 2.99% and 3.55%, respectively, and the observed difference is only 0.21 Mtoe by 2030. The two methods, therefore, exhibit almost consistent results, with an AGR that is slightly higher for the Holt–Winters method. Furthermore, the additional amount of energy gives better results for energy demand analysis compared with the annual energy consumption. This additional amount of energy reflects the capability to consume and meet the energy demand via production or import (Ediger and Tatlidil 2002). In this study, unlike the annual energy demand, the additional amount is expected to show a downwards trend, with a value of -0.19 Mtoe by 2030 (Figure 7 and Table 2). Cote d'Ivoire is still being industrialized, and energy demand is, therefore, expected to increase. However, a decrease in the additional amount of energy could signify that the energy intensity peak will be achieved in the coming decades.

The forecasts for fuel demand show the same pattern as that of the total energy demand, with solid biofuels reaching a value of 5.33 Mtoe by 2030, accounting for 50% of the total fuel demand. Hence, solid biofuels (charcoal and wood) are expected to be the major source of energy, especially for households, until 2030 (Table 3).

The total energy demand predicted using

the LEAP–Cote d'Ivoire model for the different scenarios is summarized in Table 4. Based upon the modelling objectives stated above, there are three different ways in which the total energy demand may evolve, all of which exhibit a steady increase in energy until 2030.

In the reference scenario, the total energy demand will reach 15.19 Mtoe with an AGR of 5.39%. The energy-efficiency scenario has the lowest value of 13.53 Mtoe in 2030, with an AGR of 4.57%. The total energy demand by 2030 in the energy access improvement scenario is slightly higher than that in the reference scenario by 1.55 Mtoe (see Table A1 in the Appendix). However, the objective of universal access to modern energy services, especially for electricity, will not be met by 2030. In fact, the 'Electricity for All' policy initiated since October 2014 has so far connected an average of 120,000 households per year, in comparison to the originally intended 200,000. A simple computation of this average, with the addition of the usual 50,000 households connected annually, yields an estimation of only 53.41% of households having access to electricity by 2030. This figure can only grow to 61.48% if the 'Electricity for All' policy is strictly implemented as planned.

The energy savings made under the efficiency scenario clearly show that the same activities can be performed with lower amount of energy.

With regard to the energy demand by fuel, we notice a preponderance of electricity and solid biofuels in the reference scenario, with respective shares of 27% and 26% of the total fuel demand. The efficiency scenario follows more or less the same pattern of fuel consumption. However, in the energy access improvement scenario, a high LPG consumption is expected

Table 3 Fuel demand in million tonnes of oil equivalent estimated by the Holt-Winters method

Fuels	2016	2018	2020	2022	2024	2026	2028	2030	AGR(%)
Electricity	0.56	0.66	0.76	0.86	0.96	1.06	1.15	1.25	5.79
B & W	4.34	4.48	4.62	4.76	4.91	5.05	5.19	5.33	1.48
Gas	0.23	0.23	0.23	0.23	0.22	0.22	0.22	0.22	-0.45
Oil	1.86	2.15	2.43	2.72	3.00	3.29	3.57	3.85	5.25

AGR: Annual growth rate; B & W: Biofuels and wastes

that is likely to account for 31% of the total fuel demand. The share of solid biofuel is expected to drop accordingly to 6%, while electricity will have 30%. This pattern can be attributed to the objectives of the SE4All policy, which aims to establish universal access to modern and reliable energy services. The consumption of petroleum products will rise at an average growth rate of

Table 4 Energy demand final units (Mtoe)

Scenarios	2015	2020	2025	2030	AGR(%)
Reference	6.93	9.06	11.83	15.19	5.37
Energy access improvement	6.93	9.07	12.57	16.74	6.06
Energy efficiency	6.93	5.56	08.28	13.54	4.57

AGR: Annual growth rate

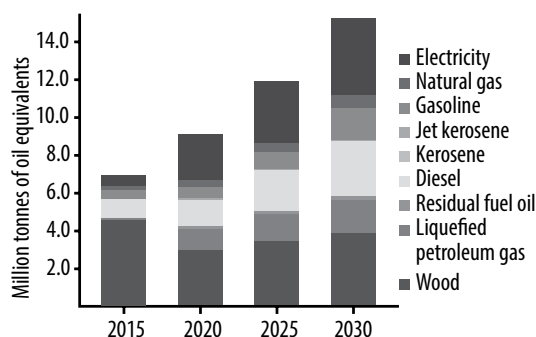


Figure 8 Energy demand by fuel, final units, reference scenario

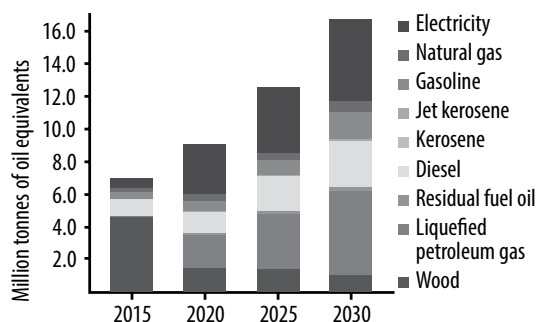


Figure 9 Energy demand by fuel, final units, energy access improvement scenario

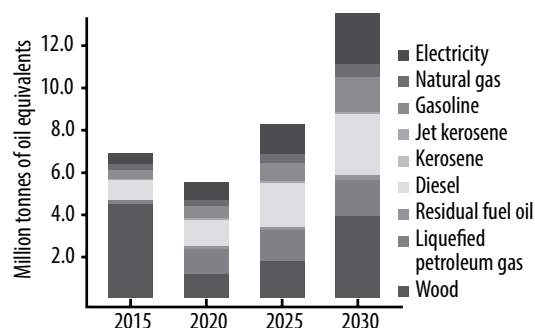


Figure 10 Energy demand by fuel, final units, energy-efficiency scenario

17%, regardless of the scenario (Figures 8 to 10).

Sectoral analysis

The LEAP–Cote d'Ivoire model shows that the residential sector will remain the largest energy consumer, with an overall average of 47% of the total energy demand by 2030. The industry and transport sectors will occupy proportions of 16% and 24%, respectively, by 2030, regardless of the scenario. These two sectors will also have the highest growth rates in energy demand. Both the sectors show slightly more than 8.5% growth rate in all the scenarios (Figures 11 to 13). This can be interpreted in terms of the efforts deployed by the government to industrialize and modernize the economy. The results obtained by the Holt–Winters method display the same pattern, with

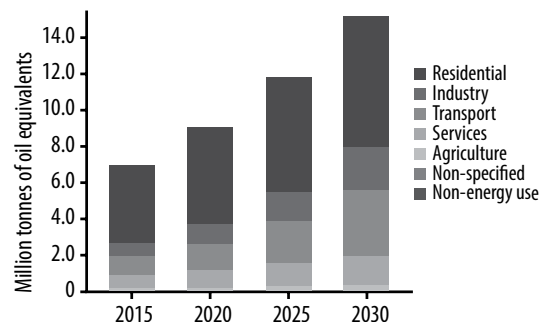


Figure 11 Sectoral demand, all fuels, reference scenario

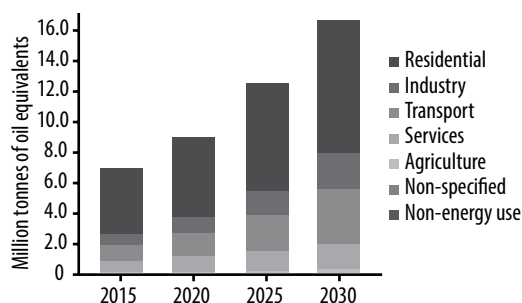


Figure 12 Sectoral demand, all fuels, energy access improvement scenario

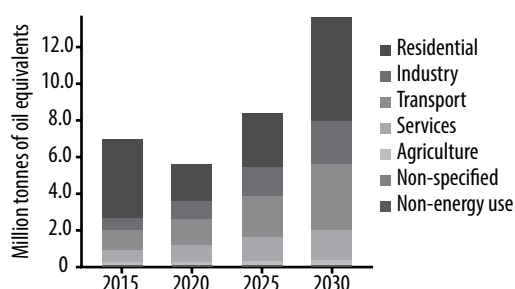


Figure 13 Sectoral demand, all fuels, energy-efficiency scenario

residential use accounting for 51% of the total energy consumption (Table 5).

Supply outlook

Power sector: Electricity generation in Cote d'Ivoire is dominated by thermal plants, which use natural gas as the main feedstock fuel and heavy fuel oil as substitute fuels. They are predicted to account for 55% of the electricity

production in the reference scenario (Figure 14) and 47% in the renewable energy scenario by 2030 (Figure 15). The second largest electricity producer in the country are the hydropower plants, which are forecasted to have a 24% and 26% share of electricity production in 2030 in the reference and renewable scenarios, respectively. In the reference scenario, the hydropower and thermal plants undergo an annual rate of decrease of 0.33% between 2025 and 2030. However, over the same period, an annual growth rate of 3% is expected in the renewable scenario for hydropower plants, while thermal plants are expected to undergo an annual decrease rate of 0.33%. Another important aspect of the renewable scenario is the significant annual growth rate in the use of solid biofuels, which is expected to amount to 26% by 2030. Coal and solar plants will appear by 2020. Hence, by 2020, five sources of electricity generation are expected to make up the Ivorian power sector: hydropower, thermal, solar, solid biofuels (wastes), and coal. In the other scenarios, electricity production has almost the same pattern, with thermal plants making up a fair proportion of the input.

Furthermore, 3.37 Mtoe of electricity will be produced in the renewable scenario in 2030, as compared with 2.29 Mtoe for the energy-efficiency scenario. These are the highest and lowest values (see Table A3 in the Appendix). The renewable scenario involves massive investments as part of the SE4All policy, which

Table 5 Energy demand by sector in Mtoe estimated by the Holt–Winters method

Sectors	2016	2018	2020	2022	2024	2026	2028	2030	AGR(%)
Industry	0.71	0.75	0.79	0.83	0.88	0.92	0.96	1.00	2.53
Transport	1.13	1.37	1.61	1.85	2.09	2.34	2.58	2.82	6.59
Residential	4.24	4.38	4.52	4.66	4.80	4.94	5.08	5.22	0.07
Services	0.78	0.84	0.89	0.95	1.00	1.06	1.11	1.17	0.02

AGR: Annual growth rate

aims to increase the share of renewable energy sources in the electricity mix. In addition, an increase is observed in the share of solid biofuels (wastes). By 2030, the total share of renewable sources of energy in the electricity mix should reach 38%, meaning that the objective of SE4All of green sources of energy making up 42% of the electricity mix by 2030 will not be met.

The average electricity demand in all the scenarios is 2.72 Mtoe, and the average electricity supply is 2.83 Mtoe, meaning that electricity demand is expected to be met even if the difference is small. A combination of renewable energy and improvements in access to energy and efficiency give an electricity demand and supply of 1.62 Mtoe and 2.94 Mtoe, respectively. The difference between those two previous values is an amount of 1.32 Mtoe, which is the highest value for all the scenarios. This means that by combining the efforts of these three scenarios, electricity demand not only can be fully met but also large savings can be made for other types of usage. For instance, energy access in rural areas can be increased. It will improve the healthcare and education system. Besides, it will enhance

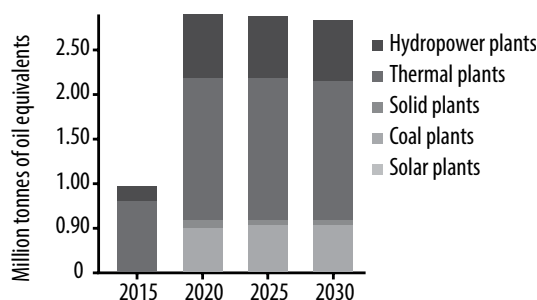


Figure 14 Electricity generation by input plants reference scenario

local economies by the creation of income-generating activities such as small agro-industrial units.

Charcoal production: Charcoal production is expected to increase at an annual growth rate of 1.57%, reaching 0.46 Mtoe by 2030. However, the proportion of charcoal produced by efficient

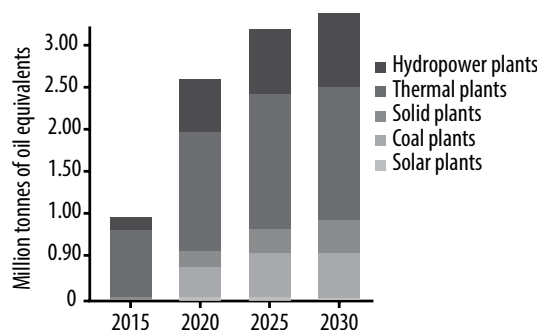


Figure 15 Electricity generation by input plants, renewable scenario

combustion is still low, and is expected to reach 6% by 2020. Charcoal and fuelwood will still account for a fair proportion of the energy mix used by households in the short and medium term in Cote d'Ivoire (Zidago and Wu 2015). However, this could be reversed by implementing the energy access improvement scenario which promotes instead the dissemination of improved cooking stoves and the use of cleaner cooking fuel such as liquefied petroleum gas. That scenario has indeed the lowest solid biofuels demand.

Greenhouse gas emissions

The total carbon emissions in the different scenarios between 2015 and 2030 are summarized in Table 6.

In the reference scenario, the values range from 7.16 million tonnes (Mt-C) to 27 Mt-C, with an annual growth rate of 9%. The same pattern is seen for the other scenarios, with the energy access improvement scenario in particular having both the highest CO₂ emissions value of 37 Mt-C in 2030 and the highest annual growth rate of 12%. However, in the renewable and efficiency scenarios 1.6 Mt-C of emission savings are made compared to the reference scenario. The introduction of cleaner sources of energy and the implementation of efficient actions are necessary to lower the economy's carbon footprint. These high values of CO₂ emissions can be explained by the massive use of fossil fuels in the

transport sector, which is the primary polluter. This sector alone will release 11 Mt-C by 2030, accounting for 41% of the total CO₂ emissions in the reference scenario. The promotion of renewable energy sources such as biofuels should therefore be considered in the transport sector.

Table 6 Carbon dioxide (non-biogenic), all fuels (million tonnes)

Scenarios	2015	2020	2025	2030
Reference	7.16	16.57	21.12	27.10
Energy access improvement	7.16	19.24	27.20	37.41
Energy efficiency	7.16	11.83	17.61	25.77
Renewable energy	7.16	15.49	21.12	27.10
Renewable and efficiency	7.16	11.52	17.28	25.49

Concluding remarks and policy recommendations

This study used three different methods for estimating the energy demand between 2015 and 2030. While the ARIMA and Holt–Winters forecasts are nearly the same, the LEAP–Cote d’Ivoire model exhibits higher values, with a difference of 3 Mtoe from the two aforementioned models in the reference scenario. In fact, since the LEAP–Cote d’Ivoire model integrates the important demographic parameter of population growth rate, and energy demand in Cote d’Ivoire is highly correlated with population (Figure 5), it is believed that the LEAP model yields the best estimates.

Five scenarios portraying different energy policy options were investigated using the LEAP–Cote d’Ivoire model from 2015 to 2030. It was observed that energy demand is expected to nearly double in all the cases by 2030. On the other hand, CO₂ emissions are expected to increase by at least three times the 2015 value, regardless of the scenario. The energy access improvement scenario, which aims to accelerate energy access and clean cooking methods, is

expected to increase the amount of CO₂ emissions by a factor of five by 2030, mainly due to a high proportion of petroleum products, which is an excessive result. The energy efficiency and combination scenarios have the lowest carbon footprints, but their effects are assumed to be insignificant.

As stated earlier, the requirements of SE4All will not be met by 2030. The ambitious ‘Electricity for All’ policy is taking effect more slowly than foreseen, mainly due to lack of finances. The investments planned for the period to 2030 will not be sufficient to give a 42% share of renewable energy sources in the electricity mix. Actions promoting efficiency are still very limited.

Furthermore, this study has shown that the transport sector emits far more pollution than the other end-user sectors. The promotion of clean fuels such as biofuels should therefore be undertaken.

The supply–demand nexus in the power sector is very tense, meaning that the issues in relation to energy security will still be important in 2030. Although laudable efforts are being made to increase the share of green energy sources in the electricity mix, the introduction of coal will exacerbate greenhouse gas emissions.

Although energy access and low emission development strategies require colossal financial resources, the most important considerations for the Ivorian government are to opt for clean sources of energy, to intensify and educate all citizens and organizations on efficiency actions in every sector, and, above all, to maintain a climate of peace in the country.

The government clearly mentioned in the Electricity Code of 2014 its will to achieve energy efficiency in the short-term. Efficiency actions targeting buildings, home appliances, and the industrial sector have been planned since but not practically executed.

These combined efforts can lead to universal energy access and reduced greenhouse gas emissions, with their subsequent health benefits. In future research, depending on data availability, a cost analysis of the different scenarios should be conducted for better decision-making.

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Appendix

Table A1 Energy demand by fuel, final units (Mtoe)

Fuels	2015	2020	2025	2030
Reference scenarios				
Electricity	0.52	2.38	3.17	4.04
Natural gas	0.25	0.33	0.45	0.61
Gasoline	0.42	0.64	0.92	1.71
Jet kerosene	0.00	0.02	0.04	0.06
Diesel	1.01	1.35	2.13	2.86
Residual fuel oil	0.03	0.10	0.17	0.21
LPG	0.12	1.18	1.45	1.76
Wood	4.57	3.01	3.46	3.88
Total	6.93	9.06	11.83	15.19
Energy access improvement scenario				
Electricity	0.52	3.09	3.99	5.02
Natural gas	0.25	0.33	0.45	0.61
Gasoline	0.42	0.64	0.92	1.71
Jet kerosene	0.00	0.02	0.04	0.06
Kerosene	0.00	0.01	0.01	0.01
Diesel	1.01	1.35	2.13	2.86
Residual fuel oil	0.03	0.10	0.17	0.21
LPG	0.12	2.08	3.48	5.18
Wood	4.57	1.46	1.40	1.09
Total	6.93	9.07	12.57	16.74

Table A1 Energy demand by fuel, final units (Mtoe)

Fuels	2015	2020	2025	2030
Energy-efficiency scenario				
Electricity	0.52	0.82	1.35	2.36
Natural gas	0.25	0.28	0.40	0.60
Gasoline	0.42	0.58	0.89	1.68
Jet kerosene	0.00	0.02	0.04	0.06
Kerosene	0.00	0.05	0.05	0.06
Diesel	1.01	1.26	2.09	2.86
Residual fuel oil	0.03	0.10	0.17	0.21
LPG	0.12	1.18	1.45	1.75
Wood	4.57	1.27	1.86	3.96
Total	6.93	5.56	8.28	13.54

Table A2 Sectoral demand, all fuels (Mtoe)

Branches	2015	2020	2025	2030
Reference scenarios				
Residential	4.32	5.34	6.35	7.25
Industry	0.69	1.04	1.58	2.35
Transport	1.04	1.50	2.37	3.63
Services	0.72	1.00	1.29	1.36
Agriculture	0.12	0.15	0.21	0.29
Non-specified	-	-	-	-
Non-energy use	0.04	0.04	0.04	0.04
Total	6.93	9.06	11.83	15.19
Energy access improvement scenario				
Residential	4.32	5.36	7.09	8.81
Industry	0.69	1.04	1.58	2.35
Transport	1.04	1.50	2.37	3.63
Services	0.72	1.00	1.29	1.63
Agriculture	0.12	0.15	0.21	0.29
Non-specified	-	-	-	-
Non-energy use	0.04	0.04	0.04	0.04
Total	6.93	9.07	12.57	16.74

Table A2 Sectoral demand, all fuels (Mtoe)

Branches	2015	2020	2025	2030
Energy-efficiency scenario				
Residential	4.32	2.04	2.92	5.64
Industry	0.69	0.97	1.55	2.34
Transport	1.04	1.37	2.29	3.61
Services	0.72	1.00	1.29	1.63
Agriculture	0.12	0.15	0.21	0.29
Non-specified	-	-	-	-
Non-energy use	0.04	0.04	0.04	0.04
Total	6.93	5.56	8.28	13.54

Table A3 Electricity generation by share of input plants (Mtoe)

Branches	2015	2020	2025	2030
Scenarios: Reference, all fuels, feedstock fuels				
Hydropower plants	0.15	0.71	0.70	0.68
Thermal plants	0.80	1.61	1.60	1.57
Solid biofuels	0.01	0.06	0.06	0.06
Coal plant	-	0.52	0.53	0.53
Solar plants	-	-	-	-
Total	0.96	2.90	2.88	2.84

Table A3 Electricity generation by share of input plants (Mtoe)

Branches	2015	2020	2025	2030
Scenarios: Renewable energy, all fuels, feedstock fuels				
Hydropower plants	0.15	0.62	0.75	0.87
Thermal plants	0.80	1.40	1.60	1.57
Solid biofuels	0.01	0.17	0.28	0.38
Coal plant	-	0.37	0.53	0.53
Solar plants	-	0.02	0.02	0.02
Total	0.96	2.59	3.17	3.37

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Book Review

Gender, Power and Identity – Essays on Masculinities in Rural North India

Prem Chowdhry, Orient BlackSwan, 2019

Reviewed by Shivani Bhardwaj, Founder, Sathi All For Partnerships

Understanding violence in north India as a reaction of crises faced by masculinity required a deep dive into its causal roots. Prem Chowdhry has analysed the iniquitous causality of gender inequality by comparing the economy of power relations from pre-colonial to the post-globalized era. The introduction explains how masculinities as an academic pursuit in India have not picked up as a genre of work. Some essays published elsewhere have been placed in a systemic order, the conclusions are reworked to situate the crises on democracy resulting from the contradictions of solutions posed by Indian masculinity trends.

This book has addressed the gap in understanding concepts such as honour, liaison within caste boundaries, and the internalization of social control in the rural hierarchy with the economic perspective of volatile gender relations. The establishment of new state boundaries as in the case of Haryana redefined loyalty towards sanctions curtailing an existing culture of freedom. The author thus situates the concept of honour as a construct for maintaining social caste hierarchy which got juxtaposed with the militarization of masculinities.

The highlight of this book is a methodological delight. This chapter sets the trend of the alternate through a humorously presented family history of the author. Besides this chapter, all the essays authored by her were published between the period 2005 to 2015, with a very rich referencing that interlinks official data, archival evidence, laced with captivating oral traditions from Haryana.

The use of oral traditions informs analysis to communicate norms. From this study I was informed that oral traditions were used not only at the local grassroots but also by colonizers to work their recruitment and justice systems. Such an exercise helped them to perpetuate the image of patriarchal benevolence to win loyalist. Similar nuanced administrative strategies have been substantiated with examples from seasoned data from her 35 years of rich field and desk research in the region. Credibility of sourcing data to trace the history of masculinity from the undivided Punjab to the time of establishment of Haryana has interesting element of detail from the verdicts given by traditional rural authority that has existed through the ages, even today, to undermine the current ruling statutory power system.

The author argues that gender relations in the pre-colonial times were defined by consent in marriage as well as sexual liaison. She narrates folklore and idioms to evidence the existence of gender-equal choice. Both women and men made choices driven by the demand of labour to make the unproductive Haryana terrain yield agriculture and animal husbandry produce.

The option of earning through a job in the British army and government services such as schools and the postal department required basic education. The British loyalist were paid off through concessions and positions to foster inequality resulting in establishing the insubordination to germinate violent seeds of masculine norms.

The cultural context of rural north from the masculinity lens has been well depicted in two different essays to trace the strengthening of an ideological construct of patriarchal assertion. The male use of violence in the region is on the decline as quoted by Chowdhury who traces alternatives and the wind of change through different historic periods.

Caste and class hierarchy are not the only ones that challenge the masculinized hegemony which is ridiculed by women besides the lethal strokes of socio-economic waves. The author sites specific details through examples of the contestation of the male stature as reflected in the mood and messaging of three different folk songs sung by married women in the essay titled 'Popular Perceptions of Masculinity'. The women when left alone during marriages sing songs where they chide their aspiration of seeking lovers from among the outliers like fakirs, performers and lower caste men in search for better male virility. The organized attempt to subvert such discourse by men according to the author's research did not work and this situates contestation of power within the gender hierarchy. This subversion opens the possibility towards gender democracy that remains alive in women's popular culture. The narrative of the challenge women pose on the sexual adequacy on the male and his ability to income source is always within the hearing distance of the men from their childhood. Men thus congregate in spaces and indulge in either building their muscles or contraband activity such as substance abuse.

The geography of masculinities through the position and public spaces it controls do not escape the author's refined reasoning in most essays through the book. The spatial determines privileges that is the pepper displayed on the fluid power bastions. Whereas jobs in colonial area were taken by higher caste men this changed when reservations gave more jobs to the Dalit men. Armed with jobs in government services, the opportunity to impact the social hierarchies opened up for the lower caste men. This was then countered with the upper caste occupation of the

Khap or the traditional Panchayat that controls the sociological framework to maintain the movement of women outside the village social net to provide labour and reproduction within equals alone.

Having read the author to refine my own learning I view this feminist historian as a lighthouse whose analysis educated the policy maker to address the gender and generation gap in inheritance. The discourse on land rights and control of resources by the land-owning communities has been enriched by the intersectionality poised by the relevance of the book to understand both the personal and the political of the reader's quest for answers. The first readings however throw more questions than answers. Subsequent readings of the same chapters shed light on historical processing of information to guide individual answers for a way out of the maze of fact and lore.

In the essay that places the Crises of Masculinities in Haryana, the loss of male control over their own destiny is unfolded. The choice before the male in the wake of high unemployment, women laying claim on their right to land and youth getting elected for formal panchayats, the police or the justice system is determined by the non-productivity of land and the constant declining sex ratio in the region. The less number of females per male and their joblessness inflicted singledom on the Haryana male. These contexts are analysed by the author to place the stances taken on by traditional or the Khap Panchayat. The power of the elder higher caste males was eroded by the youth who got elected to Gram Panchayats. The elders addressed their masculinity crises by ordaining themselves the role of safeguarding the village norms in the form of cultural and customary law. The traditional panchayat in Haryana till date prevails at a much higher hierarchy to rule through a regime that makes statutory powers redundant in the case of formalizing conjugal relationships.

The essays explain the complexity of maintaining status quo of cultural norms by

a continuous cross referencing of cases dealt through the traditional panchayat that have made to regular news in national as well as published in the vernacular press. The women of Haryana origins have registered dissent with silent support from their men, in a few cases. However, not all women born or married into the region have had much success in moving the democratic space.

The Haryana Commission for Women saw no human right violation on the issue of buying girls and women as brides for sexual and all other forms of exploitative labour. Charity to the poor by including them as slaves has been a strategic choice practiced before feudalism. The practice not only has a political impunity based on the social sanction of the caste leaders, but it also acts as an internal power balancer. The choice of buying brides is shown to be typical for lower caste men, who flaunt the price they can afford to buy their legitimate needs. It additionally completely marginalized and isolated the bride, and her child as well, who was not from the state and stayed in the field, and did not mix with the family due to language and class handicap. This price paid is often spoken off to cement the bondage of the woman to stay on till the price can be paid back for her to buyback her freedom. The apparent social and physical exploitation of the women in such a marriage is inevitable. The men who marry such women also do not hold the same position as those who have marriage liaison sanctioned by the Khap.

Industrialization brought pliable migrants to work and reservations of government job to the lower caste not only increased unemployment but also control on marital and even sexual liaison. The woman had to bear the brunt of transgression of caste and norm boundaries whereas the man valorized by traditional caste leaders and the unemployed and unmarried men for the number of murders he had successfully committed with the range of weapons used. The men had sanction to buy brides from poor families from other states even as their status for doing so only placed them lower in the social ladder of the rural hierarchy.

The concluding essay on the 'Contradictions in Masculinities' has been reworked to place the might of alternate authority that exists within the fluidity of convenience and connivance of all that is extrajudicial and unconstitutional. The hope for dissent finds a mention with examples of ordaining women as members of Khap and the upholding of a united caste that is required to keep the rural economy floating. The show of caste unity does smother the dissent into silence especially when the written law fails to protect the victims of masculinities. The chapter on 'Alternatives present to the militarized masculinities' in the post-independence era is most interesting. It showed that alternatives can always work themselves through individual hard work. Therefore, the option to strengthen the possibility of a way forward is forever a choice to be made. This is true of the all ages; therefore it is seen that dissent is omnipresent to break inevitability of emerging normative behaviours.

The lived experiences of host of informants active in civil society, media, and the academia have also been depicted in the self-curated design of the book cover that is a painting by the author. The painting of a man holding his bamboo staff depicts his combative stature with an expression that does not give away emotion, not even through his eye that do seem paralyzed in a puzzled perpetuity.

In the era of radicalization of fundamentalism, this book will be referred to by those who wish to understand causal roots to either weak or for contributing towards strengthening masculinities. Since the compilation of the essays is placed within the historical formation of trends to record social change with law, this book could be used by inquisitive lawyers. For the analysis of the local institutions such as the Khap Panchayat, and practices of safeguarding honour, the book will immensely interest social work scholars too. Gender relations courses have to use this as a text book to laud the seminal nature of this academic research on the Indian masculine discourse. The concluding paragraph of the book is powerful and deserves to be understood better through several in depth readings of facts sown together in this book.

About the reviewer: Dr Shivani Bhardwaj has researched on gender resource gap for over two decades with a human right framework. She has led work on women and land rights to advocate for policy and law reform through

networks she has set up and coordinated. Her work on mainstreaming gender and child rights, mental health results in interaction with the excluded to link with them with academic and social reform interests.

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