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The impact of residential photovoltaic power on electricity sales revenues in Cape Town, South Africa

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ABSTRACT

In South Africa, electricity is provided as a public service by municipalities. The combination of (a) rising electricity rates, (b) decreasing photovoltaic technology costs, and (c) a progressive tariff system (under which wealthier households support low tariff rates for indigent residents) leads to incentives for high-income households to cover part of their electricity demand by self-produced photovoltaic (solar) electricity. This development is simulated with hourly load profiles and radiation data, and an optimization model for a case study in Cape Town through the year 2030. Results indicate that the majority of higher-income residents are incentivized to invest in photovoltaic power production by 2020 and additionally use home battery systems by 2028. This leads to a steadily increasing gap between revenues and expenditure needs in the budget of the municipality. The budget gap can be reduced by replacing the energy-based tariff with a revenue-neutral fixed network-connection fee implementation of which is particularly effective in reducing incentives to invest in storage.

1. Introduction

With a population of about 3.7 million people, the municipality of Cape Town represents one of the cultural, commercial, and political centers of South Africa (City of Cape Town (2012); Jenkins and Wilkinson, 2002). Similar to other South African cities, Cape Town still bears the legacy of apartheid through inequality and geographical separation (Lemanski, 2007; Smith, 2004). This leads to various efforts my municipal authorities to improve living conditions for underprivileged residents, such as seeking to improve housing infrastructure or provide basic services at low tariffs (Swilling, 2010). Access to affordable electricity is considered a basic need with high political importance in South Africa, as it has also been a central point in the government's Reconstruction and Development Program (ANC, 1994). The City of Cape Town has introduced a pro-favorable tariff structure for public services, such as electricity, based on its Equitable Services Policy Framework (Government of Western Cape (2003)).

Such a policy is relatively easy to implement in South Africa, since electricity is provided as public service by municipalities in contrast to privatized and liberalized power markets found in Europe and the USA. The municipalities purchase electricity at bulk-power tariffs mainly from the monopolistic power operator ESKOM, and then supply it to customers. In the case of Cape Town, the Electricity Services Department is in charge of designing different tariffs for customers depending on their consumption level as well as certain indigence criteria. This leads to a progressive tariff structure with high and middle-income households paying up to double the rate of the tariff compared to subsidized, low-income households (City of Cape Town (2014a)). With about 35% of the total budget, the electricity revenues are the largest share of general public revenues for the city (City of Cape Town (2013a)). According to officials and the city's annual book of budget[1], revenues from electricity are also partly used for cross-subsidization of other

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[1] Table 24 provides evidence and explains of the surplus of the electricity service department being used for transfers and contributions (City of Cape Town (2013a)).

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Nomenclature

$Egrid_{t,h}$ hourly electricity consumption from the grid, kWh
$Egrid\_block_{h,block}$ block-specific monthly electricity consumption from the grid, kWh
$Epv_{t,h}$ hourly electricity consumption from the PV system, kWh
$EstorageInflow_{t,h}$ hourly Electricity stored in the ST system, kWh
$EstorageLevel_{t,h}$ hourly level of battery storage, kWh
$EstorageOutflow_{t,h}$ hourly electricity consumption from the ST system, kWh
$EtoGrid_{t,h}$ hourly excess electricity fed into the grid, kWh
Expenses objective variable representing expenses for electricity, ZAR
$Gridcost_h$ electricity bill for electricity consumption from the grid, ZAR
$Ipv_{h,kwp}$ binary variable for the PV investment decision, Binary
$Istorage_{h,stcap}$ binary variable for the ST investment decision, Binary
$PVannuity_h$ annuities for the PV investment, ZAR
$STannuity_h$ auxiliary variable for calculation ST annuities, ZAR

Parameters
$Blockcap_{h,block}$ monthly caps of blocks of each tariff, kWh
$Edemand_{t,h}$ hourly electricity demand of each household, kWh
$FreeE_h$ subsidized monthly free electricity, kWh
i interest rate, %
Inverterreplace costs for replacement of the inverter in of system costs, %
MaxDisCharge maximal level of discharge depending on the ST capacity, %
$Netfee_{block}$ monthly fixed network-connection fee being calculated and externally included, ZAR
OMcost operation and maintenance cost in of the investment costs, %
$PVannuitycost_{kWp}$ cost parameter for calculation PV annuities, Numeric
$PVcost_{kWp}$ price for a PV system per kWp including installation and excluding inverter, ZAR
PVeff efficiency of the PV system, %
$Radiation_{t,kWp}$ hourly radiation output depending on the installed capacity (kWp), kWh
$STannuitycost_{stcap}$ cost parameter for calculation ST annuities, Numeric
$STcost_{stcap}$ price for a ST system per kWh capacity, ZAR
$Stmax_{stcap}$ capacity of the ST system, kWp
Storageeff efficiency of the ST system, %
$TariffLevel_{h,block}$ block-specific per kWh rate of each tariff, ZAR
ypv life time of PV system, Years
yst life time of ST system, Years

Subscripts
t hourly time step, Hour
h household, Nr. of households
block tariff block
stcap storage capacity, kWh
kWp PV generation capacity, kWp

public services such as water supply and sanitation (City of Cape Town (2013a); Swilling, 2010). In addition, electricity revenues entail the advantage of being sold mostly via a pre-paid system, which minimizes risks of non-payment problems (McDonald, 2009).

Apart from the progressive tariff structure, Cape Town's customers have also faced significant annual tariff increases in recent years, due mainly to rising demand for electricity caused not only by increasing living standards but in particular by the government's mass electrification programs over the past decades. Inadequate investment in infrastructure recently led to power shortages and calls for new capacities. The cost of new investments combined with traditionally low electricity prices caused an underfunding of ESKOM and eventually resulted in a sharp rise of electricity rates by about 16% annually (on average) over the last 10 years (City of Cape Town (2013a); Kohler, 2014; Pegels, 2010). This development evokes an under-discussed but relevant issue not confined to South Africa: with declining costs of residential photovoltaic technology (PV) and rising electricity rates, it becomes increasingly attractive for households to generate PV electricity. Even though this development supports the transition to a sustainable energy system, an increase of self-supply with PV electricity might lead to an eroding revenue base for South African municipalities such as Cape Town. The combination of (a) continuously increasing electricity rates, (b) the progressive end-user tariff design, and (c) the decreasing PV costs may incentivize especially higher-income households (with higher electricity consumption and sufficient financial means) to save electricity expenditures through residential PV electricity generation. From the city's perspective, this leads to a decline of electricity sales to higher-income households, which decreases the electricity revenues used to support the low tariff for indigent residents (South African Department of Energy (2011)). As illustrated in Fig. 1, this might result in a budget gap between electricity expenses and revenues from sales. Without any remuneration for excess PV electricity fed into the grid (such as a feed-in tariff), PV systems are not yet cost-effective, which is a disincentive for large-scale rollout of the technology by private households. However, if grid parity is achieved (in the early stages only for high-income households with higher rates), the city's electricity sales revenues are expected to decline steadily (Gets, 2013).

These trends reveal a potential trade-off between renewable electricity supply and maintaining the current poor-favorable energy policy. On the one hand, the city administration depends on electricity sales revenues, in particular from middle- and high-income households, for expanding electricity access and providing subsidized electricity to indigent households. On the other hand, as described by Becker and Fischer (2013), South Africa also identifies development of renewable energies as important. Rapid growth of residential PV would be in line with aims of decreasing CO_2 emissions and increasing the share of renewable energies (Msimanga and Sebitosi, 2014; Winkler, 2007; Winkler et al., 2011). Both aspects of energy policy have to be considered carefully.

This research is especially relevant in non-liberalized power markets where electricity is provided as a public service (generally by state-owned enterprises). While this is often the case in developing countries (Hall et al., 2010), the majority of published studies deals with the effects of distributed electricity generation in restructured or competitive supply markets (Fouquet, 1998; Haas et al., 2013; Menges, 2003; Milstein and Tishler, 2011). In particular, the impact of PV on retail electricity rates and consequently utilities is the focus of recent articles (Cai et al., 2013; Satchwell et al., 2014). Bode and Groscurth (2013) analyze PV grid parity in the German electricity market and find a substantial financial