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The politico-economics of electricity planning in developing countries: A case study of Ghana

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HIGHLIGHTS

- There is a focus on grid and off-grid electricity planning based on economics.
- However community preferences for grid introduces a political dimension to planning.
- We develop an algorithm to examine the politico-economics of electricity planning.
- We find different priorities yield significant regional differences in grid access.
- We find that greater policy focus on the effectiveness of grid investment is needed.

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ABSTRACT

Off-grid technologies are increasingly being proposed as a way of ensuring cost efficient universal access to electricity in many developing countries. However, many un-electrified communities would prefer access to electricity via the national grid rather than off-grid technologies. Electricity planning based on cost efficiency alone could therefore be undermined by political pressure from discontented communities that are assigned off-grid technologies. Using a case study of un-electrified communities in Ghana, we develop an electricity planning algorithm based on hierarchical lexicographic programming and consider specifications where the priorities are adjusted to give weight to (1) cost efficiency and (2) political economy considerations so that communities with larger populations (and therefore votes) are given priority in terms of grid electrification. The results emphasise the need to incorporate the political economy considerations in the national planning of universal electrification, showing significant regional differences in terms of where grid extensions ought to be placed. Incorporating a political economy perspective in national planning also suggests that the most important policy trade-offs shift from considering the grid versus off-grid balance to focussing more on the effectiveness of grid investment in providing universal access.

1. Introduction

It is estimated that up to 1.3 billion of the world's population have no access to electricity and of these some 97% reside in the world's developing regions (IEA WEO, 2014). The situation is most pronounced in sub-Saharan Africa (SSA) where the overall electrification rate is about 33% only (IEA WEO, 2014) with the rural rate lower still. The positive correlation between access to electricity and development is long established (Goldemberg, 2000), and although access to electricity in itself is not a remedy for development (Bhattacharyya, 2006), modest access to electricity (e.g. for lighting) can have substantial benefits on the welfare of the poor (World Bank, 2008).

In many cases, un-electrified rural settlements are remote from existing grid networks and thinly populated. High fixed costs mean the per capita cost of extending access to electricity via grid networks to these settlements can be very high and uneconomical. Meanwhile the high potential for the use of off-grid systems in SSA, particularly drawing on renewable resources such as wind and solar has been recognised by a range of authors including Buys et al. (2007) and Painuly and Fenhann (2002). In this context, a number of electricity planning algorithms that are capable of determining grid or off-grid compatibility of un-electrified settlements have been proposed. For grid assigned settlements, they also determine optimal routing into the existing grid network.

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They include the algorithms by Lambert and Hittle (2000), Amador and Domínguez (2005), Parshall et al. (2009), Deichmann et al. (2011), and Levin and Thomas (2012).

However these algorithms prioritise cost efficiency and implicitly assume that off-grid and grid electrification are of equal value and that financing is equally available. There is ample evidence to show that un-electrified communities in low income countries prefer to be connected via the grid. Survey evidence from Ghana suggest that communities are willing to "wait for the national grid no matter how long it takes" (Bawakyillenuo, 2012, p.417, para 1). Palit and Chaurey (2011) also report that many communities perceive off-grid technologies as inferior due to its fixed availability and limited supply, while Bhattacharyya (2013) highlights that access to off-grid technologies is often simply seen as a transition to grid technology. Such community preferences for the grid may be well founded if communities believe that grid electrification is more able to allow for future electricity demand growth, so that access through the grid provides a community with an inbuilt future economic advantage over electrification via off-grid technologies.

In reality these community preferences for grid electrification can feed into how the political process determines investments in grid and off-grid electrification.[1] Bawakyillenuo (2007) highlights the significant role that politicians' promises of grid access play within political campaigns in Ghana whilst Brown and Mobarak (2009) and Min (2011) find evidence that democracy appears to improve the electricity access of communities who are less prosperous (hence less cost efficient to grid connect) but have higher electoral weight (i.e. votes). There is therefore the need to reflect these preferences and influences in designing methods for electricity planning in developing countries. Electricity planning solely based on the economics of grid and off-grid technologies may be undermined by the political process as discontent off-grid assigned communities with political clout (votes) exercise political pressure for grid electrification.

This paper introduces a hierarchical lexicographic programming algorithm to solving the problem of planning for universal electricity access in developing countries. The algorithm determines the grid and off-grid compatibility of settlements and simultaneously routes grid assigned settlements into the existing grid network. Additionally, it allows flexibility in specifying priorities reflective of both cost efficiency and political economy considerations. We apply the algorithm to a detailed spatial country level data from Ghana. Specifically, cost efficient planning solutions are derived when electricity demand is prioritised for grid electrification, while political economy of electrification is captured by alternatively prioritising population. These different priorities can lead to quite different outcomes. As demand for electricity and economic development are positively correlated, prioritising demand leads to cost efficient solutions because communities and regions which are already most economically developed are chosen for grid extension. In contrast, prioritising population in grid extension will give more weight to communities with larger populations (reflecting their electoral weight), independent of their economic development status.

The plan of the remainder of the paper is as follows. In the next section we introduce the hierarchical lexicographic programming algorithm developed in this paper and discuss two of the existing cost effective algorithms. These are the algorithms proposed by Parshall et al. (2009) and Deichmann et al. (2011). We apply these three algorithms to Ghanaian data on un-electrified settlements in order to validate the new hierarchical lexicographic programming approach and to show how the cost and political economy implications of the different approaches compare.[2] In section 3 we discuss the data and assumptions required to apply the three approaches to the spatial Ghana data. Section 4 discusses our results. We present two sets of results using the hierarchical lexicographic programming algorithm. The first prioritises the demand of unconnected consumers and which promotes cost efficiency. The second prioritises the connection of all unconnected individuals equally hence capturing the political economy of grid access where voting can influence policy decisions. We conclude in Section 5 with a discussion of the policy implications of our findings.

2. Methods

Planning how best to provide access to electricity to those currently without access is a complex spatial problem. To simplify the problem, we follow previous authors and focus on un-electrified settlements to determine the appropriate pattern of where to extend the grid and where to use off-grid technologies whilst allowing for the relative costs of each. The complexity of the underlying optimisation problem means a global cost minimum can typically not be obtained for realistic cases and therefore heuristic methods are required.[3]

Before discussing the new algorithm introduced in this paper, we first discuss two existing algorithms in the literature that we also apply to the Ghanaian data to validate our new approach. These are the algorithms developed by Parshall et al. (2009), herein referred to as the PA method; and by Deichmann et al. (2011), herein referred to as the DA method.[4]

In practice, planning to provide access to electricity is a dynamic process, i.e. grid extension or new off grid investment takes place sequentially, with re-planning and changes to the original investment plan possible after initial investments have been made. Here, following previous studies we abstract from this and assume a single plan is implemented in a single year and so the modelling has no temporal dimension and answers the question of the cost of immediate universal electrification.

2.1. The PA method

This approach begins by computing the internal grid cost for un-electrified settlements. For each settlement, this cost is computed as the sum of the cost of connecting its households and institutions including the cost of MV–LV transformers, LV lines, internal household wiring costs, etc. Also for each un-electrified settlement, the costs of the off-grid technologies under consideration are calculated. If the internal grid cost for an un-electrified settlement is less than the cost of all off-grid technologies being considered, that settlement is identified to be 'eligible' for grid connection. For each eligible settlement a value MV_{max} is calculated as the maximum allowable length of a new primary MV line to be extended from the existing MV distribution network to the settlement such that the total grid cost (i.e. internal grid cost

[1] Although electricity is a private good, the goal of universal electricity access in development and the existence of natural monopolies in transmission and distribution mean that governments are deeply involved in the development and regulation of the electricity sector (Scott and Seth, 2013). Generally political power does affect the allocation of public goods across individuals and groups (Banerjee and Somanathan, 2007).

[2] The three algorithms applied in the paper were coded and implemented using the General Algebraic Modelling Systems (GAMS) software. A copy of the GAMs code developed for all three algorithms is available from the corresponding author.

[3] The global cost minimum can only be reliably found in small scale problems (Abdul-Salam, 2015).

[4] An IDE version of the PA algorithm is accessible at http://networkplanner.modilabs.org/docs/.