

# 1 Electricity access and rural development: review of complex 2 socio-economic dynamics and causal diagrams for more 3 appropriate energy modelling

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## 17 **Abstract**

18 The causal relationships between electrification and development of poor, rural communities are  
19 complex and contextual. The existing literature focuses mainly on the impact of rural electrification  
20 and electricity use on local socio-economic development, while the reverse feedbacks of various  
21 social and economic changes on electricity demand and supply have not been fully characterised.  
22 Most electricity access impact assessments assume linear, one-way effects and linear growth in  
23 electricity demand. However, the projections rarely match the reality, creating challenges for rural  
24 utilities. From a modelling perspective, the lack of attention to dynamic complexities of the  
25 electricity-development nexus prevents the appropriate modelling of electricity demand over time  
26 and, hence, informed planning for and sizing of power plants. With the goal to improve modelling of  
27 the electricity-development nexus, we undertake a comprehensive review and extensive analysis  
28 of the peer-reviewed literature on electricity access and its impact on rural socio-economic  
29 development, and vice versa. We characterise and describe the nexus between electricity access  
30 and development through graphical causal diagrams that allow us to capture, visualise and discuss  
31 the complexity and feedback loops. Based on this, we suggest guidelines for developing  
32 appropriate models able to include and simulate such complexities.

33 Our analysis confirms that electricity use is interconnected through complex causal relations with  
34 multiple dimensions of socio-economic development, viz. income generating activities, market  
35 production and revenues, household economy, local health and population, education, and habits  
36 and social networks. The causal diagrams can be seen as a first step of the conceptualization  
37 phase of model building, which aims at describing and understanding the structure of a system.  
38 The presence of multiple uncertain parameters and complex diffusion mechanisms that describe  
39 the complex system under analysis suggests that systems-dynamic *simulations* can allow

40 modelling such complex and dynamic relations, as well as dealing with the high uncertainties at  
41 stake, especially when coupled with stochastic approaches.

42

43 **Keywords:** rural electrification, electricity-development nexus, causality diagrams, energy  
44 modelling, complexities

## 45 **Introduction**

46 The International Energy Agency (IEA) estimates that 1,1 billion people do not have access to  
47 electricity, most of them living in rural areas (International Energy Agency 2017). Lacking reliable  
48 access to electricity is considered a limit on people's opportunities and quality of life. The role of  
49 energy as a key driver to sustainable development is now widely recognized by the global  
50 community, as evidenced by the fact that the Sustainable Development Goals (SDGs) include  
51 access to affordable, reliable, sustainable, and modern energy for all by 2030 as an explicit target.  
52 While the relationship between electricity use and development is known from a macroscopic and  
53 macroeconomic point of view, the local dimensions of the electricity-development nexus in poor,  
54 rural contexts are not completely captured and characterized. Experiences of international  
55 institutions like GIZ and the Energy Sector Management Assistance Programme (ESMAP) of the  
56 World Bank have highlighted the multifaceted aspects of the issue. They have shown that it is not  
57 enough to simply provide people with access to electricity and "hope for local economic activity to  
58 pick up by itself" ((Brüderle et al. 2011) pg. 8). Indeed, the literature emphasises that electricity  
59 access should always be accompanied and sustained by other enabling activities and services, in  
60 order to contribute to greater educational attainment, more business opportunities, and higher  
61 income at the local level (Bastakoti 2003; Colombo et al. 2013; Khandker et al. 2013). Against this  
62 backdrop, in this paper we review the complex nexus between electricity access and use, and  
63 socio-economic development of rural areas in the Global South.

64 The complexity of the problem renders the use of linear or pre-defined sets of relations of cause  
65 and effect to describe the issue inaccurate, since "the dynamics of growth and electrification are  
66 complex, involving many underlying forces" ((Khandker et al. 2013) pg. 666). According to Matinga  
67 and Annegarn, "simple deterministic relations between electricity access and development  
68 outcomes do not reflect reality" ((Matinga and Annegarn 2013) pg. 301), while Ahlborg (Ahlborg  
69 2015) confirms the presence of multiple interfaces and feedbacks that shape outcomes in  
70 electrification processes. The literature also suggests that the nexus between electricity use and  
71 rural socio-economic development has dynamic components, meaning that the nexus is  
72 characterized by complex feedbacks that can reinforce or balance impacts over time (Ulsrud et al.  
73 2011). Khandker's (Khandker et al. 2013) study of Vietnam's rural electrification program  
74 exemplifies how a "virtuous circle of development" emerged as significant investments in other  
75 rural infrastructure services were undertaken (viz. water supply, roads, health and education) and  
76 rural electrification contributed to greater educational attainment, more business opportunities, and  
77 higher income, which in turn improved the affordability of electricity and appliances, leading to an  
78 increase of total electricity load and more investments in rural electrification. Khandker, as well as  
79 others (Kanagawa and Nakata 2008), suggest that electrification, if supported by enabling  
80 complementary actions, can lead to positive feedbacks on future electricity demand in a rural  
81 context.

82 In rural electricity planning, being able to analyse and forecast electricity demand is pivotal to the  
83 development of sustainable and reliable electricity models and plans, especially those dealing with

84 the architecture and sizing of off-grid solutions. Inaccurate predictions can negatively impact local  
85 socio-economic development and cause unsustainable sizing processes of energy solutions,  
86 leading to negative consequences for the technical performance of the power supply (Ulsrud et al.  
87 2011), such as supply shortages or cost recovery failures (Hartvigsson et al. 2015). Existing  
88 energy demand models for off-grid electricity planning do not capture these complexities; indeed,  
89 they usually rely on simple estimates of the energy demand and its evolution over time. Given that  
90 such linear projections are commonly inaccurate, being able to understand and model aspects and  
91 dynamics that determine rural electricity use can lead to more robust energy planning and  
92 solutions in rural areas, as well as increase the current understanding of the energy-development  
93 nexus.

94 The goal of our study is therefore to:

- 95 (i) review and analyse literature which describes, explains, and discusses – through case  
96 studies, experiences on the field, and surveys – the impact of electricity access and  
97 consumption on rural socio-economic development, and vice versa;
- 98 (ii) discuss and capitalize on the literature's findings by describing the development nexus  
99 complexity through graphical representations – viz. causal diagrams (Coyle 2000).
- 100 (iii) derive insights and set useful guidelines for developing appropriate models able to  
101 include and simulate such complexities.

102 With this work, we try to make explicit the many aspects that influence electricity use and demand  
103 – that “energy problems go beyond purely technical and economic issues” ((Morante and Zilles  
104 2001) pg. 380). Our intended audiences are researchers in energy and socio-economic  
105 development, energy modellers, energy planners and policy makers involved in the global  
106 challenge of rural electrification. In particular, we aim at providing researchers and modellers with  
107 useful guidelines for developing robust long-term energy access scenarios; while we wish to  
108 provide the latter with a clearer view of the multifaceted and interrelated techno-economic and  
109 social complexities at stake, and consequent useful information for enhancing effective and  
110 sustainable electricity access policies.

## 111 **1. Background - Electricity access and rural development**

### 112 **1.1. State-of-the art**

113 In this section, we report the state of the art for review studies that focus on electricity access and  
114 rural development, trying to highlight the methodological progress achieved in the years and the  
115 new emerging challenges. Reviews studies of the socio-economic impacts of rural electrification in  
116 developing economies and formerly colonized countries started emerging in the 1980s. Within the  
117 context of the International Labour Office's World Employment Programme's research, Fluitman  
118 published a working paper in 1983, where he reviewed the available literature on rural  
119 electrification, its effects on rural industrialisation, and its impact on such socio-economic  
120 objectives as employment and income generation. The paper concluded that the socio-economic  
121 benefits of providing people with access to electricity in rural areas seemed to be overestimated.  
122 Also, he saw a need for “more judicious planning, formulation and evaluation of rural electrification  
123 programmes (pg. v)” for maximising the positive impacts of electrification-oriented investments.

124 In more recent years, other review papers on this topic have been published both in the grey and  
125 scientific literature. There is also an increasing interest in the impacts and sustainability of  
126 renewable energy based decentralised electricity provision. Among the grey literature, many  
127 country- or region- specific reports and evaluations papers are from donor organizations (World

128 Bank 2002; Khandker et al. 2009a, 2009b, 2012; UNDP Asia-Pacific 2012). The first chapter in the  
129 joint GIZ-ESMAP study “Productive Use of Energy” (PRODUSE) is a review of the impact of  
130 electricity access on economic development (Attigah and Mayer-Tasch 2013). Their main  
131 conclusion is that, despite a growing body of literature that indicate positive impacts of both  
132 electricity use and electricity quality on firm productivity, the magnitude of such impacts is highly  
133 country- and context-specific. In their report produced for UK Department for International  
134 Development, Meadows et al. (Meadows et al. 2003) provide an overview of the impacts of modern  
135 energy on micro-enterprises in developing economies. In accordance with the PRODUSE study,  
136 they also conclude that “modern energy can, but does not necessarily, affect the emergence,  
137 development, productivity and efficiency of micro-enterprise” ((Meadows et al. 2003) pg. 23). The  
138 Independent Evaluation Group (IEG) (Independent Evaluation Group (IEG) 2008), an independent  
139 unit within the World Bank Group, published a well-known document, which reviews the  
140 methodological advances made in measuring the socio-economic benefits of rural electrification on  
141 local communities in low-income countries. They concluded that electrification can have positive  
142 impacts on local communities, in terms of growth of local income generating activities, time-  
143 savings, educational and health improvements, but such results lack a quantitative scientific  
144 evidence base. In their World Bank working paper, Bacon and Kojima (Bacon and Kojima 2016)  
145 review the methods, findings and robustness of studies reporting strong links between energy,  
146 economic growth, and poverty reduction. Their goal is to support project teams and practitioners in  
147 identifying reliable studies without serious methodological or data problems.

148 In the scientific literature, reviews examine the cumulative evidence base as well as the  
149 methodological basis for measuring impacts. The survey by Ozturk (Ozturk 2010) focuses on the  
150 causal relationship between electricity consumption and economic growth at country-level, by  
151 investigating papers that employ econometric approaches to find relations between national GDP  
152 and electricity consumption (EC) indicators. Cook (Cook 2011) reviews the literature on the role  
153 and relation of electricity infrastructure in rural areas on economic growth and social development.  
154 Brass et al. (Brass et al. 2012) offer a comprehensive review on the main outcomes – viz. short-  
155 and long-term economic, educational and health implications – of distributed generation (DG)  
156 projects and programmes in developing countries. More recently, the same authors (Baldwin et al.  
157 2015) have expanded their review on DG and rural development to cover the issue of scale in  
158 distributed energy systems. Terrapon-Pfaff et al. (Terrapon-Pfaff et al. 2014) evaluate the impact  
159 and the sustainability of 23 small-scale renewable energy projects in developing countries,  
160 suggesting that the majority of the projects had positive effects on sustainable development.

## 161 **1.2. Novelty of the work**

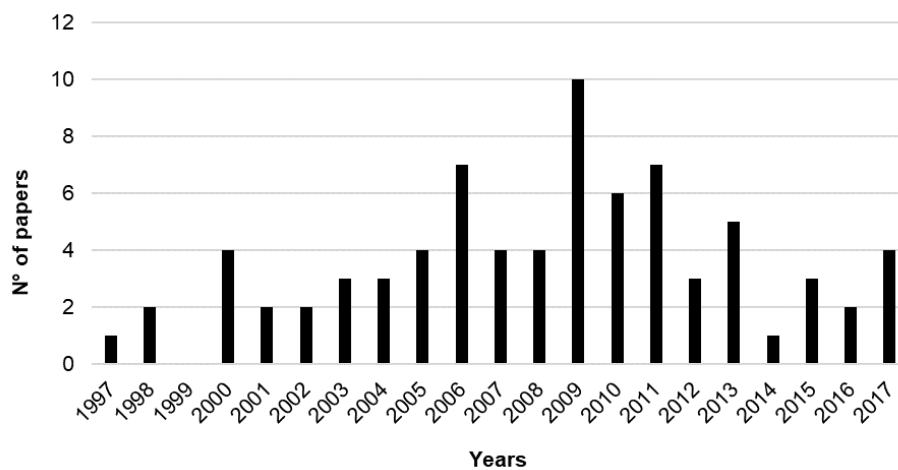
162 This review contributes a uniquely comprehensive overview of the complex causal relations  
163 between electricity access and socio-economic development. Based on our review, we find that the  
164 existing grey and scientific literature focus mainly on how rural electrification and electricity use  
165 affect local socio-economic development, while the reverse feedbacks are not systematically  
166 explored. Our review builds on the findings from existing reviews and studies, and it expands and  
167 adds the following novel elements: (i) an analysis of consequent feedbacks of socio-economic  
168 developments on electricity use and demand evolution over time, (ii) the representation – in terms  
169 of causal diagrams – of the insights that can be gained from the description of the dynamic  
170 complexities, and (iii) a discussion of the implications of the findings from an energy modelling  
171 perspective. Indeed, the electricity-development nexus is characterized by complex dynamic  
172 interactions, feedbacks, and behaviours. The understanding of such complex interactions requires  
173 therefore a more comprehensive investigation, which aims at analysing the “electricity-  
174 development nexus” as a *system* and not as a set of possible unidirectional correlations between

175 multiple dimensions – i.e. electricity use and access on one side, and socio-economic indicators on  
176 the other.

### 177 1.3. Rationale and methodology

178 We reviewed 78 peer-reviewed articles using Science Direct editorial platform and Scopus  
179 databases (some statistics are reported in Figure 1 and Figure 2). We selected only case-studies  
180 (and reviews of them) that report and discuss in-depth qualitative and quantitative findings about  
181 the nexus between electricity consumption and socio-economic development at a local level. In  
182 accordance with Brass et al. (Brass et al. 2012), we excluded grey papers, reports and documents  
183 produced by intergovernmental organizations, NGOs, donors, and government agencies, as we  
184 believe their active role in electrification projects and programmes might have biased the reporting  
185 of results and potential failures. The only exception is represented by Meadows et al.'s review  
186 (Meadows et al. 2003), which covers an unusually wide range of case studies of rural electrification  
187 and reports quantitative data. We excluded studies that only cite anecdotal evidence from other  
188 sources, as well as papers that limit their focus to feasibility studies, cost-benefit analyses, and  
189 prospective studies. In terms of technologies, we evaluate the local electricity-development nexus  
190 by considering the implementation phases (viz. material supply, construction, start-up) as a given.  
191 This choice allowed us to consider any type of electrification solution, from small standalone-PV  
192 systems to grid-extension options.

193 We delimit the review to social and economic dimensions, where the cumulative evidence is quite  
194 substantive. Some important, but less well researched (Ockwell and Byrne 2016) dimensions are  
195 outside the scope of this paper: we exclude political and institutional variables from our causal  
196 diagrams, and we do not explicitly highlight how gender relations influence the dynamics, which  
197 they do across a range of issues (Winther 2015). However, modellers can investigate gendered  
198 outcomes, to the extent that gender disaggregated data are available.



199  
200 **Figure 1.** Publication years of the reviewed papers.

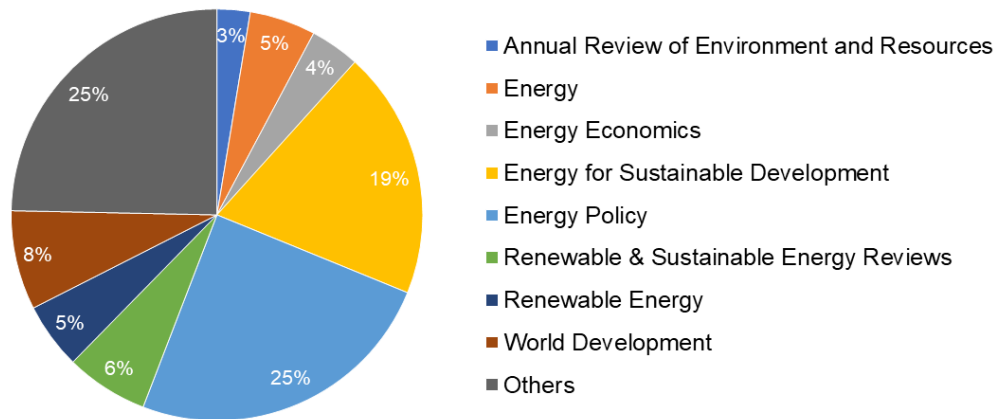


Figure 2. Journals in which the reviewed papers were published.

## 2. Review and analysis of dynamic complexities in the rural electricity-development nexus through causal diagrams

In this section we analyse the literature on the nexus between electricity demand and socio-economic development. We discuss and synthesize the main findings by representing the complex socio-economic dynamics through causal diagrams that highlight the reinforcing and balancing relations between the main variables characterising the nexus. Causal diagrams are conceptual models to represent complex systems, and therefore they include variables that are *meaningful* to people, but also *ambiguous* at the same time (e.g. the concept expressed by a variable can mean different things to different people (Luna-Reyes and Andersen 2003)). Section 3 proposes some guidelines for dealing with the formulation of possible models based on the qualitative variables conceptualized in causal diagrams. The variables in each diagram represent the different key-aspects of the electricity-development nexus mentioned in the literature. The arrows indicate the causal relationships; the positive “+” signs on the arrows indicate that the effect is positively related to the cause: an increase in the variable at the tail of the arrow causes the variable at the arrowhead to rise above what it would otherwise have been, in the absence of an increase in the cause. On the contrary, the negative “-” polarity of the arrows means that if the cause increases then the effect decreases.

From the literature, only two main dimensions of the nexus emerged clearly: (1) the *economic dimension* and (2) the *social dimension*. We analyse them separately, while we treat the impact of access to electricity on local environment as a cross-cutting dimension (e.g. household electrical lighting can cause less kerosene use, which decreases indoor air pollution with consequent possible improvements for household’s health).

### 2.1. Economic dimension

The nexus between electricity demand and local economic development develops over time. In the following, we review previous literature and discuss three main sub-nexus through which economic development might impact on the structure of a local rural economy and future electricity demand: (i) the nature and amount of *income generating activities*, (ii) *production and revenues*, and (iii) changes to the *household economy*.

#### 2.1.1. Income generating activities

With the term income generating activities (IGAs), we refer to all business activities and small-medium enterprises (SMEs) that provide a person with a regular or irregular cash-flow by selling

234 goods and services, regardless of the type of the business, the size or the location. The potentially  
 235 positive dynamics between electricity use and creation and spread of IGAs are reported and  
 236 explained at different analytical levels within the scientific literature. In this sub-section, we  
 237 organise the analysis of these dynamics into three different levels. First, we report on literature that  
 238 indicates a positive linear impact of electricity use on the creation of IGAs, but without explaining it.  
 239 Second, we discuss studies that report some causal reasons behind such potential impact, and  
 240 third, we review literature that cover nexus dynamics including feedbacks between creation of new  
 241 IGAs and electricity consumption. As expressed by Rao, “the causal effect of electricity supply on  
 242 NFE [non-farm enterprises] income is complex, and both direct and indirect” ((Rao 2013) p. 535).  
 243 Last, in this sub-section, we also summarize mechanisms that hinder a positive dynamic and  
 244 suggestions made by scholars on how to enhance the development of rural IGAs.

245 The majority of papers simply state that access to electricity brings about an increase in local IGAs,  
 246 especially the electricity-reliant ones. This portion of the literature lacks description of the  
 247 complexity of the nexus, and they mainly report the spreading of IGAs after electrification in poor  
 248 communities, as summarized in Table 1.

249 **Table 1.** Examples of impact of electricity use on IGAs' growth.

Reference	Mentioned impact of electricity use on new IGAs
Ravindranath et al. (Ravindranath and Chanakya 1986)	Access to electricity supported the creation of electric flour mills in Malanganj and B.N.Pura Indian villages
R. Kumar Bose et al. (Kumar Bose et al. 1991)	Access to electricity led to a 20% increase in business activities in three villages in Eastern Uttar Pradesh
B. Bowonder et al. (Bowonder et al. 1985)	Access to electricity led to the creation of repair and serving shops and village entertainment enterprises such as movie tents and community televisions (TVs) in eight rural communities in India
Cabraal et al. (Cabraal et al. 2005)	25% of households with electricity operated a home business in Philippines, compared to about 15% of households without electricity
Gibson and Olivia (Gibson and Olivia 2010)	Households connected to electricity increased their participation in non-farming enterprises by 13.3% in rural Indonesia, with the percentage of enterprises operated by rural households 43% higher after access to electricity
Mapako and Prasad (Mapako and Prasad 2007)	Results of the surveys on 73 small enterprises in the south west of Zimbabwe are reported with all the types and number of activities that were created after electrification; the total number of employees in these areas is reported to have been increased by 270%.
Bastakoti (Bastakoti 2006)	The Nepalese areas served by the Andhikhola Hydroelectric and Rural Electrification Centre (AHREC) experienced the creation of 54% more rural industries after electrification, allowing 600 more employees to have an income.
Prasad and Dieden (Prasad and Dieden 2007)	Data from South African national surveys suggest that somewhere between 40% and 53% of the increase in small, medium and micro-enterprises uptake is attributable to the grid roll-out.
Peters et al. (Peters et al. 2011)	The creation of electricity-reliant firms in regions with access in Rural Benin has been “a clearly positive effect of electrification” ((Peters et al. 2011) p. 781).
Jacobson (Jacobson 2007)	48% of the households interviewed in rural Kenya reported that the use of solar electricity supported some work- or income-related activities.
Adkins et al. (Adkins et al. 2010)	98.1% of adopters of solar lanterns in Malawi reported that the use of solar electricity supported some work- or income-related activities.
Kooijman-van Dijk and Clancy (Kooijman-van Dijk and Clancy 2010)	25% of households with electricity operated a home business in Philippines, compared to about 15% of households without electricity

251 At a second analytical level, some papers analyse the benefits of electrification on employment  
252 generation (related to construction, service provision and electricity use) in more detail by  
253 discussing the causal relations between access to electricity and the operation of rural economies.  
254 First, employment opportunities arise from the creation of new electrical infrastructures needed to  
255 satisfy local electricity demand and with the spread of new appliances and devices. In the causal  
256 diagram representing the dynamics between electricity demand and IGAs (Figure 3), this positive  
257 relation is represented by the link between *Electricity demand* → *Off-grid system related*  
258 *organizations* → *IGAs*. Studies such as those by Kumar et al. (Kumar et al. 2009) and  
259 Somashekhar (Somashekhar et al. 2000) report the creation of organizations in charge of  
260 manufacture, installation, operation and maintenance of new power generation infrastructures in  
261 India. Biswas et al. (Biswas et al. 2001) suggest that the operation, maintenance and  
262 administration activities of renewable energy technologies can bring positive impacts on the rural  
263 employment rate in Bangladesh. Second, an effect of rural electrification is the freeing up of time  
264 thanks to the use of electric appliances and services (instead of manual labour), especially for  
265 women who can use more time for home production (Grogan and Sadanand 2013; Khandker et al.  
266 2013) and market activities (Dinkelman 2011). The time savings allow for the establishment and  
267 extension of IGAs as mentioned in (Bastakoti 2006; Mulder and Tembe 2008; Kumar et al. 2009;  
268 Gurung et al. 2011; Sovacool et al. 2013). This dynamics is represented through the positive  
269 *Electricity demand* → *Free-time* → *IGAs* links. Finally, Dinkelman (Dinkelman 2011) indicates that  
270 South African electrification affected rural labour markets also by facilitating new activities for men  
271 and women, who started producing market services and goods at home through the adoption of  
272 new electrical appliances (e.g., food preparation, services requiring electric appliances) – positive  
273 *Electrical machines and devices* → *IGAs* link.

274 At a third level of analysis, some literature delves in more depth and investigates the propensity to  
275 establish new activities, invest in and extend IGAs, and the related feedbacks on electricity  
276 demand. As already highlighted, the possibility to use electrical devices makes new activities  
277 possible and for people to invest in: telephone booths, shops that produce and sell yoghurt, fresh  
278 drinks (Kirubi et al. 2009; Sovacool et al. 2013), ice-cream (Bastakoti 2006), office support services  
279 – e.g. faxing, word processing, photocopying, printing shops, computer centres (Lenz et al. 2017) –  
280 , energy stores, laundry services, hair dressers, photo studios (Bastakoti 2006; Shackleton et al.  
281 2009; Peters et al. 2011), saw mills, welders (Peters et al. 2011), village entertainment enterprises  
282 such as movie tents and community TVs (Bowonder et al. 1985; Bastakoti 2006), cold stores  
283 (Bastakoti 2006; Matinga and Annegarn 2013) – the positive *Electrical appliances availability* →  
284 *Propensity to invest* → *IGAs* link. Related to this, the diffusion and use of new electrical appliances  
285 and machines both require and allow the establishment of new small business activities that can  
286 offer regular maintenance and charging services (*Electricity demand* → *Local maintenance*  
287 *services*), as reported for rural Eritrea (Habtetsion and Tsighe 2002), Mali (Sovacool et al. 2013)  
288 (Moharil and Kulkarni 2009) (Meadows et al. 2003), and India (Bowonder et al. 1985). The  
289 presence and availability of local maintenance, in turn, encourages people to invest in electrical  
290 machines for starting new income generating activities, because of the easy access to repair  
291 services (Cook 2011) – positive *IGAs* → *Local maintenance services* → *Propensity to invest* →  
292 *Electrical machines and devices* → *IGAs* reinforcing loop. Thus, causal relationships are identified  
293 between the generation of new IGAs, development of maintenance services, people's willingness  
294 to make investments in electric devices and machines and further growth in electricity load – *IGAs*  
295 → *Local maintenance services* → *Propensity to invest* → *Electrical machines and devices* →  
296 *Electricity demand*.

297 What the literature also highlights is how the decision to set up a new business activity is highly  
298 dependent on the financial resources of people and their capability to mobilize these (Meadows et



299 al. 2003; Ahlborg 2015) – this is the reason why income increases from businesses or employment  
300 favour especially rich and middle income households (Jacobson 2007; Cook 2011; Kooijman-van  
301 Dijk 2012; Khandker et al. 2013; Matinga and Annegarn 2013) and increase economic inequality.  
302 Investment barriers often hinder poorer households from starting small businesses (*IGAs* →  
303 *Income inequality* → *Access to financial capital*). As a consequence, income is a pivotal driver of  
304 the decision to invest in new IGAs and new electrical devices to support businesses (Obeng and  
305 Evers 2010). Therefore, increasing the income earning opportunities and revenues, or reducing  
306 costs – for a larger part of the population – related to electricity use has a direct positive feedback  
307 on potential new investments in productive electricity demand (Ahlborg and Sjöstedt 2015) – the  
308 positive *IGAs* → *Average Income* → *Access to financial capital* → *Propensity to invest* → *Electrical*  
309 *machines and devices* feedback on *Electricity demand*.

310 Importantly, a significant portion of the literature is sceptical of the positive effects of electrification  
311 on the establishment and expansion of new IGAs (Stojanovski et al. 2017). The main reason  
312 provided by these studies is the high poverty and inequality level, which usually characterizes  
313 these contexts. As stated by Ahlborg and Hammar (Ahlborg and Hammar 2014), as long as a  
314 majority of people live below or close to the economic poverty line, the potential for beneficial  
315 dynamics between electricity access and local business and industrial development is very limited.  
316 Alazraki and Haselip (Alazraki and Haselip 2007) report that only 3% of people interviewed in rural  
317 provinces of Jujuy and Tucumán, Argentina, stated that access to electricity through PV-powered  
318 SHS allowed them to start a new business. Kooijman-van Dijk and Clancy state that employment  
319 opportunities as a consequence of access to electricity in Bolivian, Tanzanian and Vietnamese  
320 villages consist mainly of flexible and “unpaid involvement of family members” ((Kooijman-van Dijk  
321 and Clancy 2010) p. 18). Lenz et al. (Lenz et al. 2017) indicate that the majority of rural Rwandan  
322 households they interviewed were still farmers after electrification, with no significant changes in  
323 IGAs before and after electrification. One of the most recurrently identified obstacles to the  
324 expansion of rural business is the lack of a dynamic local market (Neelsen and Peters 2011;  
325 Kooijman-van Dijk 2012; Baldwin et al. 2015), leading to the “crowding out effect” of the existing  
326 firms, i.e. the creation of new IGAs that is followed by stagnation or economic losses among  
327 already existing IGAs (Kooijman-van Dijk and Clancy 2010; Peters et al. 2011), or a reduction of  
328 wages due to an abundance of labour supply over labour demand (Dinkelman 2011). We  
329 represented this effect through the positive link *IGAs* → *crowding out* which negatively affect the  
330 *Average Income* variable. In some contexts, the lack of credit for investment in new electrical  
331 equipment and grid connection represents a barrier to the set-up of new activities (Bhattacharyya  
332 2006; Grimm et al. 2013). For example, some entrepreneurs in rural Benin could not electrify their  
333 manufacturing processes because of the high cost for changing to more modern electricity-driven  
334 technologies (Peters et al. 2011); and more than three quarters of entrepreneurs interviewed in two  
335 rural communities near Lake Victoria in Uganda said that grid connection has too high a break-  
336 even point on the return on investment (Neelsen and Peters 2011). Peters et al. (Peters et al.  
337 2009) suggest that when there is a single-person business, electric machinery may have an hourly  
338 cost higher than human labour. This confirms that the lack of *Access to financial capital*  
339 discourages people in setting up or modernizing their business, i.e. it reduces people’s *Propensity*  
340 *to invest* and consequently the diffusion of new *Electrical machines and devices*. The decision to  
341 start a new activity and the consequent expansion of IGAs is also sometimes limited by the low  
342 quality of electricity supply (the negative *Power unreliability* → *Propensity to invest* link). Gibson  
343 and Olivia (Gibson and Olivia 2010) report that households in Indonesian villages, which never  
344 suffer blackouts, have an average of 1.3 more non-farm enterprises than in villages with frequent  
345 black-outs.

346 In order to overcome such barriers, several papers propose some complementary activities and  
347 actions to enhance the positive impact of electrification on the development of new IGAs,  
348 especially where no business “stemmed from electrification itself” ((Matinga and Annegarn 2013) p.  
349 299). This is especially important in order to support women entrepreneurs who in many countries  
350 find it harder than men to mobilise financial capital (Ellis et al. 2007). These exogenous activities  
351 are represented through dashed red arrows in the diagram of Figure 3. Facilitating access to credit  
352 and finance is the most common recommendation (Biswas et al. 2001; Bastakoti 2006; Adkins et  
353 al. 2010; Kooijman-van Dijk and Clancy 2010; Gurung et al. 2011; Peters et al. 2011; Brass et al.  
354 2012; Baldwin et al. 2015), since it allows people to set-up new IGAs, and facilitates a regular  
355 cash-flow, which in turn helps build financial capital (Bastakoti 2006) (*micro-credits* → *Access to*  
356 *financial capital*). Several studies (Bastakoti 2006; Cook 2011; Kooijman-van Dijk 2012; Sovacool  
357 et al. 2013; Baldwin et al. 2015) encourage stimulating the development of local markets and  
358 demand to decrease the crowding out effect (*market stimulation* → *Market demand* → *crowding*  
359 *out*) and increase people’s willingness to invest in new business opportunities (*market stimulation*  
360 → *Market demand* → *Propensity to invest*), and disseminating new technical skills through  
361 educational activities, business and manufacturing training for supporting the start of new IGAs  
362 (*capacity building* → *IGAs*). Providing access to accessible roads (*infrastructures* → *Market*  
363 *demand*) is also mentioned as a complementary activity (Kirubi et al. 2009; Gibson and Olivia  
364 2010; Kooijman-van Dijk and Clancy 2010).

365 Figure 3 represents the dynamics described above, highlighting the positive and negative  
366 feedbacks among variables, as well as indicating the complementary activities and conditions that  
367 positively enhance the dynamics. From this we learn that electricity demand in poor rural areas is  
368 characterised by variables that are highly interdependent, suggesting that the literature should put  
369 more emphasis on this aspect. The diagram indicates that the propensity to invest is a key-aspect  
370 affecting the growth of future electricity demand and the creation of new IGAs. Further, the diagram  
371 shows that people’s propensity to invest is positively affected by their financial capacity (which  
372 increases, if average income increases), the availability of electric machines and a local reliable  
373 maintenance service, and the growth of local market demand for goods and services. In particular,  
374 in case of investments in an electricity-reliant business, the “propensity to invest” variable signifies  
375 both the start of new electricity consumer-IGAs, as well as increased demand from existing  
376 electricity consumer-IGAs that expand their business by investing in more appliances and  
377 machinery.

378

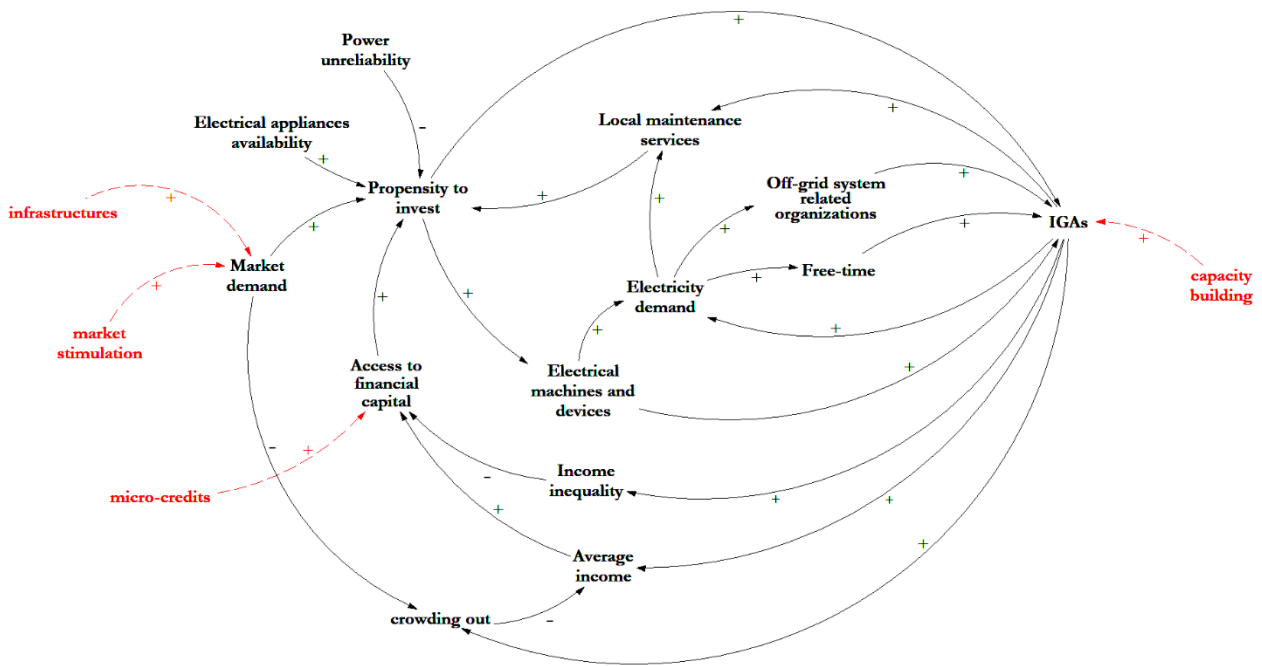


Figure 3. Causal-loop diagram representing the dynamics between electricity demand and IGAs.

### 2.1.2. Market production and revenues

The second sub-nexus we identify between access to electricity and economic impacts, is through local market production by IGAs and local revenues. We discuss the potentially positive dynamics of electricity demand and market production through different levels of analysis. First, we report on literature that indicates a positive potential impact of electricity demand on the productivity in local markets. Next, we discuss studies that analyse the impact of electricity use on the local markets – viz. the effect of electricity demand on market *demand* and *supply*. In the case of literature reporting low or no impacts, we highlight some complementary activities from the literature that might enhance the benefits of electricity on the operation of local markets. Finally, we review what feedbacks have been identified between local market production and electricity demand in the literature.

Our first level of literature analysis suggests that electricity use increases local production and people’s productivity, especially in new electricity-reliant businesses, as exemplified in Table 2.

Table 2. Examples of impact of electricity use on market production and revenues.

Reference	Mentioned impact of electricity use on market production and revenues
Ranganathan and Ramanayya (Ranganathan and Ramanayya 1998)	An extra kWh of electricity generated an incremental surplus of agricultural production for Indian farmers
Meadows and Kate (Meadows et al. 2003)	In India, energy-intensive enterprises that obtained access to modern energy achieved enhanced income levels of 30-40% more than enterprises that did not gain access.
Peters et al. (Peters et al. 2011)	In villages located in Northern Benin, the profits of connected firms were considerably higher, viz. 73.8% higher (statistically significant at the 5% level), than those of non-connected firms, and this is especially true for electricity-reliant firms.
Kooijman-van Dijk (Kooijman-van Dijk 2012)	It is found a positive relation between ‘electricity use for enterprise products and services’ and income from enterprises in the Indian Himalayas, although electricity is not considered the definitive solution to poverty reduction.

Gustavsson (Gustavsson and Ellegård 2004; Gustavsson 2007a)	In Zambia, lighting in the evening could improve teachers' income, enabling them to earn some extra income by teaching in the evening.
Cabraal et al. (Cabraal et al. 2005)	Households managing small cottage industries in rural India were able to increase their daily income using electric lighting to extend their productive hours after nightfall.

395

396 The studies that focus on the dynamics behind the possible increase in enterprises' productivity  
397 and revenues suggest that access to electricity and use may positively or negatively impact local  
398 markets by affecting local *supply* and *demand* of goods and services.

### 399 *Market demand*

400 Focusing on local market demand, the number of consumers for a given business may increase  
401 thanks to the increased use of communication devices and advertisements (Jacobson 2007)  
402 (*Electricity demand* → *Communication devices* → *Market demand*). Communication devices – e.g.  
403 TVs, radio and phones – may also introduce changes in aspirations and expenditures of rural  
404 households (Matinga and Annegarn 2013) for goods and services, diversifying purchases and  
405 leading people to shop locally rather than elsewhere (Shackleton et al. 2009). Neelsen and Peters  
406 (Neelsen and Peters 2011) report that electric lighting and the consequent increase in perceived  
407 security attracted potential customers also during the evenings in rural Uganda. Kirubi et al. (Kirubi  
408 et al. 2009) and Kooijman-van Dijk (Kooijman-van Dijk 2012) suggest that electric appliances allow  
409 for improvements in products' quality (*Electricity demand* → *Product quality* → *Market demand*)  
410 and production and/or selling of new products (*Electricity demand* → *Product innovation* → *Market*  
411 *demand*) which can attract more consumers or increase the demand per-capita, with positive  
412 impacts on local production and the consequent revenues (*Market demand* → *Goods/services sold*  
413 → *Net revenues*). In this context, Peters et al. highlight the risk that "to the extent that local  
414 consumer's purchasing power is diverted to the new electricity-reliant manufacturers, existing non-  
415 reliant manufacturers are likely to suffer a drain on business" ((Peters et al. 2011) pg. 778),  
416 increasing inequality.

417 Multiple studies report that such increases in the demand for products and services in turn causes  
418 an increase in price, due to market equilibrium rules (Meadows et al. 2003; Cabraal et al. 2005;  
419 Sovacool et al. 2013). However, this conventional equilibrating market mechanism does not always  
420 appear to apply in developing economies – as Banum and Sabot (Barnum and Sabot 1977) report  
421 for Tanzanian rural markets – which raises questions about the actual impact of improvements in  
422 products' quality on the price of goods.

423

### 424 *Market supply*

425 On the production-side, there are four mechanisms whereby electricity use can have a positive  
426 impact: (i) enhancing communication, (ii) enhancing work productivity, (iii) enabling longer work  
427 days, and (iv) decreasing energy-related costs. First, communication devices help improve the  
428 efficiency of business activities and the related market revenues (*Electricity demand* →  
429 *Communication devices* → *Production efficiency* → *Net revenues* in Figure 4). Cabraal et al.  
430 (Cabraal et al. 2005) report that the use of telephones in rural Thailand enabled farmers to  
431 regularly check prices in Bangkok and significantly increase their profits, while the use of the  
432 internet by Indian farmers allowed them to obtain current information on market prices and good  
433 farming practices, and consequently order appropriate agricultural inputs. Jacobson (Jacobson

434 2007) suggests that Kenyan owners of business activities benefited from receiving regular  
435 business information via television and radio, while the use of cell phones helped retail shops and  
436 other service-oriented businesses to place orders, make business deals, be in contact with their  
437 clients, and finally increase sales. This positive outcome of electricity use for productive purposes  
438 has been highlighted also by Khandker et al. (Khandker et al. 2013) for Vietnam.

439 Second, the use of electric machinery and appliances can help increase productivity, i.e. the  
440 number of products and services that an enterprise can supply in a given time period, which in turn  
441 increases the supply of goods to the local market. However, if the demand stays equal, it  
442 generates a drop in the price of goods, which can be offset by an increase in the volume of sales  
443 made (depending on the type of product/service), in turn increasing revenues (*Electricity demand*  
444 *→ Productivity → Market supply → Goods / services sold → Net revenues*). Kirubi et al. (Kirubi et  
445 al. 2009) report that the small-medium enterprises in a community-based electric micro-grid in rural  
446 Kenya experienced a significant increase in revenues in the order of 20–80%. Kooijman-van Dijk  
447 (Kooijman-van Dijk and Clancy 2010; Kooijman-van Dijk 2012) indicates that, when the market-  
448 demand is high, tailors that used electric sewing machines were able to increase the productivity  
449 by two to three times more than the average, while grain millers reported processing larger  
450 volumes of grains per day. The increase in demand for higher-quality products and services  
451 supplied by the use of electric machinery may enable sellers to fetch higher prices and increase  
452 revenues (Meadows et al. 2003; Kooijman-van Dijk 2012; Sovacool et al. 2013). On the other  
453 hand, an increase in productivity brought about by access to modern machines may decrease the  
454 need for human resources, causing a decrease in the employment rate and individual revenues  
455 (the negative *Productivity → Human labour → Average income* feedback): Meadows et al.  
456 (Meadows et al. 2003) report that in rural Indonesia, the introduction of a wind power pump  
457 reduced human labour input by a factor of 10, from 1040 to 100 hours.

458 Third, access to electricity may improve sales and businesses by extending operating hours thanks  
459 to lighting (Alazraki and Haselip 2007; Mishra and Behera 2016) (*Electricity demand → Evening*  
460 *work time → Market supply*). Meadows et al. (Meadows et al. 2003) state that the introduction of  
461 battery-operated lamps in rural Bangladesh allowed tailors to work for four more hours and thereby  
462 increase their revenue by 30%, while rice milling activities were performed during 7 to 9 p.m. in  
463 Hosahalli village (India). Agoramoorthy and Hsu (Agoramoorthy and Hsu 2009) report on the  
464 experience of some households in India, who suggest that lanterns provide opportunities to expand  
465 business and allow more time to work at night when compared to fuel-based lighting sources.  
466 Jacobson (Jacobson 2007) suggest that lighting in the evening can benefit and positively impact  
467 teachers' income in rural schools in Kenya, enabling them to grade papers, plan evening lessons  
468 at home and earn some extra money. Similar increases in productive hours during evenings are  
469 reported by Komatsu et al. (Komatsu et al. 2011), who report that households in the rural districts  
470 of Comilla, Kishoreganj, and Manikganj in Bangladesh extended their working hours by about two  
471 or more hours in the evening, while 56% of connected firms surveyed by Peters et al. (Peters et al.  
472 2009) in Copargo (Benin) declared working longer thanks to lighting that extended their daily  
473 operating hours. The same effect of night-lighting was reported by Chakrabarti (Chakrabarti and  
474 Chakrabarti 2002) and Baldwin et al. (Baldwin et al. 2015), who indicated that, in Sagar Dweep  
475 island in West Bengal (India), shopkeepers and workers engaged in handicrafts extended their  
476 working hours in the evening. The increase of daily working hours is especially common for  
477 commercial activities located in residential areas, where the demand is higher (Neelsen and Peters  
478 2011), shops and barbers (Meadows et al. 2003; Kooijman-van Dijk and Clancy 2010), and  
479 restaurants, whose increasing in operating hours has a direct impact on revenues (Kooijman-van  
480 Dijk 2012).

481 Several papers are also sceptical about the positive effects of electrification on the extension of  
482 operating hours. For example, Adkins et al. (Adkins et al. 2010) state that less than 10% of solar  
483 lantern users experienced expanded business opportunities by working more at night. In rural  
484 Indian Himalayas, only half of entrepreneurs with access to light worked regularly in the evening  
485 (Kooijman-van Dijk 2012), because of structural barriers, such as distance from main roads or time  
486 limitations of workers. In some cases, evening light is considered merely a means of guaranteeing  
487 more flexibility at work (Kooijman-van Dijk and Clancy 2010; Kooijman-van Dijk 2012). Moreover,  
488 for producing enterprises, increasing working hours does not result in new consumers, but simply  
489 increases production volumes (Kooijman-van Dijk 2012). Sometimes, an increase in productivity as  
490 a result of more efficient machines may even reduce working hours (Kooijman-van Dijk and Clancy  
491 2010) (the negative *Productivity* → *Evening work time* feedback). These findings suggest that two  
492 determining factors for increasing night operation may be the availability and reliability of electricity  
493 during night hours (Kooijman-van Dijk and Clancy 2010; Obeng and Evers 2010) (the negative  
494 *Power unreliability* → *Evening work time* feedback) and market demand (*Market demand* →  
495 *Evening work time*).

496 Fourth, there is evidence that the use of electricity for productive purposes may increase profit  
497 margins by reducing the cost associated with other energy resources (Habtetsion and Tsighe  
498 2002) (*Electricity demand* → *Traditional sources of energy* → *Energy cost* → *production efficiency*  
499 → *Net revenues*). Matinga and Annegarn (Matinga and Annegarn 2013) report that some  
500 shopkeepers experienced a marginal reduction of operational costs associated to refrigeration,  
501 since they found gas more expensive than electricity. Electricity may be cheaper than diesel for  
502 running machinery, as evidenced in Mawengi (Tanzania), where electric milling machines  
503 significantly reduced the cost of milling the staple maize in comparison to the previous use of  
504 diesel-powered machinery (Ahlborg 2015). In Vietnam, milling 1 ton of rice with diesel costs at  
505 least four times more than by using electricity (viz. US\$ 2.6 against US\$ 0.6) (Kooijman-van Dijk  
506 and Clancy 2010). In the Syangja District in the western region of Nepal, an electric mill could  
507 reduce costs by 30-50% with respect to diesel-powered ones (Bastakoti 2003). Sometimes,  
508 savings are attributable to a shift from grid power supply to stand-alone or microgrids (Kumar et al.  
509 2009). However, fuel-shifting may sometimes cause higher expenditures for the producer (*Power*  
510 *unreliability* increases *Energy cost*).

511 As a matter of fact, energy-cost savings are extremely dependent on the quality of electricity  
512 supply, since unreliable access to electricity – i.e. frequent black-outs, high voltage fluctuations and  
513 frequency instability – may negatively impact productivity and cause huge economic losses  
514 (Kooijman-van Dijk 2012) and very low satisfaction with electricity supply (Aklin et al. 2016), as well  
515 as the need to pay for back-up energy options like diesel. In rural Indonesia, power supply  
516 unreliability reduced the number of activities operated by each household (Gibson and Olivia  
517 2010). Zomers (Zomers 2003) and Meadows et al. (Meadows et al. 2003) report unreliable energy  
518 service as one of the main problems that entrepreneurs in rural areas encounter. Unreliable or  
519 expensive electricity can, hence, increase the cost of production leading to an increase in price and  
520 consequent decrease of market demand and sales. Such drawbacks related to service quality and  
521 cost may deter entrepreneurs from gaining access, as in the case of rural Uganda (Nielsen and  
522 Peters 2011).

523 In light of the discussion above, we can identify factors and feedbacks that explain how electricity  
524 use can either positively boost, or have a little impact on, economic production at the local level. In  
525 order to enhance electricity-related productivity, the literature indicates the need for complementary  
526 activities and certain preconditions. First of all, reliable electricity supply is a key factor for  
527 enhancing the productivity of small-scale operators and rural enterprises (Meadows et al. 2003;

528 Wolde-Rufael 2005), highlighting the importance of appropriate operation and management  
529 activities (*appropriate O&M of power system can reduce Power unreliability* and in turn decrease  
530 the negative effect of unreliability on *Productivity*). Second, access to favourable credit terms can  
531 support the decision of local entrepreneurs to adopt new electrical devices, and therefore increase  
532 their production (Bastakoti 2003; Peters et al. 2009; Kooijman-van Dijk and Clancy 2010) (*micro-*  
533 *credits* → *Electricity demand*). A sustainable increase in production requires an accompanying  
534 increase in market demand (Peters et al. 2009), also in the evenings (Kooijman-van Dijk 2012). To  
535 facilitate such a development, other infrastructures such as roads and telecommunications need  
536 improvements, as these can reduce transactions costs and make rural IGAs “competitive in out-  
537 sourcing of business services and products destined for the lucrative urban markets” ((Kirubi et al.  
538 2009) p. 1219) (*infrastructures* → *Market demand* → *Goods/services sold*). For example, Lenz et  
539 al. (Lenz et al. 2017) report that in rural Rwanda, only rural communities located next to a main  
540 road and frequented by casual customers from outside experienced a net increase in income  
541 through sales of improved services and goods. In this context, capacity building plays an important  
542 role in supporting entrepreneurs’ social skills and networks to access new markets (*capacity*  
543 *building* → *Production efficiency*), and technical skills to innovate and sell products (*capacity*  
544 *building* → *Product innovation*) (Bastakoti 2006; Kooijman-van Dijk 2012).

545 Given the social, economic and geographical conditions of poor rural areas, the major impact of  
546 electricity use on local economies occurs when there is an increase in the net revenues or people’s  
547 incomes. Improved access to financial capital may result in a positive feedback on local electricity  
548 demand, enhancing positive dynamics at a firm-level, where net revenues can be invested in more  
549 electrical machinery (*Net-revenues* → *Average income* → *Access to financial capital* → *Electricity*  
550 *demand*) or in extending operating hours and business opportunities (*Net-revenues* → *Market*  
551 *supply*). A positive feedback can develop also at household-level if more income allows people to  
552 increase their expenditures, boosting the market demand for (new) goods and services, which in  
553 turn provides households with further opportunities to reduce costs and make money (Kooijman-  
554 van Dijk and Clancy 2010) (the reinforcing loop described by *Average income* → *Market demand*  
555 → *Goods/services sold* → *Net revenues* → *Average income*). The financial status of families is a  
556 pivotal parameter to consider for modelling their willingness to increase electricity load, especially  
557 in terms of appliance ownership. For example, Aklin et al. (Aklin et al. 2015) suggest a positive  
558 relation between income and electricity access by deriving econometrically the relation between  
559 household’s wealth, electrification status (*viz.* if an household has access to electricity or not) and  
560 hours of electricity used per day (for Indian households living in slums, urban and rural areas). We  
561 address the nexus between household economy and electricity demand more thoroughly in the  
562 next dedicated sub-section of the paper.

563 Figure 4 presents the causal loop diagram for electricity demand and market production and  
564 revenues. It visualizes the dynamics above, highlighting the positive and negative feedback among  
565 variables, as well as indicating the complementary activities and conditions that may enhance the  
566 dynamics (the dashed red lines). The main feedback on growth in electricity demand is an increase  
567 of people’s income and access to financial capital.  
568

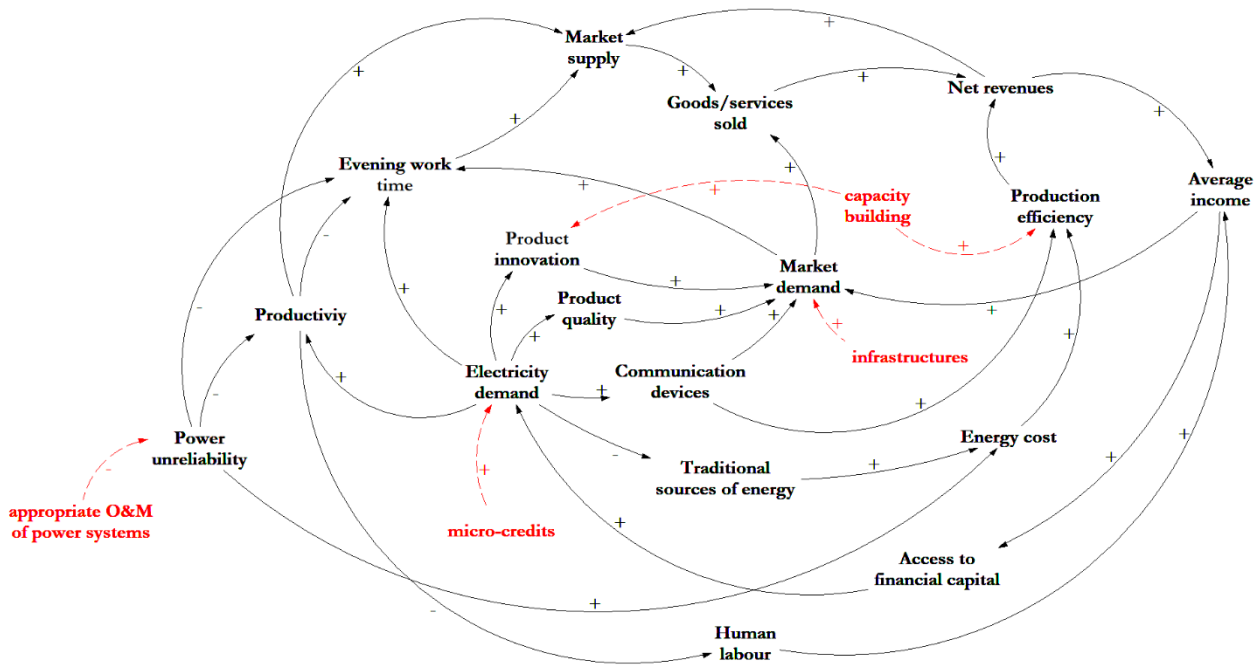


Figure 4. Causal-loop diagram representing the dynamics between electricity demand and local market production.

### 2.1.3. Household economy

In the previous sections, we identified a positive loop between increasing electricity demand, an increase in net IGAs and their sales of goods and services, which in turn can increase market revenues. Since the feedback of net revenues on electricity use involves domestic access to financial capital, in this sub-section we try to focus specifically on the nexus between electricity use and households' economy, which involve different dynamics than that related to business activities alone.

As a direct effect of the dynamics identified in the previous sections, the increase in market production and employment given by electricity use can boost households' financial capacity by a positive change in financial inflow (Ranganathan and Ramanayya 1998; Cabraal et al. 2005) (*Electricity demand* → *Net revenues* → *Income from IGAs activities* in Figure 5). Table 3 reports some examples from the literature, which suggests that access to electricity benefits the household economy, since electricity-reliant IGAs are more productive than their unconnected counterparts, in the range of 30% to 78% more, depending on the context. However, few studies provide statistically reliable estimates with appropriate intervals of confidence and clear definitions of the baseline used, reducing the reliability of data for modelling purposes.

Table 3. Examples of impact of electricity use on household economy.

Reference	Mentioned impact of electricity use household economy
Shackleton et al. (Shackleton et al. 2009)	Entrepreneurs who invested in small "productive use containers" powered by solar panels benefited from extra monthly sources of income in South Africa.
Sovacool et al. (Sovacool et al. 2013)	It is described the effect of the distribution of "multifunctional platforms", i.e. "small 8-12 horsepower diesel engines mounted on a chassis, to which various components can be attached" (pg. 117), in rural Mali. There, families experienced about 13.6% extra income per year (viz. about \$68 in additional revenue per year per family, considering that the average household lives on \$1.37 per day).
Gibson and Olivia (Gibson and Olivia 2010)	Income shares of non-farm enterprises (NFEs) are higher for rural Indonesian households that are connected to the public electricity network, viz. about 3.7% against 2.2%; it is indicated that the quality of power supply has a direct effect on income from productive



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	activities, since the share of rural income from non-farm enterprises is estimated to be 27% higher for households in villages that never suffer blackouts ( <i>Power unreliability</i> → <i>Average income</i> ).
Balisacan et al. (Balisacan et al. 2003)	Households' income benefits are mainly experienced by richer families ( <i>Income from IGAs activities</i> → <i>Income inequality</i> ): a 10% improvement in access to electricity raised income among the poor by only 2%.
Rao (Rao 2013)	Through a multivariate regression, it is estimated that at the village level, access to at least 16 h of electricity per day might be responsible for 18% higher income for connected Indian NFE than non-connected ones. The study further finds that the expected income for an electrified household is 43% higher based on a propensity score matching model.
Bensch et al. (Bensch et al. 2011)	It is found a positive difference in income between connected and non-connected households in Rwandese electrified villages. It is also confirmed a difference in income also between connected households in electrified villages and households in non-electrified villages that they identify as "likely to connect to an electricity grid". Nevertheless, the robustness and significance of the results disappear when regional differences are accounted for, suggesting caution regarding the finding of a positive effect of electricity on income.
Khandker et al. (Khandker et al. 2013)	In 42 Vietnamese communes, household electrification is responsible for a growth of 21% and 29% in total and non-farm income, respectively. They found also a substantial spill-over benefit to non-connected households ( <i>Electricity demand</i> → <i>Spill-over effect</i> feedback that reduces <i>Income inequality</i> ).

---

588

589 Electricity use impacts also on households' *financial outflows*, viz. expenditures. As discussed in  
590 the previous sub-section, this is mainly due to improvements in products' quality and the availability  
591 of new products and services, following the modernization of production and other technologies  
592 (*Electricity demand* → *Product quality* → *Average market expenditures* and *Electricity demand* →  
593 *Product innovation* → *Average market expenditures*). It attracts more consumers and increase the  
594 per capita demand for some products and services (*Average market expenditures* → *Market*  
595 *demand*). Second, since households' expenditures depend on people's access to financial capital,  
596 the potential increase in family income has a direct effect on boosting the demand for goods and  
597 services (*Average income* → *Access to financial capital* → *Average market expenditures* → *Market*  
598 *demand*). Indeed, as Kooijman-van Dijk and Clancy (Kooijman-van Dijk and Clancy 2010) state,  
599 there must be a willingness to pay for the expected "new" goods and services produced by new  
600 IGAs. Khandker et al. (Khandker et al. 2012) indicate that electrification in India increased  
601 household per capita food expenditure by 14%, non-food expenditure by 30%, and total  
602 expenditure by more than 18%. Zhang and Samad (Samad and Zhang 2016) report lower results,  
603 suggesting that gaining access to the grid in India is associated with an 8.4% increase in  
604 households' per capita food expenditure, a 14.9% increase in per capita non-food expenditure, and  
605 a 12% increase in per capita total expenditure. Again, these positive results are also dependent on  
606 the reliability of access to electricity and the quality of power supply (*Power unreliability* decreases  
607 *Market demand*). Zhang and Samad indicate that every one-hour increase in power outages may  
608 decrease food expenditures by 0.2% on average, which in turn, potentially, reduce farmers'  
609 incomes. What these results indicate is that increase in household's access to financial capital can  
610 feed back on electricity demand, i.e. the increase in families' expenditures can in turn stimulate the  
611 modernization and electrification of market production and the use of electric lighting for evening  
612 work (*Access to financial capital* → *Average market expenditures* → *Market demand* → *Market*  
613 *supply* → *Electricity demand*).

614 Electricity use causes changes in people's expenditures for domestic energy supply. Considering  
615 lighting alone, the literature confirms that households experience a reduction in expenditures for  
616 energy use, especially for purchasing kerosene (Ulsrud et al. 2015; Grimm et al. 2017) (*Electricity*

617 *demand* has a negative feedback on *Traditional sources of energy* that cause a reduction on  
618 *Energy cost expenditures*). Edwin et al. (Adkins et al. 2010) report that in rural Malawi, after the  
619 introduction of LED lanterns, lighting expenditures – all sources excluding the cost of the device –  
620 had fallen from \$1.06 per week to \$0.15 per week after lantern purchase. Similarly, Agoramoorthy  
621 and Hsu (Agoramoorthy and Hsu 2009) indicate that after the spread of solar lanterns in Indian  
622 Dahod District, each household saved on average \$91.55 ( $\pm 63.06$ ,  $n=100$ ) in energy costs per  
623 year, a huge saving if compared to households' yearly income ranging from \$150 to \$250.  
624 Wijayatunga and Attalage (Wijayatunga and Attalage 2005) report that when the cost for grid  
625 expansion is borne by the government, households in Sri Lanka are estimated to pay only \$1 per  
626 month on average, which represents a relatively high cost saving if compared to the about \$5.4 of  
627 avoided cost for kerosene usage and battery-charging. Lenz et al. (Lenz et al. 2017) report that  
628 households electrified by grid-extension in 42 rural communities in Rwanda experienced a  
629 reduction of one-third in their energy expenditures. A reduction of energy expenditures therefore  
630 means an increase in people's access to financial capital that can be allocated for more market or  
631 food expenditures (*Energy expenditures*  $\rightarrow$  *Access to financial capital*  $\rightarrow$  *Average market*  
632 *expenditures*), contributing to a positive feedback on local market production and electricity  
633 consumption.

634 However, the picture changes when the cost of power production technologies and non-lighting  
635 appliances are considered, with households experiencing sometimes an increase in energy  
636 expenditures after electrification (Davis 1998; Bensch et al. 2011)(Martinot et al. 2002) (*Electricity*  
637 *demand*  $\rightarrow$  *Energy cost expenditures*). Wijayatunga and Attalage (Wijayatunga and Attalage 2005)  
638 report that for households that received a subsidy of about \$100 for a solar home system (SHS) in  
639 Sri-Lanka, the monthly repayment of the system stood at \$8.4 for a period of 5 years, that is, \$3  
640 higher than the cost of avoided kerosene usage and battery-charging – *i.e.* a little over 15% of their  
641 income was spent on the SHS repayment, whereas the expenditure on kerosene and battery-  
642 charging before SHS installation was only around 10% of their income. Komatsu et al. (Komatsu et  
643 al. 2011) indicate that households with a SHS spent more in total on energy supply than before,  
644 because of the monthly payments for the system, though the reduced costs of kerosene and  
645 rechargeable batteries account for 20–30% of the monthly payments. Moreover, kerosene saved  
646 by some households can represent a source of income if sold to non-electrified neighbours (Roy  
647 2000). Wamukonya and Davis (Wamukonya and Davis 2001) state that Namibian households  
648 experienced a marked increase in energy expenditure after electrification. Indeed, whilst a shift  
649 from the use of candles and paraffin to electric lighting may decrease direct energy costs, the  
650 adoption and use of other appliances like irons, refrigerators, TVs, *etc.*, can substantially increase  
651 the final energy bill. If the increase of energy expenditures is not supported by a proportional  
652 increase of income, it can cause a decrease in market expenditures and in turn a decrease in  
653 market supply and electricity use.

654 Income, therefore, plays an important role in defining the capacity of people to increase their  
655 electricity use and their willingness to pay for electricity (Kobayakawa and Kandpal 2014; Alam and  
656 Bhattacharyya 2017) (*Average income*  $\rightarrow$  *Access to financial capital*  $\rightarrow$  *Electricity demand*),  
657 especially in its two main constituents:

- 658     ▪ **The installed load.** The literature suggests that the willingness of people to be connected,  
659     and to buy and own electrical household appliances, depends on their income. In their rural  
660     electrification model, Hartvigsson et al. (Hartvigsson et al. 2018) define the potential  
661     number of electrical connections as a function of different socio-economic parameters,  
662     including the average income of people. Lenz et al. (Lenz et al. 2017) state that the  
663     wealthier or more modern a household is, the more inclined it will be to get a connection. In

664 their Residential Energy Model Global (REGM) applied to India, China, South East Asia,  
665 South Africa and Brazil, Ruijven et al. (van Ruijven et al. 2011) and Daioglou et al.  
666 (Daioglou et al. 2012) represent the diffusion and ownership of household electric  
667 appliances, through a logistic (or S-shaped) curve, as a function of household's  
668 expenditures (considered in their work as a proxy of income). Louw et al. (Louw et al. 2008)  
669 suggest that the use of electricity by low-income South-African households is a cost-based  
670 decision based on income, especially regarding the ownership of electrical appliances,  
671 which depends on prices of devices and people's affordability. The importance of  
672 appliances' costs in relation to people affordability is also pointed out by Prasad (Davidson  
673 et al. 2006).

674

- 675 ■ **The kWh of electricity consumed.** The quantity of electricity consumed is another aspect  
676 that might be influenced by people's income. Louw et al. (Louw et al. 2008) conclude that  
677 for South African households the demand for electricity shows elasticities<sup>1</sup> ranging from  
678 between 0.24 and 0.53, depending on the model. This low value is probably attributable to  
679 the subsidized tariff that makes electricity more affordable for the poor. Pachauri and  
680 Filippini (Filippini and Pachauri 2004) used disaggregate survey data for about 30,000  
681 Indian households, and conclude that electricity is income inelastic in the winter, monsoon  
682 and summer seasons. They estimate that elasticity ranges between 0.60–0.64 across the  
683 three seasons. Tiwari (Tiwari 2000) derive similar results by analysing the income elasticity  
684 to electricity demand for the city of Bombay, estimating values ranging from 0.28 to 0.40  
685 based on income group. Moharil and Kulkarni (Moharil and Kulkarni 2009) suggest that  
686 despite the higher cost of electricity, people living on Sagardeep Island in West Bengal  
687 demanded more power for entertainment, comfort and developing job opportunities  
688 irrespective of their income level, suggesting very low levels of demand elasticity. Alkon et  
689 al. (Alkon et al. 2016) use nationally representative household data from India, 1987–2010,  
690 and suggest that household income is not a primary determinant for willingness to pay for  
691 high-quality modern energy. Hence, the literature seems to suggest that electricity is  
692 income inelastic (*i.e.* the quantity of electricity demanded increase less than proportional to  
693 an increase in income), since it is often considered a basic need. However, the relatively  
694 high positive values estimated (between 0.24 and 0.64, depending on the context) suggest  
695 that an eventual increase in the economic status of people would lead to a rise in electricity  
696 consumption of households, although less than proportionally.

697 To enhance a positive feedback of household economy on electricity demand, the literature  
698 suggests some complementary activities to increase households' willingness to buy and use  
699 electricity. Among the recommendations, scholars suggest that electrification projects must be  
700 accompanied by sustainable "cost of connection" policies, such as international "smart" subsidies  
701 or cost-sharing mechanisms (Sovacool et al. 2013) for covering initial investments (Zomers 2003;  
702 Baldwin et al. 2015) (*cost of connection policies* → *Access to financial capital*). The importance of  
703 appropriate tariffs built into sustainable payment plans – like the pre-paid mechanism (Moharil and  
704 Kulkarni 2009) that allow people to pay up front, sometimes via their mobile phones, which reduces  
705 travel costs (Gustavsson 2004) – is also highlighted in the literature. Such plans can favour the  
706 poor (Bhattacharyya 2006, 2013). In this context, energy needs of rural communities should be  
707 considered top of the agenda of national energy policy making processes (Habtetsion and Tsighe

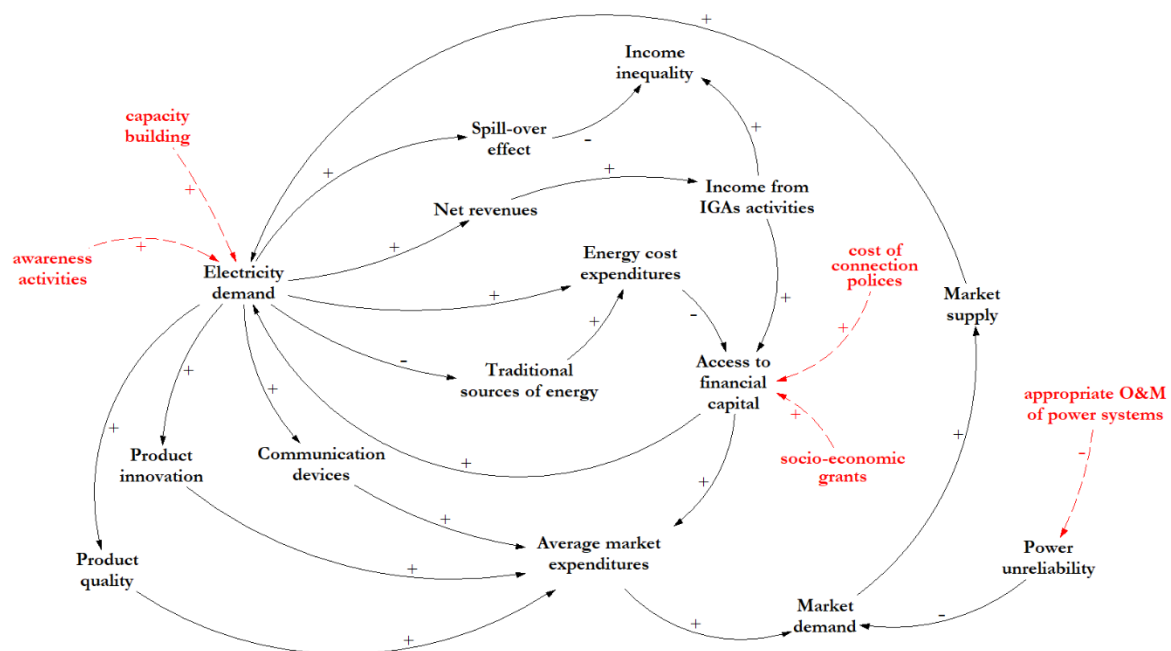
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<sup>1</sup> "Elasticity is a measure of a variable's sensitivity to a change in another variable. In business and economics, elasticity refers to the degree to which individuals, consumers or producers change their demand or the amount supplied in response to price or income changes. It is predominantly used to assess the change in consumer demand as a result of a change in a good or service's price" (Source: (Investopedia, LLC 2014)).

708 2002), e.g through a proper regulation on energy pricing, taxes, laws and product standards on  
 709 energy (Biswas et al. 2001). Further, the literature advise actors to create awareness among  
 710 beneficiaries (*awareness activities* → *Electricity demand*), by first, creating demand for the  
 711 “service” provided by energy technologies, rather than for the technology itself (Mulugetta et al.  
 712 2000), and second, involving the local community and consumers, especially women (Sovacool et  
 713 al. 2013), in managing and operating energy systems (Sebitosi and Pillay 2005; Adkins et al. 2010;  
 714 Sovacool et al. 2013; Terrapon-Pfaff et al. 2014). Complementary activities, thus, involve: (a)  
 715 customer educational programmes (Sovacool et al. 2013); (b) the introduction and integration of  
 716 some energy end-use services (e.g. lighting, pumping) into daily routines and practices  
 717 (Somasheshkar et al. 2000); (c) the implementation of demonstration initiatives designed to create  
 718 knowledge regarding electricity use (Wamukonya and Davis 2001) and to boost demand for energy  
 719 technologies (Baldwin et al. 2015), and; (d) the support for the widespread ownership of mobile  
 720 telephones and accessibility of TVs sets (Matinga and Annegarn 2013) (represented through the  
 721 positive *socio-economic grants* → *Access to financial capital* → *Electricity demand* feedback).  
 722 Lastly, improving capacity building and access to information (know-how) on mechanical and  
 723 technical matters at the household level – e.g. the basic understanding of the capacity of the  
 724 system (Gustavsson and Ellegård 2004) – (*capacity building* → *Electricity demand*) as well as  
 725 organizing reliable and competent customer service (Alazraki and Haselip 2007) and ensuring an  
 726 appropriate O&M of the system (*appropriate O&M of power systems* → *Power unreliability*) are  
 727 considered important drivers for growth of electricity demand.

728 Figure 5 describes these relations between electricity demand and households’ access to finance,  
 729 expressed through its two main determinants, viz. income and expenditures.

730



731

732 **Figure 5.** Causal-loop diagram representing the dynamics between electricity demand and household's economic  
 733 availability.

734 **2.2. Social dimension**

735 In this section, we discuss the complex causalities between electricity demand and social  
 736 dimensions of local development. In particular, we focus on three main aspects: (i) the dynamics of  
 737 *local population and health*, (ii) *education*, and (iii) *habits, living standards and social networks*.

738 **2.2.1. Local health and population**

739 The literature suggests that increasing electricity access and use is beneficial to people's health  
740 (Wolde-Rufael 2005; Mulder and Tembe 2008; Sovacool et al. 2013) and can impact on local  
741 population dynamics. We discuss these dynamics by investigating the health dimension at the  
742 household, work and hospital level, and also by analysing the impact of electricity on local  
743 population growth and related feedbacks.

744 At a *household* level, access to electricity is reported to be an important driver for improved health  
745 of household members. For example, Wamukonya and Davis (Wamukonya and Davis 2001)  
746 indicate that respectively 49% and 35% of surveyed grid-electrified and solar-electrified rural  
747 Namibian households reported an improvement in health since getting electricity. The diffusion of  
748 electrical appliances can contribute to improve people's health status through:

- 749 – the use of electric refrigerators, which bring benefits by preserving food and drinks from  
750 external contamination and sustaining the qualities of food longer (Kirubi et al. 2009)  
751 (*Electricity demand* → *Food-preservation devices* → *People's health* in Figure 6);
- 752 – electric lighting that can reduce household air pollution and associated lung disease and  
753 eye problems, as well as and burns and poisonings caused by the use of kerosene  
754 (Alazraki and Haselip 2007; Gurung et al. 2011; Brass et al. 2012; Aklin et al. 2015; Grimm  
755 et al. 2017) (*Electricity demand* → *Traditional sources of energy* → *People's health*);
- 756 – access to clean and safe groundwater, which can help reduce health diseases (e.g.  
757 typhoid, diarrhoea, parasitic infections (World Health Organization 2003)) associated with  
758 contaminated sources of water (e.g. surface water) (Somashekhhar et al. 2000; Cabraal et  
759 al. 2005; Bastakoti 2006; Sovacool et al. 2013) (*Electricity demand* → *Water pumping*  
760 *devices* → *People's health*).

761 Secondly, as a consequence of more income and free time following electricity use, people are  
762 reported to care more for their health (Sovacool et al. 2013) (*Electricity demand* → *Free-time* →  
763 *People's health*). Indirectly linked to electricity, complementary activities that support the realization  
764 of sanitary facilities reduce the risk of infective and bacterial disease (Gurung et al. 2011) (*sanitary*  
765 *facilities* → *People's health*).

766 At *work* level, Bastakoti (Bastakoti 2006) reports that electrification of energy intensive IGAs led to  
767 a cleaner and more healthy operating environment in rural Nepalese villages, especially by  
768 reducing the health effects caused by the operation of diesel generators, including polluting fumes  
769 and irritation caused by grease and fuel on the body (*Electricity demand* → *Work security* →  
770 *People's health*). Similarly, Kooijman-van Dijk and Clancy (Kooijman-van Dijk and Clancy 2010)  
771 indicate that the use of electric machines are characterized by lower noise levels, dust and smoke  
772 and contributed to guaranteeing a healthier and less stressful working environment in rural Bolivia,  
773 Tanzania and Vietnam.

774 At *hospital* level – viz. local dispensaries, health centres and hospitals – access to electricity is  
775 reported to considerably improve the quality and quantity of medical services offered to local  
776 people (*Electricity demand* → *Health centres electric devices* → *Medical services* → *Quality of*  
777 *medical service*). Firstly, refrigeration facilities allow for storing medications, vaccines and blood  
778 (Habtetsion and Tsighe 2002; Cabraal et al. 2005; Brass et al. 2012; Aglina et al. 2016; Lenz et al.  
779 2017), and modern machines are used in a variety of medical examinations and treatments, such  
780 as laboratory examinations, X-ray analyses (Bastakoti 2006) and surgical machines (Brass et al.  
781 2012). Moreover, when on-grid or off-grid electricity-access replaces or reduce the use of diesel,  
782 kerosene and LPG for running appliances and machineries, hospitals might experience high  
783 energy cost savings (Lenz et al. 2017). In this context, the literature specifies that the diffusion and

784 installation of new electric equipment is highly dependent on the possibility of local health centres  
785 to afford them (Peters et al. 2009) (*Hospital financial liquidity* → *Electricity demand*) and the  
786 reliability of power supply (Brass et al. 2012) (*Power unreliability* → *Electricity demand*), suggesting  
787 the importance of giving *financial support* to local hospitals and guaranteeing an *appropriate O&M*  
788 *of power systems*. Secondly, electric lighting can highly contribute to improve medical services by  
789 extending operating hours at night (Gustavsson 2007b; Moharil and Kulkarni 2009; Aglina et al.  
790 2016) and increasing security during surgeries and childbirths (Cabraal et al. 2005) (*Electric*  
791 *demand* → *Health centres electric devices* → *Safety* → *Quality of medical service*). Thirdly,  
792 improved communication increases the possibility for health centres to provide people with more  
793 information about health-care, prevention of diseases, and to retrieve clients information (Cabraal  
794 et al. 2005; Aglina et al. 2016) (*Electricity demand* → *Health centres electric devices* → *Health-*  
795 *care related knowledge* → *People's health*), as well as attract more qualified and trained staff  
796 (Cabraal et al. 2005; Lenz et al. 2017).

797 The improvements of people's health status and medical services can result in a positive feedback  
798 on electricity use. An improved health status reduces the need to frequently spend time being sick  
799 and money for health service, therefore it preserves households' financial capacity and allows for  
800 free-time to dedicate to other activities (*People's health* → *Free-time* and *People's health* →  
801 *Health-care related expenditures*), but at the same time it reduces the *People turnout at local*  
802 *health centres*. On the other hand, the potential improvement of local medical services can  
803 positively impact on households' access to financial capital and time as well, as in rural Nepal  
804 (Bastakoti 2006) where people experienced lower cost and need to travel to cities nearby for health  
805 care (*Quality of medical service* → *People turnout at local health centres* that reduces *Long travels*  
806 *for medical treatment* and then increase *Free-time*; and *Quality of medical service* → *People*  
807 *turnout at local health centres* that reduces *Long travels for medical treatment* and *Health-care*  
808 *related expenditures*). This in turn can benefit local hospitals that experience a higher patient  
809 turnover and larger financial inflows (that can be invested in new machines and installed electric  
810 load) (*People turnout at local health centres* → *Hospital revenues* → *Hospital financial liquidity* →  
811 *Electricity demand*). As explained in sub-sections 2.1.1 and 2.1.3, an increase in people's access  
812 to financial capital given by reduced costs for health care can have a positive feedback on  
813 electricity demand (a reduction in *Health-care related expenditures* supports the positive *Access to*  
814 *financial capital* → *Electricity demand* feedback), while more time being healthy can increase the  
815 time spent on economically productive activities, sometimes the creation of new IGAs, and  
816 subsequently an increase in electricity demand (*People's health* → *Free-time* → *Electricity*  
817 *demand*).

818 The literature suggests that improvements in local health-care can have a direct positive impact on  
819 some dynamics that influence levels of population growth. Cabraal et al. (Cabraal et al. 2005) refer  
820 to a study carried out in rural Bangladesh in 2003, which reports an infant mortality rate of 4.27% in  
821 electrified households, compared to 5.38% and 5.78% in non-electrified households in electrified  
822 villages and non-electrified villages respectively. Brass et al. (Brass et al. 2012) suggest that  
823 improved medical centres can reduce maternal mortality rates (*Safety* → *Mortality rate* → *Local*  
824 *population*). Apart from having a positive impact on the health of mothers and children, electricity  
825 can positively impact on population growth locally by changing the in- and out-migration to areas  
826 (*Rural-to-urban migration rate* → *Local population*): Neelsen and Peters (Neelsen and Peters  
827 2011) point out that electrification contributed to the expansion of a southern Ugandan village,  
828 which in turn boosted market demand and profits for local IGAs (*Local population* → *Market*  
829 *demand*). Similarly, others (Kanagawa and Nakata 2008; Gurung et al. 2011) report a business in-  
830 migration of people who moved in to electrified villages – in Nepal and India respectively – in order  
831 to achieve higher levels of income, while Jacobson (Jacobson 2007) suggests a long-term



854 the beneficial impact of electricity use, while being aware of the multiple socio-economic factors  
 855 that might impact on educational levels of rural people, the reverse causalities, and the potential  
 856 biases in these results. We then review studies that explain how electricity use in schools and  
 857 houses may allow people to attain higher school grades and levels, and an improved level of  
 858 informal education. We finally discuss some possible feedbacks of higher educational attainments  
 859 on electricity consumption.

860 From a general point of view, the use of electricity seems to be associated with improved  
 861 educational standards of people (Alam et al. 1998), also in poor countries (Wolde-Rufael 2005), as  
 862 reported in Table 4.

863 **Table 4.** Examples of impact of electricity use on education.

Reference	Mentioned impact of electricity use on education
Nakata and Kanagawa (Kanagawa and Nakata 2008)	In rural areas of Assam, India, data indicate that a 1-point increase in the percentage of households electrified result in 0.17-point improvement in the percentage of literate people older than 6 years. Also, it is suggested that domestic electricity consumption per capita has a positive correlation with educational attainment, indicating that those households with very low initial levels of electricity consumption can achieve high educational benefits from increasing their consumption of electricity. Further, the literacy rate of Assam state is estimated to rise from 63.3% to 74.4% if all the rural areas were to be electrified, other factors being equal.
Aglina et al. (Aglina et al. 2016)	An increase in electricity access is correlated with an improved literacy rate in the Economic Community of West African States (ECOWAS), though countries with low national electrification rates, such as Cote d' Ivoire and Mali, have better literacy rates than Ghana that scores higher in both urban and rural electrification rate, indicating the influence of other factors.
Ranganathan and Ramanayya (Ranganathan and Ramanayya 1998)	The increase in literacy rate that occurred in Uttar Pradesh and Madhya Pradesh during the period 1991-1997 is, respectively, nearly half and two-thirds attributable to electrification.
Grogan and Sadanand (Grogan and Sadanand 2013)	Rural Nicaraguan men and women are more than twice as likely to have completed primary education if they live in households with access to electricity.
Sovacool et al. (Sovacool et al. 2013)	The communities that embraced the Multifunctional Platform (MFP) energy program <sup>2</sup> in Mali revealed lower drop-out rates, higher test scores, and higher proportions of girls entering school. A possible reason might be the time freed-up by electricity use (see sub-Section 2.1.1) (Mulder and Tembe 2008), which contributes to decreased irregular attendance (Aglina et al. 2016) and improved marks at school (Gustavsson 2007a).
Dinkelman (Dinkelman 2011)	Electrified rural areas in South Africa have higher fractions of adults with a high school-degree, compared to non-electrified communities
Gurung et al. (Gurung et al. 2011)	Increase in informal education among women in the electrified Tangting village, Nepal
Khandker et al. (Khandker et al. 2013)	An econometric model applied to 42 Vietnamese communes indicates that household electricity connection is correlated with a 9% higher school-enrolment rates for girls and 6.3% for boys.

864  
 865 At school, the use of electric lighting might benefit students by extending study hours (Aglina et al.  
 866 2016) (*Electricity demand* → *Study time at school* in Figure 7) and by allowing evening  
 867 (Gustavsson 2007a) or early morning classes (Alazraki and Haselip 2007) (*Electricity demand* →

<sup>2</sup> “a government managed, multilaterally sponsored energy program that distributed a small diesel engine attached to a variety of end-use equipment” ((Sovacool et al. 2013) pg. 115).



868 *Evening and morning classes*). Peters et al. (Peters et al. 2009) find that in rural Benin, electric  
869 lighting and the provision of evening classes allow students to work on family business and do  
870 housework during the day, contributing to the household economy (*Evening and morning classes*  
871  $\rightarrow$  *Daily-time for work*  $\rightarrow$  *Average income*). Electricity availability allows the use of new devices like  
872 computers (Bastakoti 2006; Alazraki and Haselip 2007), audio-tapes (Bastakoti 2006), TVs and  
873 radios (Alazraki and Haselip 2007; Brass et al. 2012) for educational purposes, and fans for  
874 creating a more comfortable environment for all students, finally enhancing the teaching and  
875 learning quality (Alazraki and Haselip 2007), as well as the recruitment and hiring of teachers  
876 (Aglina et al. 2016) (*Electricity demand*  $\rightarrow$  *Quality of education* and *Electricity demand*  $\rightarrow$  *Teacher*  
877 *attraction*  $\rightarrow$  *Quality of education*). In this context, the availability of funds for schools is pivotal for  
878 improving equipment and installed load, as confirmed by Bastakoti (Bastakoti 2006), who reported  
879 the diffusion of modern devices especially in private schools. In this regard, electricity might  
880 support schools in generating new income to allocate to educational improvements. In Zimbabwe,  
881 a rural school started a milling service and generated new income (Mapako and Prasad 2007) – it  
882 generates the reinforcing *Electricity demand*  $\rightarrow$  *school IGAs*  $\rightarrow$  *school financial availability*  $\rightarrow$   
883 *Electricity demand* loop. To summarize, these effects contribute to increasing children and adults'  
884 *school enrolment*, attendance of classes and grades achievements (Dinkelman 2011; Gurung et al.  
885 2011; Sovacool et al. 2013), i.e. *Education attainments*.

886 Since electricity use has been found to enhance socio-economic status of rural households, there  
887 is also an indirect effect of electrification on school enrolment. Smits and Huisman's work  
888 (Huisman and Smits 2009) demonstrate, through a multilevel logistic regression analysis applied to  
889 30 developing countries, that an increase in the level of household's wealth, parents' occupation  
890 (especially the father), and education has a positive impact on primary school enrolment of children  
891 (*Electricity demand*  $\rightarrow$  *Average income*  $\rightarrow$  *Education attainments*). Similarly, Al-Zboun and Neacșu  
892 (Al-zboun and Neacșu 2015) interviewed more than 2000 principals and directors of public schools  
893 in Jordan, and found that a lack of opportunities, low economic level of households, low quality of  
894 educational infrastructures, and low cultural level of parents were pivotal factors affecting the non-  
895 enrolment of children in primary schools. This suggests that complementary activities to support  
896 community awareness of educational benefits might enhance enrolment (*educational benefits*  
897 *awareness campaigns*  $\rightarrow$  *School enrolment*). A result that contradicts these findings, is from Lenz  
898 et al. (Lenz et al. 2017) who indicate, based on both econometric models and qualitative interviews  
899 with teachers, that the probability of rural Rwandan households sending their children to school  
900 does not increase as an effect of grid-electrification.

901 At *home*, many studies mention the increase in evening study hours as the main benefit of  
902 electricity on education (Baldwin 1987; Somashekhar et al. 2000; Wamukonya and Davis 2001;  
903 Wijayatunga and Attalage 2005; Alazraki and Haselip 2007; Moharil and Kulkarni 2009; Kumar et  
904 al. 2009; Gurung et al. 2011; Aclin et al. 2015; Baldwin et al. 2015; Aglina et al. 2016; Mishra and  
905 Behera 2016; Grimm et al. 2017; Lenz et al. 2017) (*Evening study time*  $\rightarrow$  *Education attainments*).  
906 Since electricity allows replacing or decreasing fuels use (e.g. kerosene, paraffin, candles) and the  
907 related environmental and economic drawbacks (Cabraal et al. 2005), Gustavsson and Ellegård  
908 (Gustavsson and Ellegård 2004) report that children study at night in 89% of households with a  
909 solar home system, compared to 42% of non-electrified households, where children complain  
910 about smearing eyes, lack of candles or paraffin and too weak light (*Electricity demand*  $\rightarrow$   
911 *Electrical lighting decreases Traditional sources of energy's drawbacks* and then increases  
912 *Evening study time*. Gurung et al. (Gurung et al. 2011) indicate an increase of reading hours for  
913 students after electrification of Tangting village, Nepal, due to a reduction in the use of hazardous  
914 traditional lamps. Komatsu et al. (Komatsu et al. 2011) report that the introduction of SHS in  
915 Comilla, Kishoreganj, and Manikganj districts in rural Bangladesh allowed children to study in a

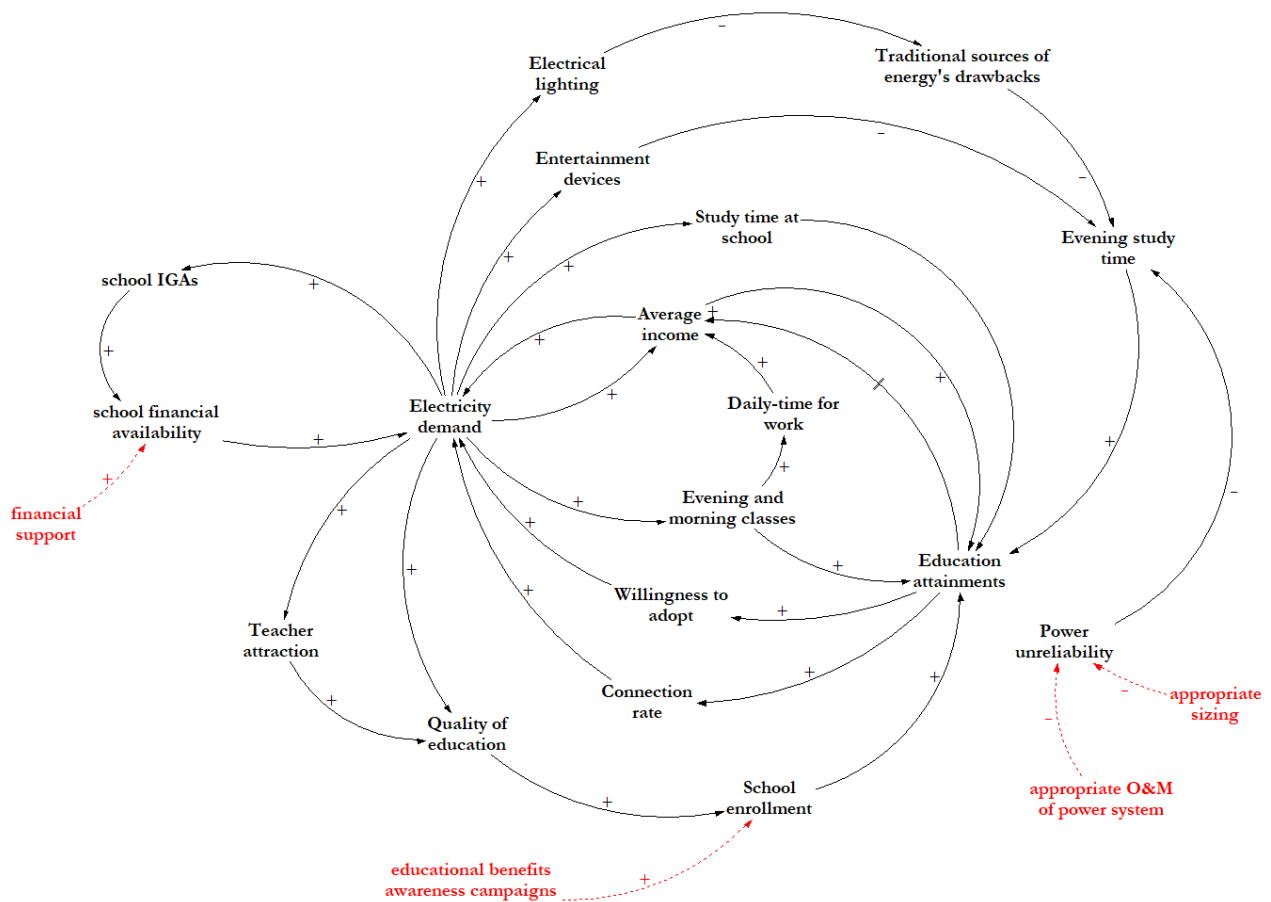
916 better environment and to extend their study-time from 8–9 pm until 10–11 pm. Similarly positive  
917 results for solar PV based lighting were seen in Ludanzi, Zambia (Gustavsson 2007b) and Gujarat  
918 State, India (Agoramoorthy and Hsu 2009).

919 A part of the literature reports limited or very little positive impact of electricity use on educational  
920 attainment. Jacobson (Jacobson 2007) indicates that despite nearly 80% of rural Kenyan  
921 households surveyed by the author having school age children, solar lighting was used for studying  
922 in only 47% of these homes. Gustavsson (Gustavsson 2007a) reports no evidence of actual  
923 improvements of school children's marks as a consequence of access to solar services in the  
924 surveyed Eastern Province of Zambia (Gustavsson 2007a). Bastakoti (Bastakoti 2006) and  
925 Komatsu (Komatsu et al. 2011) find that in rural western Nepal and Bangladesh respectively,  
926 children reported an overindulgence in watching TV that limited their willingness to complete their  
927 homework in time (*Electricity demand* → *Entertainment devices* → *Evening study time*). In this  
928 context, the availability and quality of power supply are two crucial factors (*Power unreliability* →  
929 *Evening study time*). In analysing the social changes in Kenya achieved with solar electrification,  
930 Jacobson (Jacobson 2007) suggests that children in households with a larger PV system are much  
931 more likely to have access to electric light for studying than children in households with smaller  
932 systems. Gustavsson and Ellegård (Gustavsson and Ellegård 2004) also report that children  
933 complained about black-outs and restrictions in the use of the power as crucial limiting factors for  
934 evening study.

935 Improving educational attainment can generate positive feedbacks on electricity demand in the  
936 long term. Louw et al. (Louw et al. 2008) suggest that education is one of the factors that drives  
937 households' fuel choices, as well as the "subsequent energy portfolio used" (p. 2813). Urpelainen  
938 and Yoon (Urpelainen and Yoon 2015) conducted a survey among 760 respondents in rural Uttar  
939 Pradesh, India, and found that high levels of education increased the willingness to pay for a SHS.  
940 Aklin et al. (Aklin et al. 2015) derive econometrically the relation between household's educational  
941 level (*viz.* average years of education) and both electrification status (*viz.* if a household has  
942 access to electricity or not) and daily hours of electricity for Indian households living in slums,  
943 urban and rural areas. They find that more educated households have more need for electric  
944 assets and may be more willing to pay for a connection (*Education attainments* → *Connection rate*  
945 → *Electricity demand*). Similarly, Bensch et al. (Bensch et al. 2011) estimate a probit-regression  
946 model to determine that the variable "years of education of household head" is positively correlated  
947 at 1% significance level with connection status in Rwanda. On the contrary, Kandpal and  
948 Kobayakawa (Kobayakawa and Kandpal 2014) find that in Kaylapara village, Sagar Island of West  
949 Bengal (India), the mean class completed by the family head does not show significant difference  
950 between households with and without connection to the micro-grid. Rao and Ummel (Rao and  
951 Ummel 2017) evaluate the marginal change in the probability to own a refrigerator, a washing  
952 machine and a TV in India, South Africa and Brazil in relation to head-of-household's years of  
953 schooling, suggesting that more educated households are more willing to adopt new technologies  
954 (*Education attainments* → *Willingness to adopt* → *Electricity to adopt*). Cabraal et al. (Cabraal et  
955 al. 2005) report empirical evidence from rural India and Peru, where the combined provision of  
956 electricity and education has been found to generate a greater effect on households' income than  
957 each variable taken separately. As a matter of fact, Kirubi et al. (Kirubi et al. 2009) report the  
958 experience of Mpeketoni Polytechnic educational institution in Kenya, which after connection to the  
959 grid became an important source of technical know-how and skills for youths who then found  
960 employment in local IGAs, generating a time-delayed feedback between *Educational attainment*  
961 and *Average income* (marked with two dashes in Figure 7). Khandker et al. (Khandker et al. 2013)  
962 suggest that higher educational benefits achieved by rural Vietnamese children as an effect of  
963 electrification might have resulted in higher and more productive employment levels. In his

964 econometric study, Rao (Rao 2013) found that the years of education of household' head is a  
 965 positive determinant of income for Indian NFEs. Since households' income and financial availability  
 966 have been found to be pivotal drivers of electricity use, all these studies confirm that improving  
 967 peoples' educational attainments can positively impact future electricity consumption (*Education*  
 968 *attainments* → *Average income* → *Electricity demand*).

969 Figure 7 reports the diagram of nexus causalities between electricity demand and educational  
 970 attainment. The mark on the causal link, which connects *educational attainment* and *average*  
 971 *income*, indicates a time-delay in the occurrence of the represented feedback as evident from the  
 972 literature. We also highlight the importance of combining electrification activities with awareness  
 973 campaigns regarding the benefits of education, programmes of financial support to local schools  
 974 (*financial support* → *school financial availability*), and correct O&M of the power systems  
 975 (*appropriate O&M of power system* → *Power unreliability*).  
 976



977  
 978 **Figure 7.** Causal-loop diagram representing the dynamics between electricity demand and education.

979 **2.2.3. Habits and social networks**

980 In terms of changes in people's daily habits and activity scheduling, the availability of electrical  
 981 lighting can contribute to extending the length of people's active day (*Electricity demand* →  
 982 *Electrical lighting* → *Daily-time extension* in Figure 8). Matinga and Annegam (Matinga and  
 983 Annegarn 2013) report that the provision of access to electricity in Tsilitwa village, South Africa,  
 984 allowed household members to wake up earlier, about half-hour before sun-rise, and go to bed  
 985 about 2-3 hours later. Similarly, Roy (Roy 2000) indicates that the lighting hours in households  
 986 provided with solar lanterns in a rural Indian village went up from 2 hours to 4 on average (and up  
 987 to 6 hours in some cases). Lenz et al. (Lenz et al. 2017) state that in rural Rwanda, "the availability

988 of electricity in the communities clearly had a significant effect on the daily routine of all household  
989 members” (p. 99), since it extended the day by 50 minutes on average. On the contrary, Grimm et  
990 al. (Grimm et al. 2017) did not find statistically significant changes in the time spent on daily and  
991 evening domestic labour between electrified and non-electrified rural households in Rwanda. In  
992 addition to this daily time extension, the literature reports that access to electricity can facilitate  
993 household activities by decreasing the burden of work and time. Kumar (Kumar et al. 2009) reports  
994 that in 5 centres in Sagar Dweep Island in India, 38% of households stated a benefit from time  
995 savings for cooking (*Electricity demand* → *Efficiency (completion rate) of housework* → *Daily*  
996 *burden of housework*), while 17% indicated having more time for household work at night (*Evening*  
997 *housework* → *Daily burden of housework*). More time available for women’s household work at  
998 night has been reported also by others (Agoramoorthy and Hsu 2009; Moharil and Kulkarni 2009).  
999 Obviously, the diffusion of TVs and entertainment devices might reduce time dedicated to  
1000 housework (*Electricity demand* → *Entertainment devices* → *Evening housework*). Bastakoti  
1001 (Bastakoti 2006) indicates that the use of electric water pumps in rural Nepal allowed people to  
1002 reduce time for collecting water from 7-8 hours per day initially to 1/2 hour per family, increasing  
1003 available time for farming and leisure activities. Also Grogan and Sadanand (Grogan and  
1004 Sadanand 2013) report a decrease in time for fetching water (and firewood) in Nicaragua. Komatsu  
1005 et al. (Komatsu et al. 2011) report that households owning a SHS in rural Bangladesh spend less  
1006 time for recharging car batteries at recharge stations, experiencing less burdens (*viz.* heavy  
1007 weights to carry), and more free time (saving at least 40 minutes for the round trip on average plus  
1008 the recharging time for batteries).

1009 According to Grogan and Sadanand (Grogan and Sadanand 2013) in Nicaragua, “electrification,  
1010 particularly for poor people, may be more about the extension of the working day than about  
1011 labour-saving appliances” (p. 253). In this context, time freed-up by electricity can be devoted to  
1012 productive activities and it has been found to have a positive effect on people’s propensity to start  
1013 a new IGA, with a consequent feedback on electricity demand (sub-section 2.1.1 and 2.1.2) (*Daily*  
1014 *burden of housework* → *Free-time* → *Average income* → *Electricity demand*). Grogan and  
1015 Sadanand (Grogan and Sadanand 2013) suggest that the daily time spent by rural Nicaraguan  
1016 women living in electrified households in salaried work can be three times as much as the time  
1017 spent by women living in unelectrified households. Similarly, they report that men living in  
1018 households with access to electricity decreased by half their time spent in family agriculture and  
1019 doubled the time spent in non-agricultural activities. On the contrary, Lenz et al. (Lenz et al. 2017)  
1020 do not observe a change in income generation patterns as an effect of free-time in electrified  
1021 Rwandan households. More available free-time seems to increase time dedicated to reading and  
1022 cultural activities (Gustavsson 2004; Bastakoti 2006; Gurung et al. 2011), which may potentially  
1023 benefit people’s educational attainments and all the consequent feedbacks that has on electricity  
1024 use (*Free-time* → *Education attainments* → *Electricity demand*). However, Sovacool et al.  
1025 (Sovacool et al. 2013) highlight that people are sometimes unable to capitalize on the free time  
1026 created, suggesting the need to implement parallel educational activities and capacity building  
1027 (*educational awareness activities* → *Education attainments* and *capacity building* → *Average*  
1028 *income*).

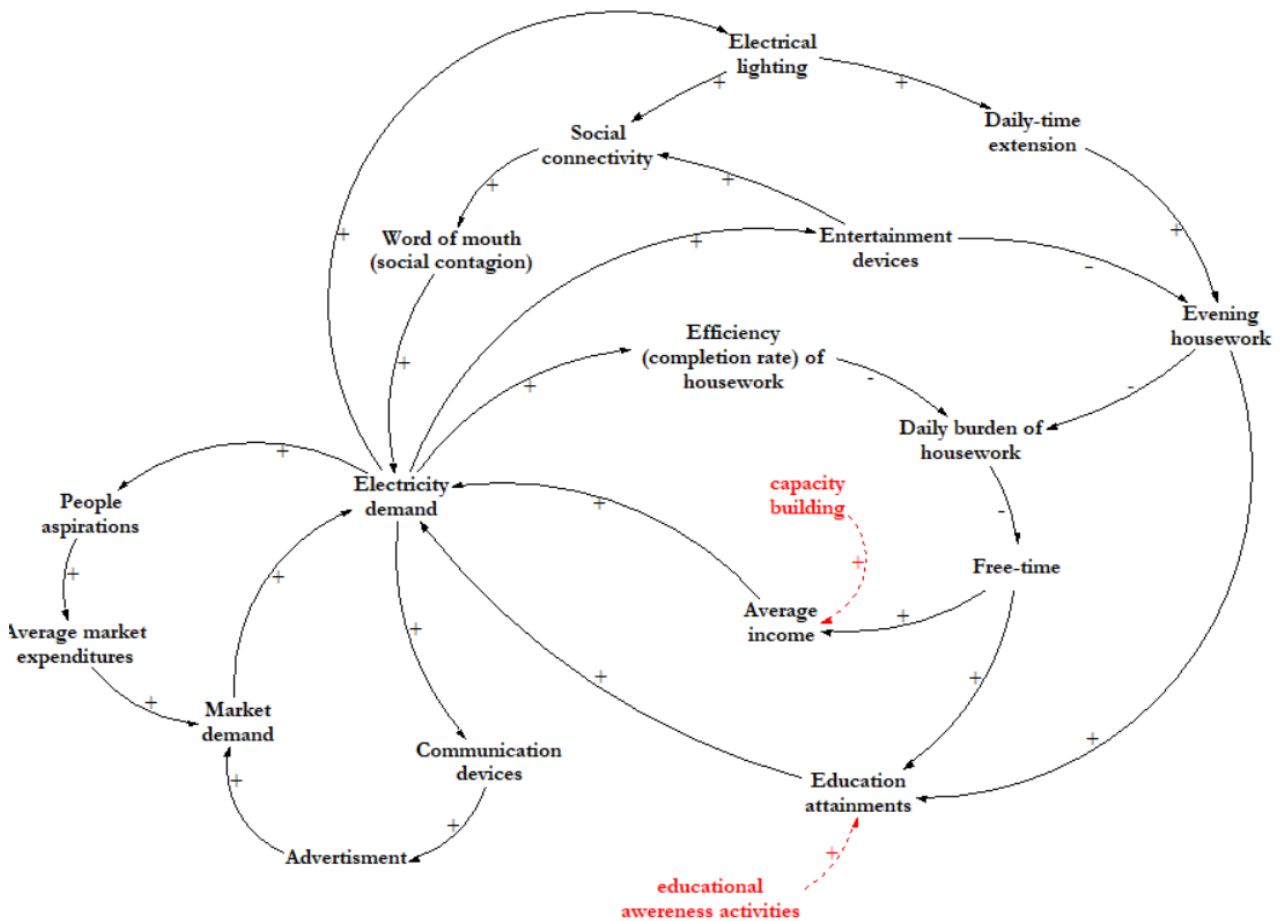
1029 The evolution of electricity demand can impact the social structure and network of electrified  
1030 communities (Baldwin et al. 2015). In Tsilitwa village, South Africa, Matinga and Annegam report  
1031 that differences in household electrical appliances intensified the feelings of exclusion and  
1032 inequality, highlighting that “electrical appliances displayed in houses of the better-off represent a  
1033 world from which they [poorest families] felt excluded” ((Matinga and Annegarn 2013), pg. 295),  
1034 pushing people into changes in aspirations and spending (*Electricity demand* → *People aspirations*  
1035 → *Average market expenditures*). However, this reinforcing feedback is sometimes hindered by

1036 the local social habits, traditions, gender relations and culture that can negatively influence  
1037 people's aspirations and investment decisions, such as people in Zanzibar having food  
1038 preferences for traditionally prepared food over use of electric cookstoves, or male control over  
1039 money and technology, limiting women's abilities to purchase household equipment (Winther  
1040 2008). Rahman and Ahmad (Rahman and Ahmad 2013) observe that the diffusion of SHS in rural  
1041 Bangladesh brought mostly recreational and leisure benefits. Bastakoti (Bastakoti 2006) indicates  
1042 that the possession of a television is considered a luxury and status symbol in rural South Africa.  
1043 On the other hand, the same author suggests that families without cable frequently go to their  
1044 richer neighbours' homes to watch TV, increasing households' meetings and time together  
1045 (*Electricity demand* → *Entertainment devices* → *Social connectivity*). Komatsu (Komatsu et al.  
1046 2011) and Lenz et al. (Lenz et al. 2017) report the same dynamics also for rural Bangladeshi and  
1047 Rwandan households respectively. Similarly, Gustavsson and Ellegård (Gustavsson and Ellegård  
1048 2004) report that children living in villages located in the district of Nyimba, Zambia, gathered  
1049 together in one of the houses with a SHS to study. Lighting and the related perceived improved  
1050 security, as well as evening market operation, seem to increase outdoor and/or indoor evening  
1051 meetings and chats, and connectivity among people (Gustavsson 2004; Alazraki and Haselip  
1052 2007; Shackleton et al. 2009; Kooijman-van Dijk and Clancy 2010; Matinga and Annegarn 2013)  
1053 (*Electricity demand* → *Electrical lighting* → *Social connectivity*). Even within the same household,  
1054 Wijayatunga et al. (Wijayatunga and Attalage 2005) report that 68% of surveyed households in  
1055 Badulla district, Sri Lanka, claimed to benefit from having more time together through activities  
1056 such as watching television while having dinner.

1057 Electrification allowed enhanced access to information (Kooijman-van Dijk and Clancy 2010),  
1058 communication and connectivity even outside local communities (Baldwin et al. 2015) (*Electricity*  
1059 *demand* → *Communication devices*). Jacobson (Jacobson 2007) report that rural electrification in  
1060 Kenya facilitated rural–urban communication through the diffusion of television, radio, and cellular  
1061 telephone charging, increasing rural–urban connectivity, especially for the rural elite and middle  
1062 class. Similarly, Rwandan households interviewed by Lenz et al. (Lenz et al. 2017) indicated that  
1063 mobile phones are especially used for calling people who live outside the province. Gustavsson  
1064 (Gustavsson 2007a) suggests that children and adults in rural Zambia experienced more access to  
1065 news and events taking place outside the rural community through radio and TV broadcasts.

1066 In accordance to the theory of innovation diffusion (Bass 1969; Peres et al. 2010), enhancing  
1067 connectivity and social networks increase the process of word of mouth, acceptability of new  
1068 products, and related probability to become an adopter, enhancing the diffusion of electrical products  
1069 and its feedback on the evolution of electricity demand (*Social connectivity* → *Word of mouth (social*  
1070 *connectivity)* → *Electricity demand*). In this context, local government officials or heads of the villages  
1071 can play the role of "influentials" (Van den Bulte and Joshi 2007; Goldenberg et al. 2009; Urmee and  
1072 Md 2016) in bringing electricity to their communities and enhancing the diffusion of electrical devices  
1073 (Kooijman-van Dijk and Clancy 2010). Since the use of television and radio might facilitate the ability  
1074 of business advertisers to reach a wider audience (Jacobson 2007) and increase local demand for  
1075 goods and services, local shops and retailers can experience higher trades and revenues, with  
1076 related feedbacks on electricity use, as discussed in sub-section 2.1.1 and 2.1.2 (*Communication*  
1077 *devices* → *Advertisement* → *Market demand* → *Electricity demand*).

1078 Figure 8 reports the diagram of nexus causalities between electricity demand, habits and social  
1079 networks.



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**Figure 8.** Causal-loop diagram representing the dynamics between electricity demand, habits, and social networks.

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### 3. Insights from literature for energy modelling

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In this section, we discuss the implications of our findings from an energy modelling perspective. We discuss how the conceptualized variables, feedbacks and causal diagrams can be useful to understand the complexities in the energy-development nexus and to formulate possible appropriate energy models. Our review confirms that the energy-development nexus is complex. As such, the behaviour/outcome of the nexus cannot be intuitively understood (Forrester 1971). In order to improve understanding of complex systems, a number of computer aided modelling methods have been developed over the last decades, e.g. agent based modelling, system dynamics, neural networks, and operational research. With the usage of these tools and methods, complex problems can be analysed and tested in computer environments in order to improve understanding of the studied systems.

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Through the use of causal diagrams, this paper has presented a conceptualization of factors and processes found in the energy-development nexus (see Figure 3 to Figure 8). Causal diagrams are similar to the causal loop diagrams used in system dynamics modelling methods. In system dynamics, causal loop diagrams are commonly used for formulating a problem through a dynamic hypothesis, for communicating a model (Morecroft 1982), and for making qualitative analysis of complex systems (Wolstenholme and Coyle 1984). Even though conceptual models are often used as intermediate steps towards simulation models (Robinson 2008), important insights can be drawn from qualitatively analysing conceptual models (Wolstenholme and Coyle 1984). A few of the factors in the energy-development nexus were identified to be exogenous, but the main part of the diagram depicts the relationship of the factors through closed causal loops. The causal loop

1103 diagrams show how factors identified in the energy-development nexus literature are  
1104 interconnected, thereby improving our understanding of the energy-development nexus. This  
1105 results in two insights:

- 1106 (i) As factors are largely interconnected, it is not suitable to use reductionist methods to  
1107 analyse the energy-development nexus: e.g. the relationship cannot be sufficiently  
1108 studied using only a limited set of factors without having knowledge of the full  
1109 contextual setting. Instead a systems-thinking approach that includes the full complexity  
1110 is needed and advised.
- 1111 (ii) Many of the identified factors are connected through feedback loops. In order to identify  
1112 the system's behaviour and to capture the dynamics in the energy-development nexus,  
1113 a simulation approach that takes feedbacks into account is needed.

1114 The initial methods or procedure in developing many models consists of a process of identifying  
1115 factors and processes that are important for the considered problem, as we did in the Section 1. A  
1116 process of formulation of a *simulation model* follows. This part consists of formulating factors into  
1117 variables and formulating the explicit mathematical relationships between variables. In terms of  
1118 modelling complex systems, the identification of factors and processes is a substantial part of the  
1119 modelling work load. Even though there are several tools (Luna-Reyes and Andersen 2003)  
1120 available to help modellers and scientists to identify and assign variables and parameters in  
1121 models, the process of quantification is inherently problematic when dealing with social science  
1122 problems. This is evident from the limited extent this has been done in existing studies dealing with  
1123 the energy-development nexus. A cause of concern is that studies often analyse a specific  
1124 relationship or assume a direct relationship between highly aggregated indicators and thereby rely  
1125 on a range of assumptions, often implicitly. This results in a wide range of numbers, often with low  
1126 or no statistical confidence, which can seem contradicting or unusual. However, reported  
1127 quantitative estimates from literature can still be useful in the simulation process. Using methods of  
1128 parameter estimation and condition tests, the ranges reported in literature can be used to build  
1129 confidence in a simulation model. One tool to handle variable and parameter uncertainty is the use  
1130 of Monte Carlo simulation to investigate the relationship between parameter space and behaviour  
1131 space (Pruyt and Islam 2015). This allows the modeller to relate behaviour modes with parameter  
1132 ranges to improve model confidence. In addition, this allows the modeller to use the model as a  
1133 learning tool and improve the understanding of the energy-development nexus, e.g. by simulating  
1134 the impact of the exogenous variables represented at the tail of the dashed lines (Figure 3 to  
1135 Figure 8) in the dynamics under study. However, in order to make such tests realistic, they need to  
1136 rely on some knowledge of contextual factors.

1137 In addition, the lack of access to data when working in rural areas in developing countries adds  
1138 further difficulties to the simulation process. Access to time-series data for statistical analysis is  
1139 considered important in system dynamics for model calibration (Sterman 2000). Therefore, if long-  
1140 term data sets are not available, alternatives to deal with stochastic uncertainties need to be  
1141 considered. We want to emphasize that we consider long-term time series to be important both in  
1142 model development and validation, and that lack of time-series data can never be substituted.  
1143 However, we do not consider the lack of time-series data to be a sufficient problem for not  
1144 considering a system dynamics approach. Even though high-quality long time-series are not  
1145 common when working in rural areas in developing countries, high-quality qualitative data can  
1146 often be obtained through case studies and structured interviews. As local residents often have a  
1147 plethora of practical knowledge and 'know-how', even though they lack precision, they can be good  
1148 sources for retrieving estimates on reference modes and historical trends.

## 1149 **Conclusion**

1150 Around the world, more than a billion people do not have reliable access to electricity. This is  
1151 considered a limiting factor to the socio-economic development of, especially, rural communities.  
1152 During the last decades, international donors, organizations, NGOs, universities, energy planners,  
1153 practitioners, and private companies have been investing a lot of resources in programmes and  
1154 projects that aim at improving people's socio-economic conditions through access to energy.  
1155 Despite these investments, the scientific literature reports only fragmentary and sometimes  
1156 contrasting results regarding impacts, and methodological inconsistencies limit the comparability  
1157 and generalisability of results. It is, however, not just a question of undertaking statistical  
1158 comparative studies. Existing literature shows that the electricity access-development nexus is  
1159 very context- and time-specific, with high complexity and emergent dynamics. Hence, the  
1160 application of linear or pre-defined sets of relations of cause and effect necessarily fail to  
1161 accurately describe, or predict, the impacts with any level of precision that such results are useful  
1162 for planning and making electricity provision work in practice, at the local level.

1163 In the context of rural electricity planning, the limited knowledge of the impact of electricity access  
1164 on local socio-economic development and the consequent feedback on electricity demand can  
1165 negatively impact on the sizing process of energy systems, especially the off-grid ones. Therefore,  
1166 being able to understand and model the aspects and dynamics that determine rural electricity use  
1167 can lead to more robust energy planning solutions in rural areas. With our work, we therefore  
1168 analyse the dynamic complexities related to the impact of electricity access and consumption on  
1169 rural socio-economic development, and vice versa, and we develop graphical representation of the  
1170 multiple existing causal relations of the issue. Our final goal is to enhance a better understanding  
1171 of the electricity-development nexus, as well as to derive insights and useful guidelines for  
1172 developing appropriate models capable of incorporating and simulating such complex relations.

1173 Our results confirm that the energy-development nexus is complex to an extent that it can be  
1174 usefully described as a 'complex system'. Electricity use is interconnected through complex causal  
1175 relations with multiple dimensions of socio-economic development: *income generating activities,*  
1176 *market production and revenues, household's economy, local health and population, education,*  
1177 *and habits and social networks.* We find that focusing on the impact of electricity use for only a  
1178 unique or isolated set of socio-economic aspects provides a limited and incomplete view of the  
1179 issue. Indeed, our causal diagrams suggest that the electricity-development nexus should, if  
1180 possible, be investigated as a whole, since all the dimensions are interconnected, and positive  
1181 dynamics on one side can create negative feedbacks on the other. In this context, the nexus  
1182 between electricity use and each socio-economic dimension generates positive dynamics only  
1183 when complementary activities are considered (e.g. capacity building, awareness campaigns,  
1184 access to credit, etc.) and infrastructural preconditions are guaranteed (e.g. asphalted roads,  
1185 reliability of the electric network, etc.).

1186 From a modelling perspective, our causal diagrams can be seen as a first step of the  
1187 *conceptualization* phase of model building, which aims at describing and understanding the  
1188 structure of a system. The presence of multiple uncertain parameters, strong non-linear  
1189 phenomena, complex diffusion mechanisms, and time-adjustments of technology perceptions that  
1190 describe the complex system under analysis suggest that systems-dynamic *simulations* can allow  
1191 dealing with the high uncertainties at stake, especially when coupled with stochastic approaches  
1192 such as Monte Carlo simulations and qualitative data eliciting techniques. However, we stress the  
1193 need to calibrate and validate models when historical data are present. Adequate data and  
1194 calibration are recurrent issues when dealing with electricity-development issues. Indeed, we finally



1195 encourage all practitioners and the scientific community involved in rural electrification studies to  
1196 intensify efforts towards reliable data collection and publishing.

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