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Access to Modern Energy: a Review of Barriers, Drivers and Impacts

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Summary

Universal access to modern energy services, in terms of access to electricity and to modern cooking facilities, has been recognized as a fundamental challenge for development. Despite strong praise for action and the deployment of large-scale electrification programs and improved cookstove (ICS) distribution campaigns, few studies have shed light on the barriers to, the enablers of and the impacts of access to energy on development outcomes, using rigorous methodologies. This paper reviews this recent strand of research, trying to fill these gaps. We focus on the demand-side and household perspective. Our main outcomes of interest are electricity connection and ICS adoption for the analysis of barriers, time allocation, labour market outcomes and welfare for the impact analysis. We provide evidence of significant wellbeing impacts of electrification, and mixed evidence for cookstoves.

Keywords: Impact Evaluation, Energy Poverty, Energy Access, Rural Electrification, Modern Cookstoves, Literature Review

JEL Classification: O1, O13, Q4, Q48

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Abstract
Universal access to modern energy services, in terms of access to electricity and to modern cooking facilities, has been recognized as a fundamental challenge for development. Despite strong praise for action and the deployment of large-scale electrification programs and improved cookstove (ICS) distribution campaigns, few studies have shed light on the barriers to, the enablers of and the impacts of access to energy on development outcomes, using rigorous methodologies. This paper reviews this recent strand of research, trying to fill these gaps. We focus on the demand-side and household perspective. Our main outcomes of interest are electricity connection and ICS adoption for the analysis of barriers, time allocation, labour market outcomes and welfare for the impact analysis. We provide evidence of significant wellbeing impacts of electrification, and mixed evidence for cookstoves.

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1. Introduction

Energy poverty is defined as lack, scarcity or difficulty in accessing modern energy services by households, in particular it refers to the access to electricity and to modern and clean cooking facilities (ICS). The International Energy Agency estimates that currently 1.26 billion people (18% of the worldwide population) lack access to electricity and 2.64 billion (38% of the global population) rely on traditional cooking methods based on the use of biomass with severe consequences on health due to indoor air pollution (IEA 2013). The geographical distribution of such phenomena is uneven across the world: 84% of people lacking access to modern energy services live in rural areas; people without electricity are mostly in developing Asia (51%) and Africa (44%); similarly, those still relying on traditional cookstoves and fuels are concentrated in developing Asia (72%) and Africa (25%)[1]. According to the IEA's scenarios, the situation will not change significantly by 2030: about 1 billion people will still lack electricity, with strong improvements in Latin America, the Middle East and developing Asia, but no progress in Sub-Saharan Africa. 2.5 billion people will still rely on biomass for cooking, basically with no progress in absolute terms with respect to the current situation.

The crucial role of energy access for sustainable development has been recognized in the definition of goal number 7 in the Sustainable Development Agenda, which calls for Ensuring access to affordable, reliable, sustainable and modern energy for all.

In general, access to modern energy services may allow reallocation of household time from inefficient energy provision to improved education and income generation. People would also benefit from greater flexibility in time allocation throughout the day and evening derived from better lighting. It would have a direct impact on health, via substitution of more harmful technologies. The World Health Organization estimates that the use of traditional cooking methods, through wood and biomass combustion, has severe consequences on the health of households, due to indoor air pollution. The recent Global Burden Disease study estimates that almost four million people die every year from indoor air pollution due to the use of traditional cooking fuels and stoves (Lim et al. 2013, Martin et al. 2011). Finally, access to modern energy can have important external effects, as a result of better labour and business opportunities. However, the strong correlation between energy access and development indicators does not necessarily imply causal relationship. The evaluation of impacts is subject to critical methodological challenges such as selection bias, endogenous program placement, reverse causality and other confounding trends.

The main contribution of this paper is to review the available rigorous evidence emerging from the recent economic literature, by framing it into a comprehensive framework for access to modern energy services and the overall policy context. We conduct a review of the rigorous evidence on two fundamental aspects: first, we look at the barriers to and drivers of access; secondly, we analyze the impacts of access to modern energy on economic development and poverty reduction outcomes. The analysis focuses on the household level and is conducted in parallel for both the access to electricity and to modern and efficient cookstoves (ICS). The papers included in the current review meet stringent criteria in terms of identification design and investigation of causal relationships. In particular, we focus on studies proposing credible counterfactuals and/or credible sources of exogenous variation. This includes both experimental (RCTs) and non-experimental approaches (instrumental variable estimation, longitudinal studies like difference in differences and fixed effects, propensity score matching, regression discontinuity designs and Heckman selection models).

[1] Energy and fuel poverty is becoming more and more important even in developed countries. For example, it has been estimated that 9.8% of households in EU27 and 15.8% of households in the 12 new Member States could not afford to heat their home adequately in 2011 (Thomson and Snell, 2013).

The paper is organized as follows: we introduce the main objectives identified in the international agenda in order to fight energy poverty at global level and we present the most salient determinants of successful policies, from selected rural electrification and ICS distribution programs. We then present the main challenges in the estimation of causal relationships. A general conceptual framework motivating our exercise is presented in section 2, while section 3 presents the inclusion criteria and rating of papers in this review. In section 4 we focus on the barriers to and enablers of access to energy, while section 5 is on impacts. In both sections the discussion proceeds in parallel for electricity and ICS, first with a presentation of the theory of change, then with the review of the evidence and the proposal of policy recommendations and further research directions. Section 6 concludes.

1.1 Policies for fighting energy poverty

Sustainable energy development enters the international inter-governmental agenda for the first time at the United Nations General Assembly in 1997. In 2000 the World Energy Assessment first addresses the nexus among energy, social issues, health and environment in a general context of energy access and security, efficiency, particularly at rural level. Key international meetings at later dates set energy sustainability as a priority for global development: the Ninth Session of the Commission on Sustainable Development in 2001 and the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002. In the latter, energy access is recognized as a crucial aspect toward the achievement of the Millennium Development Goals, calling for the implementation of sustainable patterns of energy production and use. In 2010 the Advisory Group on Energy and Climate Change to the United Nations' Secretary-General proposes to the international community a set of energy-related goals (AGECC 2010), summarized by universal energy access by 2030. 2012 is declared the International Year of Sustainable Energy for All by the UN General Assembly, in order to catalyze global attention and commitment on these topics. In 2012 the SEFA - Sustainable Energy for All – program is launched, as one of the results of the Rio+20 Conference. Its main goal is to assure universal access to modern and sustainable energy by 2030, improving the rate of renewables in the energy mix and promoting energy efficiency. The objectives are to increase the percentage of renewable energy from the current 15% to 30% of the global energy mix, and to double the global rate of improvement in energy efficiency by 2030. In 2015 previous efforts and programs flowed into the new sustainable development agenda which include the goal of ensuring access to affordable, reliable, sustainable and modern energy for all (SDG7), by 2030. All the societal actors, i.e. governments, private sector and civil society, are called upon to contribute to the achievement of this goal. However, the largest scale interventions for improving the access to modern energy in developing countries have been implemented by the public sector, through rural electrification programs and initiatives for the diffusion of ICS for the large proportion of households still relying on traditional technologies. In September 2010, the United Nations Foundation announced the formation of the Global Alliance for Clean Cookstoves (GACC), a public-private partnership calling for 100 million homes to adopt clean and efficient stoves and fuels by 2020. The initiative aims to draw the international attention on this issue, by mobilizing a wide range of private, public and non-profit stakeholders at global level in order to create a thriving global market for clean and efficient cooking solutions for households. The program has several objectives in order to strengthen both demand and supply side and to foster an enabling environment for the development of a sustainable global clean cookstove market (Simon, Bailis et al. 2014).

Starting from the ‘80s, several developing governments set policy interventions to improve and expand access to modern energy, through rural electrification and ICS diffusion programs. In what follows, we review the major drivers of success and failure of public programs in such contexts.

The main obstacles to be tackled in rural electrification programs pertain to the high investment required *vis à vis* very limited returns in the short and medium run. The cost of expanding the grid or constructing off-grid infrastructure often exceeds the returns from relatively low connection rates in remote and scattered communities with low electric consumption and low ability to pay for connection. This requires substantial subsidies. Yet, many countries have made progress in connecting remote rural areas to electricity. In particular, several emerging economies have included rural electrification programs in their agenda in order to reduce the strong urban-rural divide. Some examples of large national rural electrification programs are represented by Brazil, China and India, which have achieved an electrification rate greater than 65% through significant public investments[2]. Smaller countries such as Thailand, Costa Rica and Tunisia have reached even higher connection rates in the rural population (Barnes, 2007). Successful rural electrification programs have followed several models which can be considered context-specific, for example through the involvement of the private sector or electric cooperatives. However, some common features seemed to have guided successful programs in their deployment (Barnes, 2007). First, the introduction of efficient, effective and equitable subsidies. Second, the presence of an adequate and effective implementing agency, with high-degree of operating autonomy (particularly from possible political pressure) and accountability in the targets to reach. Third, adequate expansion plans, which consider the actual needs and possibilities of communities, ensure financial viability and economic impact: premature rural electrification may miss the objective of contributing to sustainable community development, if other conditions enabling economic development are not present. Fourth, tariff policy is an important ingredient as it has to ensure financial sustainability and cost recovery from one side, and, on the other, it has to consider customers’ realistic ability to pay. Finding financial solutions for lowering the connection charges is also a driver of higher connection rates.

The policies implemented at national level aimed to improve cooking strategies and to avoid health problems related to high exposure to IAP have followed three main strategies. The first tried to promote cleaner fuel adoption by replacing biomass with kerosene and LPG. This has been the case for Ecuador and Indonesia, where poor households could benefit from subsidized kerosene for cooking (Barnes and Helpern, 2000). However, drawbacks emerged such as the high cost of kerosene and LPG together with difficulties to supply them in remote areas, given poor infrastructure. More recently, a second practice has seemed to prevail: the development and promotion of improved cooking stoves which use wood and biomass in a more efficient way while reducing exposure to air pollutants through the introduction of a chimney. The important pros of the substitution of cookstoves rely on the fact that the technology is relatively easy to up-scale using local materials and producers (which may lead to job creation in the area and use of local materials), prices are affordable even for poor households and the final product is similar to traditional cookstoves, allowing the reduction of the cultural “gap” arising from the introduction of a new technology. A third option is the introduction of small scale bio-digesters for the production of biogas at community and

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[2]For a more detailed overview of the electrification programs in emerging countries, see Niez (2010)

household level, though a wide diffusion of such technologies has been slow in several developing countries[3].

As for rural electrification programs, several emerging countries have developed different initiatives for the diffusion of improved cookstoves for the large proportion of households still relying on traditional technologies, some of which have been deemed successful, others less. Key features of successful programs include both supply and demand-side aspects combined with the development of enabling institutional and market environments. From the supply-side, product design aspects such as the compatibility with household needs, housing, cultural and environmental conditions have shown crucial factors for large-scale product take-up (Lewis and Pattanayak, 2012). Quality and durability of cookstoves are critical conditions to realize sustained improvements in efficiency and/or IAP reduction. From the demand side, efforts in filling households information gaps about the advantages of ICS take-up through information campaigns and social marketing as well as innovative financial solutions to overcome credit constraints are key drivers of success. Enabling institutional and market conditions at local level include the involvement of local institutions, the development of the supply chain for production and after sale services, the use of robust independent monitoring and evaluation tools.

A useful illustration of the drivers of success and failure of large-scale national programs for ICS adoption is represented by the Chinese National Improved Stove Program (Smith et al. 1993; Sinton et al. 2004) and the National Program on Improved Chulhas in India (Kishore and Ramana, 2002; Venkataraman et al. 2010), respectively.

1.2 The challenges of rigorous impact evaluation

Despite the great effort and investment in the energy sector to increase rural electrification and the diffusion of modern cooking systems, relatively little is known about the effective impact of such policies on households' well-being. The justification of large public programs to improve the access to modern energy has often relied on supposed benefits and transformative effects on households' health, education, labour market outcomes and, ultimately poverty level. However, there is still limited evidence to substantiate such impacts, given the methodological challenges of attribution. Assessing the impact of rural electrification or campaigns for the diffusion of ICS requires addressing the attribution issue through the use of identifications which tackle endogeneity and selection bias problems. Endogeneity arises, for instance, from the fact that grid expansion may not necessarily be random across or within localities. For example, connecting more advantaged (disadvantaged) areas may respond to different policy aims, but would bias impact estimations upwards (downwards). In other words, if we compared advantaged targeted localities with disadvantaged untargeted ones, we would be unable to disentangle the actual impact of the intervention from the other factors such as better connectedness to markets, other infrastructure development, etc. The consequence of this would necessarily be an overestimation of the project's impacts. Moreover, access to infrastructures influence households' welfare through different channels, which will be detailed later, but it also affects the supply and demand of infrastructure. Such simultaneity is another source of bias if not adequately accounted for.

[3] For a review and classification of available cookstove and biogas technologies, see Mapelli and Mungwe (2013). An impact evaluation of digesters on energy expenditure and fuel use in Rwanda can be found in Bedi et al. 2015.

Selection bias problems occur when one aims to estimate the impact of an intervention (electrification or ICS), by looking at the differences between beneficiaries and non-beneficiaries. In such case observable and unobservable differences between individuals benefiting or not benefiting from the intervention cannot be distinguished from the true project impact, as the project's process of selection in the project is driven by observable or unobservable characteristics which also influence the outcome.

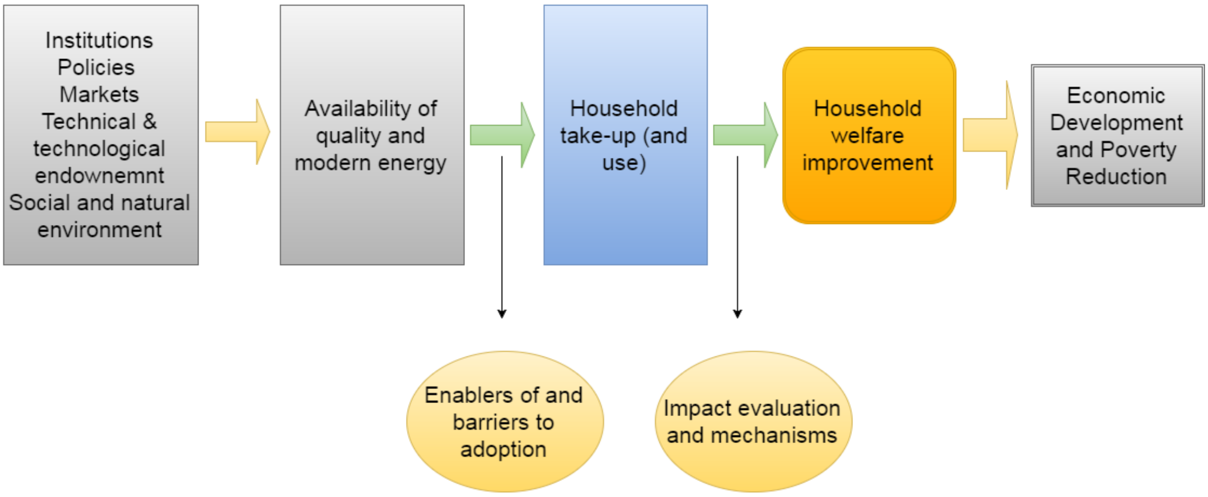
Different statistical methods have been suggested to identify counterfactuals through control groups, allowing the proper comparison of outcomes and leading to correct cause-effect assessments. Impact evaluation methods using the counterfactual can be classified in two main categories: experimental and non-experimental designs. Experimental designs construct the counterfactual through the random assignment of individuals to either treatment or control groups. As a consequence of that, individuals from the two groups differ only in being (randomly) exposed to the program or not. This allows the attribution of changes in the outcomes of interest to the intervention in a causal manner. Randomized Controlled Trials (RCT), originally used in medical and epidemiological studies, have become an important methodology in development microeconomics over the last decade (Banerjee and Duflo, 2011). Non-experimental methods are used when it is not possible to directly manipulate the assignment process of project exposure and rely on observational data, derived from the observation of the natural development of events. The identification of the counterfactual using non-experimental methods requires specific, fairly strong assumptions. The most common techniques are through the use of longitudinal data using difference-in-differences (DID) or fixed effects models (FE), propensity score matching (PSP), regression discontinuity design (RDD), instrumental variables (IV) and Heckman selection models. This review mainly focuses on works which explicitly attempt at identifying the counterfactual via experimental and non-experimental methods.

Rigorous impact evaluation also allows shedding light on the cost-effectiveness of interventions, for example when several policy options are available for the same objective.

2. Conceptual framework

Access to modern and quality energy is a fundamental input for the assessment of impacts on economic development in the sphere of households. However, it is important to consider it within a more general framework. Figure 1 shows a possible conceptual framework which includes access to energy as both output and input in a theory of change. There is a vast debate on the general conditions making modern and quality energy available to households, which spans from institutions and policies to markets, technology, social and natural environment. In the context of electrification key factors are represented by policy decisions over the energy mix, electricity generation, transmission and distribution, public vs private supply, tariff plans, etc. Despite of their fundamental importance, in the theory of change, they are not the main focus of this work. From a household perspective, accessible energy does not automatically mean actual access. Several barriers and drivers in the decision to take-up the new technology need to be considered. The review of works which rigorously investigate such barriers to and drivers of adoption is one of the main objectives of this paper. The second main focus of this review is dedicated to the investigation of impacts of access to energy on household welfare and, ultimately, on economic development and poverty reduction. We look at several mechanisms linking access to energy to the outcomes of interest and review the evidence substantiating causal links. Specific conceptual frameworks are developed for the review of causal chains for both access to electricity and to ICS. This exercise also allows us to shed light on under-researched areas.

Figure 1. Conceptual framework



3. Study selection

The selection of papers to be included in this work is done through electronic searches in bibliographic databases, backward and forward citation tracking in published and unpublished papers ("snowballing"), and selective search in institutional websites (J-PAL, 3ie, DFID)[4].

The criteria for including studies in this review are established along the definitions of participants, interventions, comparison groups and outcomes (PICO), following the standards of systematic reviews. A particularly strict inclusion criterion is set on the study methodology.

The type of participants (and the unit of observation) includes individuals or households living in low and middle income countries, in accordance with the World Bank classification.

The types of interventions include, in the domain of access to electricity, the expansion of the coverage of grid, off-grid and decentralized power provision (micro PV and home solar systems) and improvements in the quality of the electricity supply. In the domain of cooking methods, interventions include policies and programs to promote cleaner and more efficient household energy technologies, intended in a very broad way, as possible progress from traditional inefficient stoves.

Eligible comparisons include both groups of people not receiving the type of intervention under study and groups receiving other types of treatment or different levels of intensity. The control group is either identified via experimental design or through the quasi-experimental methods listed below.

In the domain of the analysis of barrier of and enablers to adoption, the outcome variables are electricity connection, ICS take-up and use. In the domain of impacts, outcome measures include time allocation, labour market outcomes, welfare and health. A detailed description of outcomes is provided in the following sections dedicated to the description of the reviewed evidence.

[4] The search strategy cannot be defined "systematic" and was not conducted through the definition of an ex-ante protocol and comprehensive search in multiple international databases. The "grey literature" has been purposively excluded from the current review. However, the mass of papers we end up with using this strategy is in line with systematic reviews.

Eligible studies included, regardless of their publication status, experimental (RCTs) and quasi-experimental methods with a controlled comparison. Quasi-experimental designs required a cross sectional and/or longitudinal comparison. For quasi-experimental designs we indicate the method of analysis used to control for endogeneity of program placement or selection bias. We include matching, panel data methods, difference-in-differences, instrumental variable estimation, regression discontinuity designs and Heckman selection models, or combinations of them.
In order to weigh the degree of identifying assumption to obtain causal inferences as well as the credibility of results from studies with a wide range of methodologies and data sources, we use the risk of bias tool developed by the International Development Coordinating Group (IDCG) secretariat to assess risk of bias (see Baird et al. 2013 for a similar application). This tool allows to assess the degree of identifying assumption and the credibility of results, based on five categories: i. selection bias and confounding; ii. Spillovers, cross-overs, contamination; iii. Outcome reporting; iv. Analysis reporting; v. other risks of bias. In tables 2 to 5, each paper is assigned a score equal to high, medium or low. Such assessment is qualitatively taken into consideration when we discuss the evidence of causal relationships. Table 1 summarizes the number of articles which has been included by topic and methodology.

Table 1 here

4. Enablers of and barriers to household access to modern energy

The works on barriers and drivers of electricity connection and adoption of ICS is strongly connected to the literature on technology adoption and on the demand for environmental health improvements. This is related to heterogeneities in consumers' preferences, circumstances and constraints (see, among others, Pattanayak and Pfaff 2009, Suri 2011, Besley and Case 1993). The take-up of preventive and remedial practices and products is very effective in reducing the burden of morbidity and mortality, such as malaria, HIV/AIDS, waterborne and respiratory diseases (Dupas, 2011b). Similarly to ICS, insecticide-treated bednets, water treatments with chlorine, condoms, menstrual cups and deworming pills are among the possible relatively easy and inexpensive solutions whose take-up is, however, quite slow. The role of subsidies and price to mitigate liquidity constraints (Ashraf et al. 2010, Cohen and Dupas 2010, Kremer et al. 2011, Dupas 2014), credit constraints (Tarozzi et al. 2014), time preferences (Tarozzi et al. 2009), lack of information and awareness (Dupas 2009, 2011a) and peer effects (Kremer and Miguel, 2007; Oster and Thornton, 2012) are among the most important barriers to health technology adoption, particularly when returns appear uncertain.
Somehow differently from the technologies mentioned earlier, electricity connection requires the existence of a wider network of infrastructures, beyond the individual decision to connect and have important externalities in the costs of connection. This fact can have relevant consequences on the policy interventions needed to expand the coverage. However, we are convinced that the household decision to connect to electricity still presents common features with the literature mentioned.

4.1 Electricity

Reaching rural villages with electricity does not necessarily mean connections for all the households, as connection to the grid may be expensive. Lee et al. (2016a) make a distinction between "off-grid" households thar are too far away to connect to the grid without major investment, and "under-grid" households that live close enough to the grid to be connected to a low-voltage line at a relatively low cost. They show that among the latter group, only 5% of rural households and 22% of rural businesses are actually connected, even after five years from the infrastructure building and despite the relatively high population density of the study area (rural Kenya). Levels of connection remain low even for relatively well-off households and businesses. In other studies and locations households connection in newly on-grid locations does not vary sensibly: 23% in Indonesia (Chakravorty et al. 2016), 50% in India (Burlig and Preonas, 2016).

Very few papers satisfying our inclusion criteria, particularly concerning the study design and the focus on household decision-making, assess the role of barriers and drivers to the connection to the grid/mini-grid[5]. The individual decision to connect seems to be linked to the price of the connection, which may range between $50 and $250; despite subsidization, such fees may result prohibitive for most poor households. In fact, while less than 5% of the poorest rural housholds in Ghana and South Africa were connected to electricity, those in the richest quintile were more than 20% (Heltberg, 2003).
Lee et al. (2016b) study the demand side of grid connection in Kenya and find that moving away from full subsidization of connection costs leads to lower take-up rates than expected, namely 57 and 29% subsidies led to a 23 and 6% take-up rate, respectively. By randomly allocating 10 and 20% discount vouchers for connection fees to rural Ethiopian households, Bernard and Torero (2015) find that connections increase, on average, by 18%, revealing that connection fees represent a significant barrier to the adoption of electricity. Low connection rates have also been linked to low levels of understanding of payment systems or limited knowledge of the potential advantages of electricity (Ranganathan, 1993). The presence of important economic barriers to connection and electricity use is also shown in Hanna and Oliva (2015) who find that an asset transfer program in India led to a significant increase in the use of electricity as the main source of light.
Another relevant channel in household decision-making towards electricity connection is others' connection behaviour. Bernard and Torero (2015) find evidence of the *bandwagon* effect: connection to electricity carries a social status so that neighbours' connection decisions have an impact (decreasing in distance) on household connection decision.
Other explanations for reduced demand for electricity connections include bureaucracy, low reliability of power supply and credit constraints (Lee et al. 2016b), however they have not been directly and rigorously tested and they therefore need to be further investigated. As in many other cases of technology adoption, households may underestimate the benefits of electrification, perhaps perceiving it as a luxury good, instead of a productive investment (Bernard, 2012). Related to lack of knowledge and mis-perceptions, Peters et al. (2009) suggest that poor households may fear to misunderstand the billing system. It would be interesting to test such hypothesis against the evidence, by evaluating the cost-effectiveness of information campaigns following the electrification expansion.
Table 2 reports the reviewed literature on these outcomes, the geographical region where the microeconomic study has been carried out, the estimation techniques employed to identify the causal effect and the outcome of the risk of bias assessment.

[5] Several papers discuss the institutional, technological, economic and contextual barriers to the deployment of rural electrification programs (both grid and off-grid) using mixed methods, among others, for example, Chauhan and Saini (2015), Ahlborg and Hammar (2014), Sindhu et al. (2016). A systematic review by Sievert and coauthors on the effects of market-based reforms on access to electricity in developing countries is also ongoing and expected soon (Sievert et al. 2014).

Table 2 here

The effort to universal access should balance the necessary long-term sustainability of projects, which is essential in order to attract private investments, with the issue of access and affordability for the poorer. Affordability relates to the capability of households to be financially and economically capable to access and use electricity. The cost of the investment of individual households is related to the number of connections of geographically close households, pointing to the existence of positive externalities associated with new connections. This fact may justify mass connection campaigns at subsidized prices or stimulate the creation of innovative schemes aimed at overcoming the collective action problem, for example through group-based subsidies linked to the number of applicants (Lee et al. 2016). Progressive tariffs, lifeline tariffs (households consuming below a certain amount per month receive a subsidy), innovative financing solutions for connection fees, for example through microcredit or mobile payments, are among the possible tools governments can use to support access and use of electricity by rural and poor households (Winkler et al. 2011). Such solutions need to be developed, designed to local context and eventually tested against evidence.

4.2 Improved cookstoves

The adoption of improved technologies for cooking is strictly linked to fuel choice. Several models have tried to describe energy transition dynamics in developing countries (van der Kroon et al. 2013). The idea of an energy ladder implies the movement of households towards more sophisticated energy sources and cooking tools, as their income increases. This may occur through a linear process of fuel switching (Heltberg 2004) or through energy stacking, i.e. both modern and traditional fuels and cookstoves, not being mutually exclusive, are used at the same time (Ruiz-Marcado et al. 2011, Masera et al. 2000). This review focuses on the adoption of improved cookstoves. By adoption we mean not only purchase or acquisition of all types of improved cookstoves, through any possible channel, such as markets, campaigns, etc, of any type of improved cookstove, but also sustained usage over time. Given the lack of international standards defining the degrees of “improvement” of stoves, we include works describing the introduction of stoves providing all kinds of innovation (efficiency and/or health risks prevention) with respect to the traditional ones.

Some recent works have tried to investigate the role of the barriers which prevent adoption, daily use and maintenance of improved cookstoves, through regression analysis of the drivers of demand. The main drivers associated with improved cookstoves adoption are related to socio-economic status: income, education and urban location are positively associated, whereas socially marginalized status is negatively related to purchase and use. Price of firewood also seems to be a key factor. In some contexts, existing models of ICS do not seem to respond to local needs and preferences (Lewis and Pattanayak 2012, Puzzolo et al. 2013). However, most of such studies do not address the issue of causal inference through the identification of proper counterfactuals, and are therefore limited to the indication of correlations and relevant associations.

There are very few studies that assess the role of barriers to adoption of improved cookstoves using counterfactual designs. These studies are summarized in table 2, and several of them confirm the crucial role played by prices and liquidity constraints in the decisions to buy, use and maintain improved cookstoves (Hanna et al. 2016, Miller and Mobarak 2013, 2014, Alem et al. 2013, Jeuland et al. 2014), even despute relatively high subsidies, the percentage of uptake decisions remain relatively low (Mobarak et al. 2012).

As is the case for several similar technologies, individual may not know or may underestimate the benefits of the technologies. Bonan et al. (2016) find suggestive evidence of impacts on ICS take-up following an informational sessions showing the benefits associated with more efficient cookstoves compared with the traditional ones[6].

Differences in preferences across households but also within households seem to explain differential ICS take-up rates. Miller and Mobarak (2013) find that propensity to adopt modern cookstoves differs for women and men: women have a stronger preference towards the new technology but lack sufficient authority and bargaining power within the household to impose their decision on men. Heterogeneity in user preferences for different stove features is an important predictor of take-up (Jeuland et al. 2014).

Others' decision to adopt ICS also seems to influence individual decision to adopt. For example, Miller and Mobarak (2014) highlight the important role of opinion leaders and social networks in conveying information on the attributes of the new technology and decisions to adopt. Social influence and imitation through social network are also found to be an important driver for ICS take-up in Bonan et al. (2016), while Beltramo et al. (2015b) find no evidence of neighbours' adoption rates on individual decision to purchase. Adrianzen (2014) shows the importance of social capital in driving the success or failure of product diffusion within communities[7].

Social marketing and communication strategies can play an important role in favoring health preventive behavior and products (Evans et al. 2014). Investigating ICS adoption under social marketing lenses is the focus of a recent strand of research[8] (Lewis et al. 2015), however very few studies using counterfactual methodologies are currently available. Levine et al. (2013) find that an offer combining a free trial period, time payments and the right to return the stove significantly increases the purchase of the product, compared to a traditional cash-and-carry offer. In a related study, Beltramo et al. (2015) find that marketing messages conveying the benefits of improved cookstoves had no effect on willingness to pay (WTP) for them, however one has to note that the WTP exercise had poor predictive power on the actual purchase behaviour.

Although ICS take-up is seen as a fundamental first step to climb the energy ladder and fight energy poverty, there are two conditions which make it possible, after take-up has occurred. The first is the quality, effectiveness and suitability of ICS: the product has to be durable and it has to fit customers' needs and preferences beyond their "improved" attributes (Rosenbaum et al. 2015). The second condition is the sustained use and maintenance of the product. ICS adoption cannot be intended as simple take-up, but has to be considered as a dynamic process involving the stacking of new and old fuels and stoves (Ruiz-Marcado et al. 2011). An example in which the two conditions are not met is given by Hanna et al. (2016) where stove breakages combined with insufficient investments in maintenance, inappropriate cleaning and use impeded sustained usage over time and eventually did not lead to the expected impacts.

[6] However, the authors were unable to separate the effect of the information from that of a 12% price discount and of the possibility to access more easily to the product.

[7] Despite of the interesting angle of analysis, such study fails to meet the methodological requirements of this review and was not included in the summary table.

[8] The Journal of Health Communication dedicated a special issue to this topic (vol. 20-1 2015).

Learning the drivers of adoption and diffusion and continuous use is of great relevance in order to strengthen evidence-based actions and policies. Further research should focus on the roles of household level decision-making, gender, cultural traits, liquidity and credit constraints, but also behavioural factors to guide marketing interventions, through the involvement of local institutions and social networks (Foell et al. 2011). Testing different social marketing features would allow shedding more light on the role of information and preferences, whose impact on take-up is still under-researched.

Positive externalities in ICS adoption justify the introduction of subsidies or other ways to overcome households' liquidity constraints and relatively low WTP for ICS. However, such positive externalities occur only if households consistently use and maintain the products. This requires the introduction of innovative monitoring strategies which do not interfere with households' behaviour (Hawtorne effect) but which can provide systematic and objective measure of their use. The introduction of sensors and IT-based stove use monitors can represent a scalable and cost-effective solution (Ruiz-Marcado et al. 2013, Harrell et al. 2016).

The introduction of demand-side interventions, as proposed above, is likely to be effective only in the presence of stable and accessible supply of ICS. Strengthening the supply chain appears to be an important prerequisite for the success of any attempt to diffuse ICS in developing countries (Lewis et al. 2015). More effort in the development of strategies and policies for the improvement of the supply chain is needed, perhaps involving local institutions[9]. More rigorous research on supply side is required, although the attribution of causal impacts results far more difficult in such a context.

5. Impacts and mechanisms

5.1 Electricity

Access to electricity can impact household welfare, economic development and poverty reduction through a vast range of channels and mechanisms. From a household perspective, access to electricity means the opportunity to purchase electric appliances, depending on the wattage level made available, such as light, refrigerator, TV, heating and cooling appliances and electric machineries for small business. The demand of electric appliances in developing countries is expected to grow dramatically in the next decades (Wolfram et al. 2012) and is shown to be non-linearly connected to income growth, assuming household's credit constraints (Gertler et al. 2016). The identification of impacts for the adoption of individual appliances appears challenging and very few studies have attempted to investigate it. Barreca, et al. (2016) find that air conditioning lowered heat-related mortality in the US and there is a strong emerging evidence of the link between temperature and economic activity (Burke et al. 2015, Adhvaryu et al. 2016) which highlights the scope for adaptation strategies to climate change. Few studies assess the potential impact of refrigerators on food security and health. Gonzalez and Rossi (2007) find suggestive evidence of the impact of better quality of electricity provision, after privatization, on health outcomes related to nutrition, due to the increase in refrigerator use. Media exposure can have important impacts on development outcomes (La Ferrara, *forthcoming*), particularly on female empowerment (Jensen and Oster 2009), divorce (Chong and La Ferrara et al. 2009), social capital (Olken 2009) and fertility (La Ferrara et al. 2012). Besides media exposure, the introduction of electricity also seems to

[9] For example, Pattanayak and Pfaff (2009) suggest the importance of engaging with local institutions that are able to effectively implement social mobilization campaigns and serve as a channel for trust

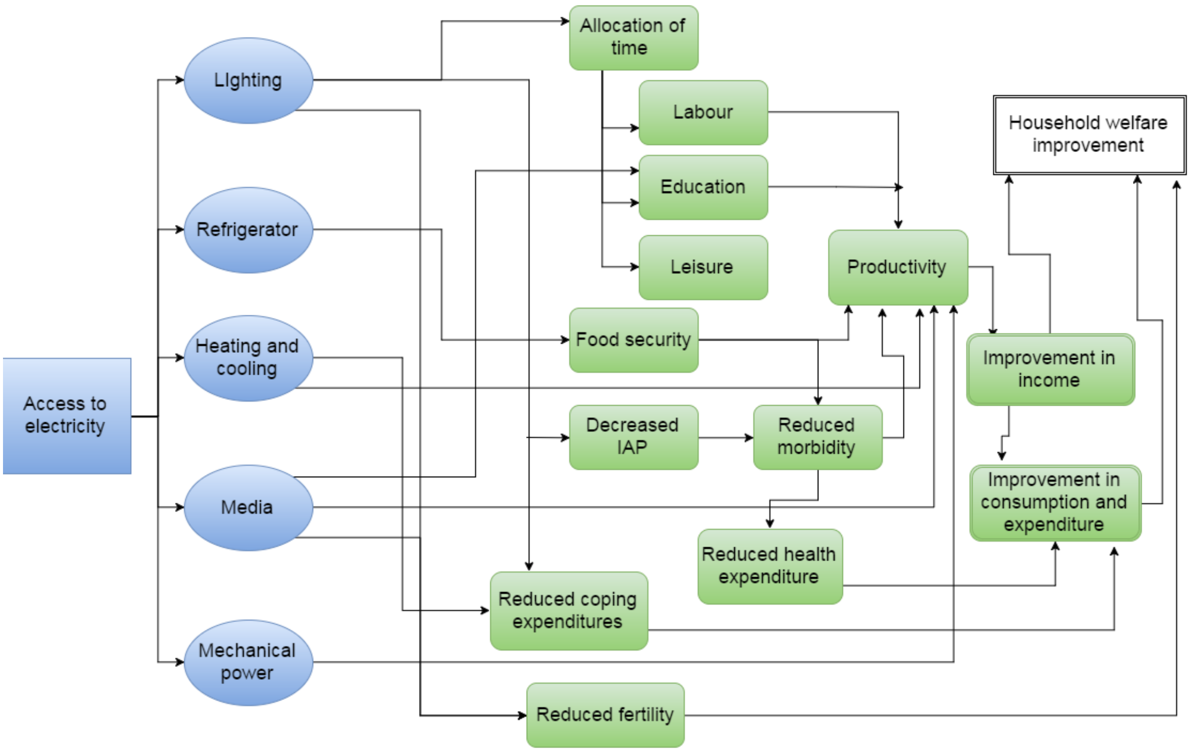
negatively affect fertility, particularly in the short-run (Grimm et al. 2015b, Burlando 2014, Fetzer et al. 2013).

Electricity is also considered a fundamental driver for the development of economic opportunities and improvement in households' productivity in both agricultural and non-agricultural sectors, by providing motive power. In the agricultural sector, it would power farm machineries such as water pumps, fodder choppers, threshers, grinders, and dryers. Electricity would contribute to the modernization of agriculture by extending cultivable land through irrigation. This would lead to increases in labour demand and in productivity (Cabraal et al. 2005). In the non-agricultural sector electricity could contribute to the development of small business opportunities, for example, in the food processing value chain, in the handicraft production, carpentry and retailing. However, no empirical evidence of impacts of electricity on small business outcomes has been found[10]. While several studies included in this review present some measures of agriculture or non-agriculture employment, production or revenues, none of them could disentangle the general access to electricity from the role of the access to specific electric items for productive use. This is an interesting area which should deserve more research.
The first and most widespread electric appliance adopted in newly electrified contexts is lighting, particularly in remote areas (Bernard 2012, Barnes 2007, Bensch et al. 2011). This is motivated both by the often low-wattage made available by grid or off-grid solutions, and by the households' relatively low ability to pay for other electric appliances. Lighting can have direct impacts on health, via the substitution of more pollutant kerosene lamps, but also potentially influences the allocation of time of all household members: women and children can divert time from fuel collection to more productive activities, such as studying or income generation. People can also benefit from greater flexibility in time allocation through the day and evening derived from better lighting. Electric light can also generate high saving from expenditure in alternatives, such as kerosene lamps, candles, diesel generators and batteries. By influencing the reallocation of activities and leisure, electric light can also have impacts on fertility, beyond the aforementioned effect through media exposure.
Finally electrification may impact households' outcomes through public good benefits, such as increased security through lighted streets, better schooling and health services, lower environmental contamination and degradation (IEG 2008). Although this is not the focus of this review, empirical evidence of such causal links remains scarce.

A representation of the causal chain linking access to electricity to economic development and poverty reduction is provided in figure 2. One has to note that the attempt to evaluate the entire causal chain in one study would be too ambitious. In general, the studies which we review could only capture different sub-set of the causal chain. The following sections describe the empirical evidence on the causal links between access to electricity (considered in a broader sense) and i. time allocation and labour market outcomes (table 3), ii. household expenditure, schooling and health (table 4).

Figure 2. Causal chain of impacts of access to electricity

[10] An ongoing randomized evaluation by Tavneet Suri and William Jack in Kenia investigates the impact of adoption of off-grid solar power on small retail businesses' revenue and profits.



5.1.1 Time allocation and labour market

The first set of channels through which access to energy may impact household welfare is time allocation of members and labour. This may occur through different mechanisms. Saving time from traditional energy-connected activities (fuel collection, cooking, etc), and extending the working day even after sunset may result in increased labour supply and employment. Connected to this, the time spent by children studying at home is also a possible relevant channel which may contribute to school attainment and performance.
Another set of mechanisms may involve improvements in productivity in the agricultural sector and/or the switch from agricultural to non-agricultural activities which electricity contributes to develop (small businesses and firms can invest in machineries, refrigeration, entertainment and communication appliances which demand non-agricultural labour). As a consequence of increased productivity, wages and earnings would increase, contributing to improvements in household income.

The impact of electrification on time allocation and labour market outcomes seems to be one of the most robust, although still not definitive. Several works lead to the conclusion that access to electricity impacts the way in which people allocate their time. For adults in India, for example, this can be a consequence of the shorter time allocated to collecting biofuels (Khandker et al. 2012), but it also contributes to important changes in children's lives, particularly with regard to the time dedicated to study and schooling. The impact of electricity on time spent studying home by children seems to be supported in several papers, across different geographical contexts, technologies (both on-grid and off-grid) and identification strategies (Bensch et al. 2012, Khandker et al. 2012, Aguirre 2014, Arraiz and Calero, 2014, Samad et al. 2013, Furukawa, 2014, Barron and Torero, 2016). Only two

studies (Bernard and Torero 2015, Grimm et al. 2015a) find no significant effect, although in the former the authors suggest that this may be due to the relatively small time window of the study and to the fact that time allocation does not adjust in the short-run, following electricity connection, while in the latter the off-grid product (pico solar PV kits) can only meet very basic energy services.
Regarding adults' time allocation and labour activities, the evidence suggests mild increases in employment and labour supply, particularly for women, non-agricultural activities and more formal activities[11]. However, the size of such effects varies significantly across studies and geographical areas. The evidence of impact of electricity on wages, earnings and income also seems to point to the direction of improvements, although less consistently than the case of employment. For example, Dinkelman (2011) finds higher earnings for men (not for women) but no average effects on wages. Higher wages for women are found by Dasso and Fernandez (2015). Similarly, Khandker et al. (2013) show significant increases in household incomes, via improvements in non-agricultural activities, but no effect on wages. Increases in non-agricultural income are also supported in studies by Dinkelman et al. (2011), Lipscomb et al. (2013) and Chakravorty et al. (2016). Reductions in electricity outages and increases in hours of electricity provision per day generate relevant improvements in non-agricultural incomes in rural India (Chakravorty et al. 2014). Other studies find no evidence of improvements in income (Bensch et al. 2011, Arraiz and Calero, 2014).

Taken together, the results seem to support the mechanism of substitution from agricultural to non-agricultural activities, leading to gains in productivity and wages, ultimately leading to income increases and welfare improvements (table 3).

Table 3 here

5.1.2 Expenditure, schooling and health

Changes in the allocation of time towards more productive activities, as well as higher earning and possibly income should be reflected in variation in consumption and expenditure which may ultimately lead to household welfare improvement. Most studies evaluating the effect of on-grid connection find significant increases in total expenditure accompanied with rises in energy expenditure (Bensch et al. 2011; van de Walle et al. 2015; Chakravorty et al. 2016). While access to off-grid such as solar PV seems to lead to lower expenditure in energy sources (Arraiz and Calero 2014; Samad et al. 2013; Grimm et al. 2015). However, one has to note that the number of studies looking at this aspect is still quite limited to draw definitive conclusions.
The impact of electricity on schooling outcomes is somehow mixed. It has positive effects on the enrolment and years of schooling of Indian girls (van de Walle et al. 2015). In other studies by such results are confirmed for both boys and girls in India, Vietnam, Brazil, Peru (Khandker et al. 2012, 2013; Lipscomb et al. 2013; Arraiz and Calero, 2014). However no effects on enrolment, negative effects on attendance and school performance are found in other studies in India, Honduras and Uganda (Burlig and Preonas, 2016; Squires, 2015; Furukawa, 2014). These findings open up the risk of occurrence of a perverse effect of electricity on children's educational outcomes. This may arise, for example, through the substitution of their parents in housing chores or their direct employment in the productive

[11] One has to note that, once again, Bernard and Torero (2015) find no effect on time spent on income generating activities, with the caveat of the short-term perspective.

sector, given the higher opportunity cost of education. This topic definitely deserves further investigation.
The evidence of the impact of electricity on health outcomes is extremely limited and mainly explores the role of two channels. The first is the effect of the introduction of refrigerators on children's health through better nutrition and less food poisoning (Gonzalez and Rossi, 2007). The second is through the substitution of kerosene lamp with electric bulbs, through decreases in indoor air pollution exposure and respiratory diseases (Samad et al. 2013, Barron and Torero, 2016). While inconclusive evidence is found on the first channel, the second channel seems to be supported.
An impact evaluation analysis of electrification on a wider set of outcome indicators and for a larger time span is provided by Lipscomb et al. (2013) for Brazil. The authors show the positive impact of electrification on development indicators such as the Human Development Index (HDI), which includes variables referring to income, schooling and health. The improvements in HDI as a consequence of access to electricity are mainly led by the income and schooling components.
The impact of electrification is not limited to rural households which are connected to the grid. Access to electricity also has externality effects on other non-connected villages. The benefits of rural electrification are shown to spill over households not connected to the grid, which have higher levels of consumption compared to non-connected households (van de Walle et al. 2013). The externality effect of electricity operating through the community is also confirmed in Burlando (2014) where villages affected by a long power outage, regardless of their level of electrification, experienced significant increases in births.
In the light of the analysis conducted (table 3), electrification seems to be beneficial for households welfare, along the causal chain presented in the conceptual framework. However, one has to note that the dimension of benefits seems to vary across geographical regions. In particular, the impacts in the African context, after excluding the case of South Africa in Dinkelman's study, seem to be quite modest (Peters and Sievert, 2016). The low access to markets, small role of private sector and the lack of other important infrastructure may have played a role in preventing or slowing down the impacts of access to electricity on productivity and labour opportunities in the non-agricultural sector. In such context, improving the productivity of the agricultural sector, for example through the development of improved irrigation systems, may lead to improvement in income, even in the short-mid-term. However, on this aspect research is silent. Although more evidence on the other channels is available, often difficulties in systematically aggregate results, given the many differences in type of energy provision (for electrification the range is from high-wattage grid, to home solar systems), the differences in the measures of outcomes, the reliability of studies, pose big challenges in drawing common lessons. Moreover, most studies reviewed do not control or correct for multiple hypothesis testing, which may lead to over-rejection of null hypothesis and overestimation of program impacts (List et al. 2015)[12].

Table 4 here

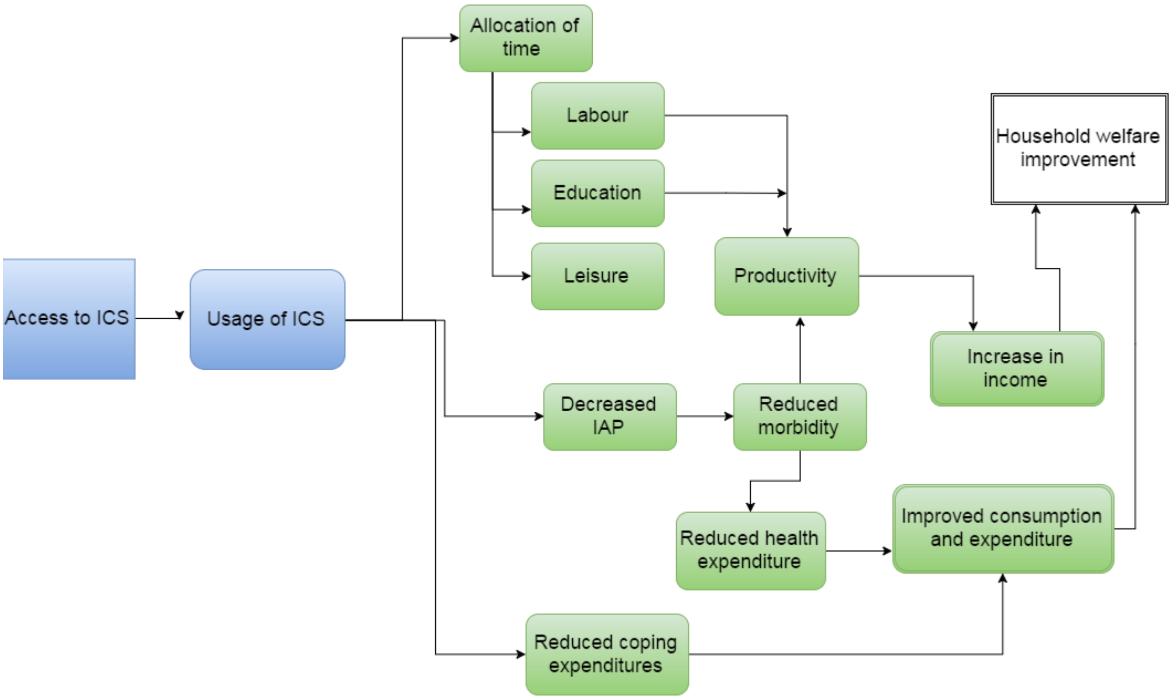
5.2 Improved cookstoves

The use of modern and improved cooking stoves may have positive consequences on household welfare and sustainable development, from several points of view: health, time

[12] However, correction for multiple hypothesis testing has not been considered as a parameter in the assessment of the risk of bias

allocation and reduced expenditure in fuels, due to efficiency gains. A graphical representation of the conceptual framework going from access to ICS to household welfare, through different channels is provided in figure 3.

Figure 3. Causal chain of impacts of access to ICS



Regarding the first channel, WHO claims that indoor air pollution caused by the use of traditional cooking stoves and fuels such as firewood and biomass has severe consequences on health. Indoor smoke inhalation is among the underlying causes of pneumonia and heart diseases, which are among the leading causes of the global burden of disease (Ezzati and Kammen, 2001). Household air pollution is estimated to be responsible for about 4 million deaths per year (Lim et al. 2013, Martin et al. 2011). Such numbers are greater than deaths from malaria, HIV/AIDS and tuberculosis (WHO 2008) which are expected to decrease substantially by 2030, whereas the current pace of fatal respiratory diseases due to indoor air pollution is not expected to decrease. The adverse effects of indoor air pollution on health are particularly severe in women and children (Smith et al. 2004). The adoption of ICS can therefore contribute to a decrease in morbidity, particularly that related to respiratory diseases, through the lower exposure to IAP

Inefficient stoves require longer cooking and fuel-gathering times. This task is mainly carried out by women and children, who divert time from education and income-generating activities (Barnes and Toman 2006)[13], although these aspects are strongly related to cultural and behavioural traits which differ from place to place and may slacken the pace of change. The adoption of ICS could therefore contribute to a reallocation of time towards more productive activities, such as study and income generation.

[13] Charmes (2006) analyses time use in several Sub-Saharan African countries, by looking at large-scale surveys, and finds that women spend 3-5 times as much time as men in domestic activities like collecting firewood and cooking. However, if we look at the two activities separately, it turns out that the picture is more balanced between men and women for firewood collection, whereas cooking activities are largely dominated by women.

Finally, more efficient stoves can generate a decrease in fuel consumption and expenditure, with the possibility to divert consequent saving into other expenditures, perhaps more productive.
Table 4 presents the main contribution of the literature on the impacts of ICS adoption.

Table 5 here

5.2.1 Health

Arguably, the most important impact of improved cookstoves on individuals and households is the limitation of indoor air pollution (IAP). Despite the great variety of products which could be defined as "improved cookstove" (World Bank 2010), the simple introduction of fireboxes and chimneys allows important improvements in terms of IAP, compared to traditional stoves (open or three stone fires). For example, Dutta et al. (2007) find that carbon monoxide concentrations drop by 38% and PM2.5 concentration by 24 to 49% as a result of improved stoves in India. Such reductions are shown to have beneficial effects on health. Several studies seem to convey that changes in cooking technologies reduce the incidence of acute respiratory infections. In general, a large strand of the literature in epidemiology and environmental science supports the existence of a strong positive association between IAP and negative health outcomes (Zhang and Smith, 2007), however most evidence relies on observational studies and is unable to identify causal effects: the choice of cooking fuel and stoves may be related to unobserved health behaviour which also affects health outcomes. For example, better respiratory health in households that cook with cleaner fuels may be due to better access to information on health prevention which may also impact on other health-related behaviours (Duflo et al. 2008). Moreover, many studies do not consider the possible mitigation of smoke inhalation reduction due to the behavioural responses of people who may not necessarily use properly and maintain cookstoves over time, after the first wave of promotion and distribution. This commonly leads to situations where reductions in IAP in the field are significantly lower than those measured during laboratory tests.

Only a handful of studies evaluate the impacts on health of improved cooking stoves using randomized controlled field trials. The project RESPIRE (Randomized Exposure Study of Pollution Indoors and Respiratory Effects) is a medical investigation on the respiratory consequences of indoor air pollution and on the potential benefits from the introduction of more modern techniques in Guatemala. The use of improved cookstoves reduces carbon monoxide exposure by 50 to 60%, and significantly reduces the risk of developing respiratory diseases, such as pneumonia, over the 18 months following the distribution of cookstoves (Smith et al. 2011; Smith-Sivertsen et al. 2009)[14]. Another study in India, based on a longer time span and on a larger sample, shows that the introduction of modern cooking stoves has only modest health effects which tend to vanish in the longer period (Hanna et al. 2016). This is mainly due to the fact that the use of such new technologies is not always continued in time, and maintenance is often neglected. Similarly, Beltramo and Levine (2013) find no effect on health (exposure to carbon monoxide or self-reported respiratory symptoms) from the take-up of a solar oven in Senegal. This was due to the inappropriateness of the product design to the local needs. Significant reductions in health problems, respiratory diseases and eye problems, are found in other studies (Bensch and Peters 2015; Burwen and Levine 2012, Yu 2011), however they are based on self-reporting.

[14] It has to be noted, though, that no significant reduction in respiratory problems was found, through physician assessments, while significant effects emerged from fieldworker assessments.

Dherani et al. (2008) use meta-analysis and find that the risk of pneumonia in young children is increased by exposure to unprocessed solid fuels by 80%. Using different non-experimental techniques, other studies highlight the relationship between the choice of cooking fuels and morbidity (among several, Ezzati and Kammen, 2002, Ezzati et al. 2000, Silwal and McKay, 2015, Gajate-Garrido, 2013, Mueller et al. 2013), however this topic lies outside the objective of the current review.

5.2.2 Time allocation, fuel use and expenditures

Rigorous evidence on the role of improved cookstoves on time allocation, female and children's conditions is quite scarce (Kohlin et al. 2011). The success of ICS adoption on time allocation, fuel use and expenditure in the few rigorous studies analyzed largely varies across studies. In some works, significant reductions in time spent in fuel collection, fuel consumption and cooking time are observed (Brooks et al. 2016; Bensch and Peters 2015; Adrianzen 2013), while in others no such effects are found (Hanna et al. 2016; Beltramo and Levine 2013; Burwen and Levine 2012).

As previously discussed, the benefits of ICS on household welfare are strictly related to two main issues: first the quality, suitability to the context and durability of ICS, second to the behavioral component which leads to adoption, intended as take-up and sustained use over time. On the first aspect, new ICS diffusion campaigns should first assess the suitability of product design to local needs, cultural and environmental conditions. For example, one should consider that in some contexts multiple stoves are used simultaneously, the new and the traditional ones (Ruiz-Marcado et al. 2011) and that stoves need to be large enough to accommodate extended families which cook on a centralized basis to generate economies of scale (Beltramo and Levine, 2013; Bonan et al. 2016). On the second aspect, new policies should acknowledge the existence of a gap from ICS take-up to actual, continuous and sustained usage over time. In order to cover "the last mile", efforts should not just focus on the distribution side, but should incorporate adequate interventions to induce households behavioural change. This is a crucial condition to ultimately realize the expected benefits in household welfare and the positive externalities. These may include, for example, informational campaigns, the provision of some sort of after-sale service mechanism to support ICS maintenance, nudges and incentives. Multiplier effects may be obtained by exploiting natural social network dynamics and thorough marketing strategies.

On the research front, more evidence is needed to test products and cost-effectiveness of models in different contexts. However, researchers need to complement self-reporting with objective measures of usage and impacts. Such an exercise is particularly costly, but it is extremely useful if one wants to minimize measurement error and self-reporting bias. Useful examples for objective IAP measures, ICS usage monitoring and morbidity assessments are provided in Barron and Torero (2016), Ruiz-Marcado et al. (2011) and Beltramo and Levine (2013), Hanna et al. (2016). This may induce the development of innovative financing mechanisms, for example through carbon and impact finance (Simon et al. 2014).

6. Conclusions

Large global imbalances and inequity in access to energy have recently stimulated an important policy debate which has influenced the post-2015 development agenda leading to the incorporation of the universal access to affordable, reliable and modern energy in the Sustainable Development Goals.. Access to electricity, particularly in rural areas, and the introduction of improved cooking technologies, beyond the use of wood and biomass, are crucial development challenges for their close link to and implication for household health, education, welfare and labour market. Although a great effort in the last decades has been made to monitor progress and report initiatives, rigorous impact evaluation studies of programs (at all scales) are rare. This paper reviews the most recent literature on the barriers of, enablers to and impact evaluation of access to electrification and adoption of improved cookstoves on several relevant outcomes, based on solid identification strategies and estimation techniques.

This review unveiled some important elements beyond the common consideration of grid expansion as a panacea for development, although the evidence supporting substantial causal impacts on household welfare is compelling in some contexts. New emerging challenges are related to the relatively low connection rates in on-grid areas and the relatively little impact of electricity expansion both in the short (Bernard and Torero 2015) and the mid-run (Burlig and Preonas 2016) particularly in some areas, like the African context, where effects are somehow smaller or take longer to emerge (Peters and Sievert, 2016). More evidence involving rigorous technique is needed to better understand the barriers to electricity connection and when, where and after how long electricity access has the greatest impact. Some randomized field works are ongoing and hopefully will contribute to this debate (Miguel et al 2014; Ryan et al. 2014)[15].

Electrification policies should consider two aspects more thoroughly. First, the role of barriers to connections, finding innovative solutions incorporating household decision-making. Such solutions should be tested against the evidence. Second, policy-makers should balance the actual quantified benefits and the different costs of electricity provision, depending on the different distribution options. This should take into consideration the documented good success of off-grid solutions for the provision of basic energy services, like lighting.

Similar considerations hold for ICS diffusion policies. Enhancing household adoption requires more effort to understand and develop both the supply and the demand side. The large varieties of products currently available in the decentralized markets and the lack of standard of quality and testing metrics (Simon et al. 2014), pose important challenges. Although "fit for all" products cannot be viable solutions, ICS need to fit local contexts and preferences. Given the important private and public benefits they can generate, innovative interventions should focus on financing mechanisms, coupled with demand-side considerations on household economic and behavioural constraints in climbing the energy ladder. This may imply the introduction of marketing interventions and post-sale services in order to maximize take-up and sustained usage over time. Once again, drawing on local social dynamics may support the diffusion process.

The focus of the review is on the household level. However, poor electricity infrastructures are considered among the most relevant barriers to economic growth, particularly for the development of industrial activities which heavily rely on the quality supply of electricity. The lack of quality and reliable electric infrastructures leads firms to self-generate energy, often with consequently higher costs. A nascent literature is trying to assess the impacts on business outcomes for firms, but it is still quite scarce and would require more effort from the academic community. Electricity access expansion has found to positively impact industrial growth through increases in production levels and in the number of industrial activities (Rud 2012; Peters et al. 2011). Quality of electric supply has also been shown to have important

[15] A systematic review on the impacts of electricity on health education and welfare is also expected by Mathur et al. (2015).

impacts on revenues, productivity, investments (Allcott et al. 2016; Fisher-Vanden et al. 2012; Reinikka and Svensson, 2002).

Understanding the impact of access to modern energy services on households, firms and communities outcomes is the best way to help decision-makers to implement effective policies and interventions. Evidence-based considerations on efficacy and efficiency of modern energy adoption-enhancing strategies are extremely important when budget constraints for development are limited and markets are not mature yet.

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Table 1. Summary of included studies

	Barriers to adoption		Impacts	
	Electricity	ICS	Electricity	ICS
Total number of studies	3	8	21	8
Experimental	3	7	4	5
Non Experimental	0	1	17	3
DD-FE		1	3	
IV			9	1
PSM-Heckaman			4	2
RDD			1	

Table 2. Barriers to and enablers of access to energy

Outcome	Study, geographical region	Main results	Method	Sample size (level)	Period (n. of time obs)	Risk of bias
Electrification						
Liquidy constraints	Bernard and Torero (2015), Ethiopia	20% reduction of fixed connection cost leads to 15% increase in connection	RCT	565 (household)	(2)	Low
	Lee et al. (2016), Kenya	100, 57, 29% reduction in fixed connection cost leads to 95, 23,6% take-up	RCT	2289 (household)	2014 (1)	Low
	Hanna and Oliva (2015), India	Asset transfer program leads to increase in electricity use for lighting	RCT	812 (household)	2007-2011 (3)	Low
Social networks	Bernard and Torero (2015), Ethiopia	Evidence of bandwagon effects in the decision of connecting to the grid in rural areas: having more people connected in the neighbourhood increases individual propensity to be connected	RCT	565 (household)	(2)	Low
Cookstoves						
Prices, Adoption rate, use and maintenance	Alem et al. (2013); Ethiopia	Household economic status, access to credit, price of electricity and price of firewood are significant determinants of ICS	Panel data	2934 (household)	200-2009 (3)	Medium
	Hanna et al. (2016); India	60% adoption rate with a 94% subsidy. Only 3 more meals on the improved stove per weeks. 36% more hh maintained the improved cookstove	RCT	2651 (household)	2005-2010 (2)	Low
	Miller and Mobarak (2013); Bangladesh	97% orders and 69,5% purchases for free stove; 70% orders and 27.5% for subsidized at 80% average subsidy	RCT	800 (household)	2008 (1)	Low
	Miller and Mobarak (2014); Bangladesh	25% orders and 4% actual purchases at full price; 40% orders and 11% purchases at half price	RCT	2100 (household)	2008-2009 (2)	Low
	Mobarak et al. (2012); Bangladesh	50% discount implies an increase of 25% in intentions to buy; 5-12% increase in actual purchase. Small actual purchases at full price (2-5%).	RCT	2280 (household)	2008 (1)	Low
Information	Bonan et al. (2016); Mali	Large positive effects (+25pp) of a training session with cooking show and 12% discount offer	RCT	1077 (households	2014 (2)	Low-Medium
Marketing	Levine, Beltramo, Blalock and Cotterman (2013, WP)	4% uptake with traditional cash and carry offer and 46% uptake with a novel offer with free trial and time payments. Individually time payments generate 22% uptake and right to return 33%. Cookstoves were offered at full price (6-10$)	RCT	1690 (household)	2010 (1)	Low

Intra-household decision making	Miller and Mobarak (2013); Bangladesh	When offered for free, women take-up more than men, particularly the health-improving stoves. When small prices are charged, no difference between men and women	RCT	800 (household)	2008 (1)	Low
Social networks	Miller and Mobarak (2014); Bangladesh	Positive (negative) effect of unanimous acceptance (rejection) of purchase by opinion leaders on efficiency stove orders. No positive effect on chimney stove, only significant negative effect from unanimous rejection. Info from opinion leaders is more salient at lower prices. No effect of opinion leader on actual purchase. Only unanimous rejection significantly decreases actual purchase	RCT	2100 (household)	2008-2009 (2)	Low
	Miller and Mobarak (2014); Bangladesh	Negative effect of social network on purchase: more network members purchased in first round, less likelihood of buying in the second round for members of the same network: overly optimistic opinions about benefits of cookstoves	RCT	2100 (household)	2008-2009 (2)	Low
	Bonan et al. (2016); Mali	Women are more likely to buy if they receive info about peer's purchasing behaviour	RCT	1077 (households	2014 (2)	Low

Table 3. Causal effects of access to electricity on time allocation and labour market

Outcome	Study, geographical region	Source of electricity	Results	Method	Sample size (level)	Period (n. of time obs)	Risk of bias
Allocation of time	Grimm et al. 2015, Rwanda	Solar Pico PV	No effect on time allocation of hh members	RCT	300 (households)	2011-2012 (2)	Low
	Arraiz and Calero (2014); Peru	Solar PV	More time awake; women spend less time in agriculture, more time in household activities; more people spend time on home business; children spend more time studying at home	PSM	1329 (households)	2013 (1)	Medium
	Samad et al. (2013), Bangladesh	Solar PV	Increase in study time for children and in time for fuel collection for women	PSM	4000 (households)	2012 (1)	High
	Khandker et al. (2012), India	On-grid	Large significant decrease in time collecting biofuel for women and men. Small slightly significant for boys. No effect on girls Significant increase in time spent studying for both boys and girls	IV	~24000 (households)	2005 (1)	Medium -High
	Bensch et al. (2011), Rwanda	Micro-hydro mini-grids	Small positive effects on the children studying at home	PSM	531 (household)	2005 (1)	Medium
	Bernard and Torero (2015), Ethiopia	On-grid	No short run effect on children study time	RCT	563 (household)	(2)	Low
	Aguirre (2014), Peru	On-grid	Positive and significant effect on time studying home by children	IV	987 (households)	2013 (1)	Medium -High
	Furukawa (2014), Uganda	Pico-PV lamp	Increase in study time	RCT	155 (students)	2011 (2)	Medium
	Barron and Torero (2015), El Salvador	On-grid	Strong positive effect on children participation in educational activities and more time spent on household chores	RCT	500 (households)	2007-2012 (4)	Low
Employment and labour supply	Barron and Torero (2015), El Salvador	On-grid	Increase in non-farm employement and in home business, particularly for women	RCT	500 (households)	2007-2012 (4)	Low
	Squires (2015), Honduras	On-grid	Increase in children employment rate; increase in female employment	FE-IV	~19.000 (houeholds)		Medium
	Dinkelman (2011), South Africa	On-grid	Increase in employmnt for women and no significant effect for men	D-D - IV	1816 (community)	1996-2001 (2)	Medium
	Burlig and Preonas (2016), India	On-grid	Small decrease in share of men working in agriculture and small increase in non-agriculture activities. No effect on female employment	RDD	30.000 (villages)	2001-2011 (2)	Low

	Libscomb et al. (2013); Brazil	On-grid	Strong effect on activity rate and employment in the formal sector, both in rural and urban areas	FE - IV	2184 (county)	1960-2000 (5)	Low-Medium
	Grogan and Sadanand (2013); Nicaragua	On-grid	Significant increase in the propensity to work outside the home for women. No effect for men	FE-IV	6882 (household)	1971-2005 (3)	Medium
	Bernard and Torero (2015), Ethiopia	On-grid	No short-run effect of rural electrification on time spent on income generating activities	RCT	563 (household)	(2)	Low-Medium
	Dinkelman (2011), South Africa	On-grid	Increase in labour supply for both women and men (only OLS)	pooled OLS & FE	1816 (community)	1996-2001 (2)	Medium
	van de Walle et al. (2015); India	On-grid	Significant substitution of days of work from causal wage works to regular wage and agriculture self-employment for men. Small significant reduction of female causal wage work.	Panel data & IV	~3000 (household)	1981-1999 (2)	Medium
	Dasso and Fernandez (2015); Peru	On-grid	Increase in male working hours, no effect on women. Decrease in the likelihood of having more than one job among males Women: higher employent, lower probability of working in agricultural sector	FE	3980 (individuals)	2006-2012 (6)	Medium
	Alcazar et al. (2007), Peru	On-grid / better supply	Significant reduction in hours worked in agriculture and increase in non-farm activities	PSM	6690 (households)	2005	Medium
Wages, Earnings, Income	Dinkelman (2011), South Africa	On-grid	No significant effect on wages. Higher earnings for men, no significant impacts for women	pooled OLS & FE	1816 (community)	1996-2001 (2)	Medium
	Khandker et al. (2013); Vietnam	On-grid	Significant increase in total hh income, due to the increase in non-agricultural income. No effect on wages	Panel data &FE	1120 (household)	2002-2005 (2)	Medium-High
	Bensch et al. (2011), Rwanda	Micro-hydro mini-grids	Inconclusive evidence of increase in income	PSM	531 (household)	2005 (1)	Medium
	Libscomb et al. (2013); Brazil	On-grid	Strong effect on household income	FE - IV	2184 (county)	1960-2000 (5)	Low-Medium
	Arraiz and Calero (2014); Peru	Solar PV	No effect on income	PSM	1329 (households)	2013 (1)	Medium
	Chakravorty et al. (2016); Philippines	On-grid	Significant increase in household income	FE-IV	~12.000 (households)	2003, 2012 (4)	Low-Medium
	Chakravorty et al. (2014); India	On-grid / better supply	Strong effect on household non-agricultural income. Also the quality of electricity (frequency of outages) matters for hh income	FE - IV	9790 (household)	1994-2005 (2)	Medim
	Barron and Torero (2015), El Salvador	On-grid	Positive effect on household profit from small business and household income	RCT	500 (households)	2007-2012 (4)	Low

	Dasso and Fernandez (2015); Peru	On-grid	Higher wages for women	FE	3980 (individuals)	2006-2012 (6)	Medium

Table 4. Causal effects of access to electricity on consumption, schooling and health

Outcome	Study, geographical region	Source of electricity	Results	Method	Sample size	Period (n. of time obs)	Risk of bias
Consumption and expenditure	van de Walle et al. (2015); India	On-grid	Significant increases in total expenditure, particluarly for food and fuel. Significant increase in the purchase of kerosene stove	Panel data & IV	~3000 (households)	1981-1999 (2)	Medium
	Khandker et al. (2013); Vietnam	On-grid	Significant increase in household expenditure	Panel data & FE	1120 (household)	2002-2005 (2)	Medium-High
	Bensch et al. (2011), Rwanda	Micro-hydro mini-grids	Increase in energy expenditure	PSM			Medium
	Arraiz and Calero (2014); Peru	Solar PV	Significant decrease in expenditure for candles, batteries and firewood	PSM	1329 (households)	2013 (1)	Medium
	Chakravorty et al. (2016); Philippines	On-grid	Large significant increase in total expenditure and energy expenditure increases	FE-IV	~12.000 (households)	2003, 2012 (4)	Low-Medium
	Burlig and Preonas (2016), India	On-grid	No impact on asset ownership and housing stock	RDD	30.000 (villages)	2001-2011 (2)	Low
	Samad et al. (2013), Bangladesh	Solar PV	Significant higher total expenditure, decrease in expenditure for kerosene	PSM	4000 (households)	2012 (1)	High
	Grimm et al. 2015, Rwanda	Solar Pico PV	Significant decrease in fuel expenditure	RCT	300 (households)	2011-2012 (2)	Low
Schooling	van de Walle et al. (2015); India	On-grid	Significant positive effects o on enrollment and the average years of schooling as a share of the maximum possible for a given age, only for girls.	Panel data & IV	~3000 (households)	1981-1999 (2)	Medium
	Khandker et al. (2012), India	On-grid	Significant increase in school enrolmen and years of completed schooling for both boys and girls	IV	~24000 (households)	2005 (1)	Medium-High
	Khandker et al. (2013, EDCC); Vietnam	On-grid	Significant increase in school enrolment and years of completed schooling for both boys and girls	Panel data & FE	1120 (household)	2002-2005 (2)	Medium-High
	Libscomb et al. (2013); Brazil	On-grid	Strong effect on literacy and enrolment: increase in years of schooling (+2 years)	FE - IV	2184 (county)	1960-2000 (5)	Low-Medium
	Arraiz and Calero (2014); Peru	Solar PV	Positive effect on years of schooling for children at elementary school, higher enrollement rate for children at secondary school	PSM	1329 (households)	2013 (1)	Medium
	Burlig and Preonas (2016), India	On-grid	No significant effect on enrollment	RDD	30.000 (villages)	2001-2011 (2)	Low
	Squires (2015), Honduras	On-grid	Reduction in attendance (-4pp), attainment and higher drop-out rate	FE-IV	~19.000 (houehold s)		Medium

	Furukawa (2014), Uganda	Pico-PV lamp	Decrease in school performance	RCT	155 (students)	2011 (2)	Medium
Health	Gonzalez and Rossi (2007), Argentina	On-grid / better supply	Inconclusive evidence of reduction of low birth weight and lower child mortality rates caused by food poisoning	DD	264 (households)	(2)	Medium-High
	Samad et al. (2013), Bangladesh	Solar PV	Reduction in respiratory deseases for women	PSM	4000 (households)	2012 (1)	High
	Barron and Torero (2016), El Salvador	On-grid	Large significant reduction of PM2.5 concentration, due to less kerosene consumption for lighting Large significant reduction of acute respiratory infections among children under 6 (self-reported)	RCT	486 (household)	2009-2012 (4)	Low

Table 5. Causal effects of improved cookstove adoption on health and household welfare

Outcome	Study, geographical region	ICS main feature (fuel and imprved features)	Results	Method	Sample size (level)	Period (n. of time obs)	Risk of bias
IAP exposure and health	Smith et al. (2011); Guatemala	Fuelwood, reduced IAP	Significant decrease in carbon monoxide concentration Significant carbon monoxide exposure reduction for children and women. No effect on physician-diagnosed pneumonia. Positive effect of fieldworker assessed severe pneumonia	RCT	534 (household)	2002-2004 (weekly)	Low
	Hanna et al. (2016); India	Fuelwood, reduced IAP	Significan carbon monoxide exposure reduction in the first year. No effect in the longer run . No effect on lung functioning (measured with spirometry) and self-reported measures	RCT	2651 (household)	2005-2010 (2)	Low
	Bensch and Peters (2015); Senegal	Charcoal/fuelwood, efficiency	Significant effect on self-reported symptoms of respiratory diseases and eye problems	RCT	253 (household)	2009-2010 (2)	Low
	Bruwen and Levine (2012); Ghana	Fuelwood, reduced IAP, efficiency	No effect on carbon monoxide exposure. Significant decline in self-reported symptoms associated with cooking	RCT	488 (household)	2009 (2)	Medium
	Beltramo and Levine (2013); Senegal	Solar, efficiency, reduced IAP	No effect on carbon monoxide exposure (measured on a small sub sample). No effect on self-reported symptoms associated with cooking	RCT	790 (household)	2008 (2)	Low-Medium
	Yu (2011), China		Significant effects on acute respiratory infections	PSM-DD	5500 (households)	2003-2005 (2)	High
Time allocation, fuel use and expenditure	Brooks et al. (2016), India		Significant decrease in time spent collecting biomass fuels and cooking on traditional stoves. Significant decrease in biomass fuel consumption	Two-steps Heckman	1234	2012 (1)	Medium-High

	Hanna Duflo and Greenstone (2015); India	Fuelwood, reduced IAP	No effect on time for cooking No effect on wood use and expenditure	RCT	2651 (household)	2005-2010 (2)	Low
	Bensch and Peters (2015); Senegal	Charcoal/fuelwood, efficiency	Significant reduction in daily cooking time. No significant effect on time spent collecting wood Significant reduction in wood consumption	RCT	253 (household)	2009-2010 (2)	Low
	Beltramo and Levine (2013); Senegal	Solar, efficiency, reduced IAP	No effect on time spent for wood collection and time of cooking Slight decline in wood use only for large households	RCT	790 (household)	2008 (2)	Low-Medium
	Adrianzen (2013), Peru	Fuelwood, efficiency, reduced IAP	Significan decrease in firewood consumption	IV	194 (households)	2008 (1)	Medium-high
	Bruwen and Levine (2012); Ghana	Fuelwood, reduced IAP, efficiency	No effect on wood consumption	RCT	488 (household)	2009 (2)	Medium

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