Council on Energy,
Environment and Water

February 2015 | New Delhi, India

CEEW Report

Clean, Affordable and Sustainable Cooking Energy for India

Possibilities and Realities beyond LPG

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CEEW Report February 2015 ceew.in

A report on 'Clean, Affordable and Sustainable Cooking Energy for India: Possibilities and Realities beyond LPG'.

This programme of work was funded in part by the Government of Denmark in collaboration with the International Institute for Sustainable Development. The views expressed in this report are those of the authors and do not necessarily reflect the views and policies of the Council on Energy, Environment and Water.

The authors would like to thank Vihan Khanna, Shalu Agrawal, and Aditya Ramji for their inputs and several anonymous reviewers for their comments and reviews.

Editor: Arunabha Ghosh

Design and Layout: Mihir Shah

The Council on Energy, Environment and Water (http://ceew.in/) is an independent, not-for-profit policy research institution. CEEW addresses pressing global challenges through an integrated and internationally focused approach. It does so through high quality research, partnerships with public and private institutions, and engagement with and outreach to the wider public. CEEW has been ranked as India's top climate change think-tank two years in a row (ICCG Climate Think Tank Ranking). CEEW has been ranked best in India (and South Asia) in several categories two years running in the Global Go To Think Tank Index.

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ABOUT CEEW

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ABOUT THE AUTHORS

Abhishek Jain

Abhishek Jain is a Junior Research Associate at Council on Energy, Environment and Water - CEEW. His current research focus is on Renewable Energy, Decentralized Energy, Energy Access, Fossil Fuel Subsidies, Integrated Energy Planning and Circular Economy. He is a recipient of Chevening scholarship from Foreign & Commonwealth Office of the United Kingdom. Abhishek is also an honorary scholar of Cambridge Commonwealth Trust. In the past, Abhishek has worked in the manufacturing industry in engineering design, energy management and project management roles with a leading MNC.

In last 4 years he has worked on diverse issues of energy, engineering management and environment. He has researched and published on various areas including forecasting of electrification access scenarios in India, rural electrification through decentralised approaches, challenges to sustainable transportation in New Delhi, field research and assessment of hydroelectric power plants in the state of Himachal Pradesh, to name a few. In addition, Abhishek has completed multiple research and short term project stints with various organizations in India, Germany and the UK. He strongly believes in sustainable development led through inclusive growth and the importance of sound policy advisory in achieving the same.

Abhishek holds an MPhil degree in 'Engineering for Sustainable Development' from University of Cambridge and a B.Tech degree in mechanical engineering from Indian Institute of Technology (IIT) Roorkee. Abhishek is also a 'Certified Associate in Project Management' (CAPM®), accredited by PMI.

Poulami Choudhury

Poulami Choudhury works as a Programme Officer with the Council on Energy, Environment and Water (CEEW). She has done extensive work on decentralised renewable energy projects which includes formulating a roadmap for a countrywide network on scaling off-grid energy in India – the Clean Energy Access Network (CLEAN); documenting applications of renewable energy beyond electricity (with the WWF) and drafting recommendations for DERC's Net Metering Guidelines. She has also worked on drafting a roadmap for reaching India' solar target of 100 GW; assessed jobs created by the renewable energy sector by 2022 and India's green industrial policies for grid connected solar and wind power.

She is a post graduate in Natural Resources Management from The Energy and Resources Institute (TERI) and has done her graduation in Microbiology from the Institute of Home Economics, Delhi University. Following post-graduation, she had a short stint at J.M. EnviroNet Pvt. Ltd. where she worked as a consultant for Environment Impact Assessment (EIA) projects. She went on to work for C40, in partnership with the Clinton Climate

Initiative (C40-CCI) as a Program Analyst for two years. During her tenure with C40-CCI, she was involved in developing models for calculating greenhouse gas emission reductions resulting from various waste management projects, developing questionnaires, ward monitoring plans and Request for Proposals and Concession Agreements for the East Delhi Municipal Corporation. She has also worked extensively on developing material for C40-CCI's Knowledge Platform on solid waste management, wherein she assembled a comprehensive database and generated profiles for global cities (C40 cities) to better characterize their solid waste management systems that would facilitate city-to-city solid waste networks and help identify opportunities to improve municipal waste management in various cities. In addition to these Waste projects, Poulami also conducted other work for the Solar team of the Clinton Climate Initiative, such as preparing papers and reports related to Rajasthan solar park and technical specifications for CSP projects planned under National Solar Mission.

She has co-authored a research paper entitled, "Optimization Studies for hybrid and storage designs for parabolic solar trough systems with the System Advisor Model" which was published in the journal of Environmental Progress and Sustainable Energy in 2011.

Karthik Ganesan

Karthik Ganesan is a Senior Research Associate at CEEW, India. He leads the research efforts in the area of energy access and the future energy consumption pathways of rural India, and the opportunities for industrial energy efficiency gains. Most recently, he carried out an extensive analysis of the Indian government's policy support for RE industry and the cost implications of the exchequer. His focus has been to bring quantitative techniques from other domains, such as consumer choice models and system dynamics modelling to provide a holistic understanding of the various factors that influence energy policy and their impact in turn, on development and sustainability.

Prior to his association with CEEW he has worked on an array of projects in collaboration with various international institutions, with a focus on technology and environmental valuation. His published (and under review) works include the *Power Sector Expansion Plans in the Greater Mekong Sub-region: Regional governance challenges* (ADB), *Carbon Capture and Storage Potential for SE Asia* (ADB), *Valuation of Health Impact of Air pollution from Thermal Power Plants* (ADB), and *India's Energy Conundrum – What the future holds* (World Scientific).

Karthik graduated with a Masters in Public Policy from the Lee Kuan Yew School of Public Policy at the National University of Singapore. He has an M.Tech in Infrastructure Engineering and a B.Tech in Civil Engineering from the Indian Institute of Technology, Madras in Chennai.

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EXECUTIVE SUMMARY

Over the last decade, the number of domestic LPG connections in the country, and concomitantly the associated subsidy outlay, has increased at an unprecedented rate. The rising subsidy burden and high import dependency for LPG are posing challenges to current account deficit and nation security. Despite the growth in its consumption, the transition to LPG is not complete; with 80% of Indian households continuing to use traditional fuels for cooking, as of 2011-12. As a result, the problem of indoor air pollution continues to be a major public health menace for the country, which accounted for more than 1.3 million premature deaths in year 2010. Given this background it is vital to look at and compare other clean cooking energy solutions vis-à-vis LPG, which can reduce the indoor air pollution burden and drudgery associated with the use of traditional cooking fuels, while being affordable and sustainable in the long run.

There is a dearth of research and studies, which compare different cooking energy options, especially using a multi-dimensional approach. With the objective of promoting clean, affordable and sustainable cooking energy for all, this study analysed the potential of the alternatives, going beyond LPG. The options which were assessed include the centrally distributed commodities like LPG, PNG, electricity as well as the decentralised options such as biogas and improved biomass cookstoves. A multi-criteria comparative analysis was conducted, incorporating various dimensions such as economics, fuel supply assurance, technology resilience, cooking convenience, environmental impacts, etc. The analysis utilised the existing wealth of literature and secondary data, while tapping into the knowledge and experience of technology experts through online surveys and interviews. The key findings from the analysis are:

1) On the **economic front**, biogas emerged as the most attractive option, along with PNG, while LPG and pellet-based cookstoves were among the costliest. One major finding was regarding improved cookstoves, which was largely perceived to be the most economical solution due to 'free-of-cost' biomass. However, NSS data over the years suggests that more than 70% of biomass consumed in rural households is commercially procured and thus carries a real cost, apart from the notional cost associated even with the free-of-cost biomass.

2) In terms of **health improvements** due to indoor air pollution, all technologies fared well, except improved cookstoves, which still need substantial technological improvements to reduce emissions to safe levels. However, a major finding is that unless there is a complete transition to cleaner cooking options both at the household level as well as at the community level, the full potential of health benefits of clean cooking would not be realised.

3) On **assurance of fuel supply** front, which also pertains to energy security at national level, traditional biomass was marked with the highest fuel supply assurance,

followed by PNG, biogas, LPG and lastly the electricity based solutions.

4) For **convenience of cooking**, which incorporated multiple sub-attributes influencing the overall cooking experience, the balance was tilted in the favour of gaseous fuel based options due to their improved heat control, higher heat intensities, accommodation to variety of cooking needs and so on. Thus, LPG and PNG were rated highly, along with biogas, followed by electricity-based solutions. Improved cookstoves were deemed as least convenient among the considered options.

5) In terms of **technology resilience**, biogas and improved cookstoves both fared low, whereas the LPG and PNG solutions were rated as highly resilient. Electricity-based cooking solutions received a mediocre score.

6) Next, considering the **global environmental impacts**, i.e. climate forcing, all the clean cooking energy technologies were evaluated as better than the traditional *chulha*. This is mainly due to avoidance of high emissions of black carbon resulting from incomplete combustion in traditional stoves. Improved cookstoves were the best, as only non-CO_2 emissions were considered, assuming sustainable harvesting. Next was biogas, followed by PNG and LPG. Electricity based solutions had the highest impact in terms of climate forcing due to the predominance of thermal generation in the electricity mix of India.

Based on the comparative analysis and overall findings, the following **key recommendations** are proposed:

Technology Specific Recommendations

1) **PNG, faring high on the multi-dimensional assessment, should be promoted in the urban areas**, beginning with densely populated cities, while developing the medium to long term strategies for sourcing the commodity at competitive prices.

2) Create an enabling environment to **support the market-based promotion of biogas** as a cooking energy solution while eliminating the challenges of technology resilience and management through innovative approaches such as service-based enterprise models. It must be promoted selectively, in areas with climatic feasibility, resource feasibility, and community acceptance, in order to maintain high success rate and thus establish community confidence in the technology.

3) **For improved cookstoves, technology development should be the main focus**, in order to improve (i) emission performance; (ii) technology resilience and; (iii) cooking convenience. They should be promoted only in areas where biogas is not feasible and LPG is not affordable.

4) Finally, unless there is radical technical innovation on improved cookstoves and increased deployment of other emerging technologies, like waste-to-biogas, **LPG**

would continue to play a significant role in meeting the clean cooking energy needs of the country. As the challenges of affordability and import dependency are likely to continue with LPG, it is imperative to promote the efficient use of the commodity, while improving the subsidy targeting to unintended users and uses.

A Clean Cooking Energy Mission

1) Multiple efforts are already being pursued by the government on all the different fronts such as Rajiv Gandhi Gramin LPG Vitaran Yojana (RGGLVY) to increase the LPG distribution and consumer base, expansion of PNG networks, and respective central government programme on biogas and improved cookstoves. However, due to the lack of a unified approach to the broader goal of achieving clean cooking energy for all, the efforts are not leading to commensurate achievements, and different technologies are not getting their fair share of attention (funds) and adequate direction of interventions.

2) Thus, there is a need to unify these government efforts under a common framework, with a vision (and mission) to achieve **clean, affordable and sustainable cooking energy for every Indian household**.

3) The primary objective of such a mission should be to create awareness about negative impacts of the use of the traditional *chulha*, in order to generate a bottom-up demand of clean cooking solutions, while ensuring their sustained use and a complete transition, which is necessary to completely realised the associated health and social benefits.

4) Operational implementation of such a mission and related decision-making should be based on top-down and bottom-up collaborations (driven by the nature of technology). Local-level decision-making authorities should play a critical part in determining the best possible technologies under the local context of demand, socio-economic factors and resource endowments.

The study has proposed a framework for comparative analysis of various cooking energy options across a range of criteria in order to provide a holistic and comprehensive view of the state of technology options. With the evolution of technology, the analysis outcomes may vary in the years to come, but the framework would continue to provide a robust methodology for evaluation and thus help the decision-making towards clean cooking energy for all.

1. INTRODUCTION – THE NEED TO LOOK BEYOND LPG

India has subsidised LPG for over three decades in order to facilitate a transition from unclean traditional cooking fuels to modern and cleaner forms of cooking energy. Although the complete transition is only limited to 20% of the population (Jain, Agrawal, & Ganesan, 2014), the rising subsidy outlay on domestic LPG and excessive import dependence pose grand challenges in meeting the demand. India's reliance on this imported fossil fuel was as high as ~89% for the year 2012-13 (CSO, 2013). Such sustained and high import dependence has two negative implications; the rising current account deficit and the increasing concerns about energy security associated with the provision of an essential service such as clean cooking energy for the massive population.

Given the increasing subsidy burden, import bills, energy security concerns and long term sustainability, universal LPG coverage in the country may prove to be a sub-optimal solution to meet clean cooking energy needs. The lack of diversification and a near-total reliance on LPG would also have repercussions for energy security from the point of view of locking into a single technology. Moreover, the challenges and resources associated with transportation and distribution of LPG, especially to the far flung remote areas with poor and limited accessibility, pose barriers to universal LPG adoption.

Thus, in order to provide clean cooking energy to all, while LPG is being promoted and adopted, it is necessary to look at the alternative cooking energy options and evaluate their suitability to provide clean, affordable and sustainable cooking energy under different contexts, while recognising the difference in the level of service provided by each. Such a process would have to consider, *inter alia*, the economics and financial viability, the impact on energy security, the reliability and usability of each option. Only such an exhaustive evaluation can inform policymakers of the options, which can complement or effectively displace LPG in providing universal coverage of clean cooking energy for all. This report attempts to conduct such an evaluation of the alternative options and present a comparative assessment across multiple criteria.

In the past, only a few studies have attempted to make such a comparative assessment across cooking energy alternatives for India. Ramanathan & Ganesh (1994) conducted a multi-objective analysis across various cooking energy options with an aim to provide optimal mix for the city of Madras (now Chennai). This exercise in 'goal-programming' provided a snapshot of technologies and the relative importance of various objectives, as perceived about two decades ago. Another study compared multiple cooking energy options but the analysis was limited to economic aspects only (Gupta & Ravindranath, 1997). About a decade ago, researchers also conducted a multi-criteria assessment of various cooking energy options with an objective to promote parabolic solar cooker in India (Pohekar & Ramachandran, 2004). Apart from this limited literature, there has been no recent (in last 10 years) study which has looked at the issue of cooking energy in a holistic manner. In addition to the evolution of technology over the years, the science and understanding of the negative health impacts of indoor air pollution has become stronger. Similarly, the knowledge base on what drives the choice of cooking energy technology has increased. The study utilises this entire body of knowledge to provide an evidence based analysis of how various technologies fare against each other and can contribute to the objective of providing clean and affordable cooking energy to all.

The report has been structured as follows:

Section 2 provides an overview of the various alternative cooking energy options which are considered for this study. It also discusses the broad limitations of some of the technologies barring their in-depth analysis.

Section 3 discusses the research methodology used for the analysis while elaborating on the various aspects of the multi-criteria framework, employed for the evaluation of technologies.

Section 4 provides the overview of each technology which is considered for in-depth analysis, from improved cookstoves to biogas, and electricity-based cooking to piped natural gas (PNG). It covers the current status quo of the technology, learning from past policy and program experience (wherever existing), and technical overview of the technology.

Section 5 forms the core of the study and provides an in-depth analysis of each technology against each criteria of the multi-dimensional framework.

Section 6 synthesises all the major findings of comparative assessment together to provide an overall picture which emerges from the evaluation of the technologies.

Section 7 provides the overarching recommendations towards achieving the goal of clean cooking energy for all. It also discusses specific recommendations for each technology given the current state of affairs.

Section 8 provides the concluding remarks for the overall study

2. TECHNOLOGY OPTIONS

The technological options, which could potentially provide clean cooking energy to significant proportion of population, are several and diverse. The following have been considered for the analysis:

i) Improved biomass cookstoves

ii) Biogas generation and supply – both community and home-based

iii) Piped Natural Gas (PNG)

iv) Electricity based cooking - Electrical and Induction

v) Liquefied Petroleum Gas (LPG)

In addition to the above options, there are others such as kerosene, processed liquid biofuels, community level biomass gasification, and waste-to-energy. Except kerosene, all other options have limited on-ground experience for cooking energy application, not going beyond demonstration projects in most cases. Solar energy based cooking technologies are not considered for the analysis, as these cannot meet entire cooking energy needs and can only play a supportive role owing to the intermittency associated with its availability and existing limitations of the technology.

Community level biomass gasification typically consists of a centralised biomass gasifier which can consume a variety of biomass as feedstock turning it into 'producer gas' (a mixture of methane and carbon monoxide). The gasifier is followed by a scrubber and other accessories to process and clean the generated gas, which is then pumped into a local pipe-grid through a low pressure in-line blower. The generated gas is thus supplied to the local households. The technology has very little on-ground experience, with some literature evidence of the deployment of community level gasification systems in China, but substantial details are not available. No such installation has been carried out in India yet. As per our discussions with technology experts, the option seems technically viable, but the highly capital intensive nature of the technology poses barriers to its economic feasibility. A few pilot projects followed by cost optimisation through design improvements and innovative business models could help to ascertain the potential of community level biomass gasification in India. Exploring the option is valuable and important, as the technology provides cooking convenience and emissions performance of a gaseous fuel, with traditional biomass being the primary feed.

Processed liquid biofuels for cooking have not yet experienced any significant deployment in India. The major interest in the biofuels so far has been in using them as transportation fuel in the form of biodiesel and bio-ethanol. Even in this sector India has not managed to fulfil the replacement norms for gasoline, as per the National Biofuels Policy. Moreover, as bioenergy crops compete with food crops for agricultural land, the ethical argument suggests that only fallow lands and land not suitable for food production must be considered towards cultivation of biofuel crops. In a power deficit country like India, crop residue or spent biomass (bagasse, agricultural cuttings, etc.) are very attractive for power generation and for providing industrial heating needs. Given the complex nature of competing demands and the apparent lack of policy certainty in pursuing liquid biofuels, it is unlikely that they will contribute a significant share to cooking energy.

Waste-to-energy, specifically the biomethanation route has the potential to serve as a cooking energy option for nearby locations, through piped supply of the generated biogas. Both the biodegradable municipal solid waste as well as waste water (sewage) holds potential for biogas generation. In the urban context, given the low energy content of the feedstock (kitchen or food waste primarily), the ability to cover the entire cooking needs of a household is low and invariably the biogas generated is used for electricity generation. In combination with human waste, the option needs an evaluation of its potential to complement or even replace LPG or PNG, especially in upcoming and new residential spaces. It also provides a feasible solution for managing solid organic waste and sewage water in decentralised manner without adding to the load on the already crumbling infrastructure for waste handling and processing in large cities. The current scenario around the technology and the limitation of resources do not permit an in-depth analysis of the option. It is estimated that, by 2030, nearly 9 MTOE of energy (or ~ 15% of the total demand for LPG in that year), will be landfilled annually in urban areas, as a result of poor waste management practices (Annepu, 2012). In rural areas, the organic waste can supplement the feed for dung based biogas plants which are covered in the analysis.

Kerosene is a prevalent cooking energy fuel in India, but mainly used by the urban-poor section lacking access to LPG. As per the Census 2011, only 0.7% of rural household use kerosene as their primary cooking fuel. It is not considered for the analysis mainly because (i) as per WHO guidelines on indoor air quality, the use of kerosene should be discouraged, as emissions from kerosene stoves (both wick and pressure) are higher than prescribed limits; (ii) as both LPG and kerosene are distillate of crude with effective price being very close to each other, it is better to promote LPG over kerosene, which significantly reduces the harmful emissions and increases the cooking convenience.

3. METHODOLOGY FOR ASSESSMENT

In order to arrive at a set of criteria or attributes to assess and compare various technologies, the analysis considers two key decision-makers who primarily influence and determine the cooking energy mix across the country. The first and the more important of the two is the end consumer, who determines which technology or cooking energy solution he or she would like to use. The second is the policymaker who influences the decision of consumers, by promoting one set of technologies over the other, by creating an environment conducive for them to thrive in the market place, providing financial and research support, developing the necessary infrastructure and so on. In addition to these two, there is another set of stakeholders, constituting technology developers, manufacturers, entrepreneurs, market agents and civil society organisations, which also plays an important role in determining the technologies that would thrive and be deployed. They can significantly change the technology landscape with their innovations on technical, financial and the service delivery front. However, the drivers of their actions have been captured (directly or indirectly) by the attributes important to the two primary stakeholders. Thus, for determining the assessment criteria, only end consumers and policymakers are considered.

The following few paragraphs discuss the various criteria which are identified based on the existing literature and expert opinions, while taking into account the concerns of two primary stakeholders. These criteria range across economics, fuel supply assurance, energy security, technology resilience, cooking convenience, environmental impacts and so on. The overall set of criteria are summarised in Table 1.

The economics, and hence the affordability of the clean cooking energy, is one of the most important criterion for the end-consumer. At the same time, affordability of the fuel for the population at large is important for policymakers for the welfare of the society, as is evident from the prevailing LPG subsidies.

The smokeless operation of cooking devices is also reported as an important decision making criterion for the end-consumers. At the same time, indoor air pollution has direct public health consequences, which makes it a cause of concern for the policymakers.

Next, from the perspective of the end-user, the assurance of fuel supply in sufficient quantities, in an easy to procure manner, is an important factor. At the aggregated level, for the policymaker, assurance of fuel supply pertains to the energy security of the cooking needs of the country. For fuels, where the supply is centrally driven (LPG, PNG, kerosene and electricity), both the fuel sourcing and the supply infrastructure, would determine the fuel security (at the national level) and the supply assurance (at the household level). It is assumed that for these fuels, the cost of expanding the supply network and logistics is reflected in the delivered price of the fuel itself (which is covered in the economic evaluation of the alternatives). In the case of decentralised fuel options such as biogas and firewood, fuel supply assurance is determined by the conditions of the local environment, which would be a consideration for local-level decision-makers, while selecting the appropriate technologies for promotion or deployment.

The resilience of a cooking energy solution also influences the end consumer's decision, as it directly relates to how dependable the technology would be, as a primary solution. The breakdown frequency, availability of repair and maintenance services and the need of having a backup, all collectively determine the technology resilience.

The convenience of cooking is another important determinant of the user acceptability towards a cooking energy technology. This is envisaged as a composite attribute arising from multiple underlying criteria. These sub-criteria of cooking convenience, which were determined on the basis of literature review and experts' opinion, are listed in Table 1. Along with the cooking convenience, the safety associated with the use of fuels and cooking device is also an important consideration for the end-users. While assessing safety for different options, there needs to be two levels of scrutiny. First, the rate and severity of incidents (breach of safety) associated with the various technologies. Second, the perception of end users about the level of safety they attribute to different technologies. In the search that was carried out, no data or literature could be located on the incidents rates or the end-user perceptions against various technologies. Thus, even though safety is mentioned as an important parameter influencing end-user preferences, due to lack of data, the technology assessment on safety front was not conducted.

The impact on the global environment, through the release of climate pollutants, is the final criterion chosen for the analysis of these technology alternatives. Though not much of a concern for the average household, it holds significance at the national level. Cumulative GHG emissions[1] resulting from the large scale adoption of a technology, can significantly impact the overall stock of emissions for the country. As a result, a technology choice that substantially alters the GHG emissions from the residential sector would be of interest to the policymakers.

[1] SO_X, NO_X, carbon dioxide, methane, carbon monoxide and black carbon emissions are measured in equivalents of CO_2

<table>
<tr><th colspan="4">Table 1: Framework for the Analysis - List of Attributes</th></tr>
<tr><th>S. No.</th><th>End consumer (Decision making at the household level)</th><th>Policy maker (Decision making at the national level)</th><th>Metric used for assessment</th></tr>
<tr><td rowspan="2">1</td><td>(Unsubsidised) Cost of cooking energy to the end-consumer</td><td>Affordability of the cooking energy</td><td rowspan="2">Levelised Cost of Energy (LCOE)[2]</td></tr>
<tr><td colspan="2">Though LCOE is an apt metric for comparison of affordability of various options, it is not the only consideration. Adoption of a solution is influenced by the considerations of the upfront capital cost and the availability of financing to cover these, especially for low-income households. The analysis assumes availability of such financing.</td></tr>
<tr><td>2</td><td>Smokeless operation</td><td>Public health impact of indoor air pollution</td><td>Health impacts based on local pollutant emissions and exposure</td></tr>
<tr><td>3</td><td>Assurance of fuel supply (including ease of fuel procurement)</td><td>Energy Security (for domestic cooking energy of the country)</td><td>Aggregated Supply data analysis for fuels + Ratings from Experts' survey</td></tr>
<tr><td>4</td><td>Resilience of the technology</td><td>-</td><td>Number of installations; Success rate; State of technology development; Ratings from Experts' survey</td></tr>
<tr><td>5</td><td>Convenience of cooking
a. Ease of control of flame or heat intensity
b. Suitability to accommodate variety of cooking needs (utensils and food items)
c. Quick start-stop operations
d. Time taken for cooking a meal
e. Ease of operation and maintenance of the cooking solution</td><td>-</td><td>Average ratings (on a 10 point scale), based on a survey of experts</td></tr>
<tr><td>6</td><td>-</td><td>Cumulative (global) environmental impacts from cooking; Local environmental implications</td><td>GHG emissions + Qualitative discussion on local environmental considerations</td></tr>
</table>

In the next section, each cooking energy solution is profiled and discussed. Subsequently, Section 5 provides the overall comparative assessment, followed by the assessment summary in Section 6.

[2] For the purpose of this analysis, LCOE would refer to the levelised cost of 'delivered' energy.

4. OVERVIEW OF ASSESSED COOKING ENERGY OPTIONS

The section provides a broad overview comprising the technology description, current status of deployment, and past experiences and learning. It also details the specific models of each technology which are considered for the analysis.

4.1 Improved Biomass Cookstoves

At present, traditional cookstoves or *chulhas* are the most widely used solutions for cooking in rural India. Data from the 68th round of the National Sample Survey (NSS) suggests that as of 2011-12, around 80% of the Indian households used some form of traditional fuels to satisfy their cooking and heating needs (Jain et al., 2014). Traditional cookstoves typically exhibit very low thermal efficiency (of the order of 10% - 15%) and produce harmful emissions as a result of inefficient combustion process, thereby adversely impacting both human health (resulting from indoor air pollution) and environment.

Against this backdrop, the role of improved cookstoves (ICS) in reducing the health impacts, due to better combustion efficiencies, cannot be understated. As per the estimates by the International Energy Agency (IEA), 632 million people in India would continue to depend on solid unprocessed biomass for cooking and space heating needs, even in 2030 (Kar, 2012). Given such estimations around continued reliance on traditional fuels, it is important to look towards improved cookstoves as a potential solution.

'Improved cookstoves' (ICS) is used as an umbrella term that refers to an array of stove designs and technologies. There are multiple ways by which these stoves can be classified. One of the widely used segregation is on the basis of the 'mechanism of air augmentation inside the combustion chamber'. On this basis the stoves can be classified as *natural draft* and *forced draft*. On the basis of portability, the stoves can be segregated into *fixed* and *portable* types. A notable feature of ICS is that there is no single model that can address the needs of all the consumers. This stems from the diverse consumer needs across regions, which are driven by food types, cooking practices, fuel availability, household incomes, and awareness levels.

Presently, dissemination of ICS by the government is being carried out under the ***Unnat Chulha Abhiyan***, which was launched in June 2014. The programme has a three pronged approach, which aims: (i) to deploy ICS in rural, semi-urban and urban areas; (ii) to mitigate drudgery of women and children using traditional *chulha*; and (iii) to mitigate climate change by reducing black carbon emission. The programme has a target to disseminate 2.4 million household-level improved cookstoves and 3.5 million community sized stoves by the end by 2017. A budget of INR 294 crore has been earmarked to meet the programme objectives (MNRE, 2014b). In addition to the central government programmes, few states are also deploying improved cookstoves through state level projects.

Box 1 - Past Policies and Programmes

National Programme on Improved Chulhas (NPIC): The very first initiative to promote improved cookstoves in the country dates back to 1983, when the Department of Non-conventional Energy Sources (now the Ministry of New and Renewable Energy) launched the National Programme for Improved Cookstoves (NPIC), with the primary objective of reducing fuel wood consumption and removing/reducing smoke from kitchens (Kishore & Ramana, 2002). The NPIC was responsible for introducing ICS to reportedly around 35 million households but failed to ensure their sustained use. The Global Alliance for Clean Cookstoves reports that only a fraction (0.25%) of Indian households (> 1 million) actually use ICS (GIZ, 2014). NPIC was discontinued in the year 2002. Certain independent studies also suggest that the NPIC "improved" stoves often had higher emissions than their traditional counterparts (Smith, 1989). Following were the **key reasons of failure** of the NPIC (GIZ, 2013; Sinha, 2002):

- **Large government subsidies with minimal user contribution:** Under the NPIC, government covered the major share of constructions costs of the stoves, with consumers providing small monetary contribution. Heavy subsidies meant that the stove builders were only concerned with fulfilling government specifications, incognisant of the consumers' preferences. Further, this inhibited the development of a market based approach which could have promoted greater competition and innovation in this space.
- **Lack of effective monitoring and evaluation system:** The government's only measure of the programme's success was the number of stoves developed or disseminated. Indicators such as sustained use of the stove, improvement in indoor air quality and cooking convenience were not monitored or considered.
- **Limited awareness raising and training programmes:** The NPIC had failed to generate sufficient awareness regarding adverse health impacts of indoor air pollution caused by traditional cooking practices. This limited the adoption and sustained use of improved cookstoves. The lack of training for using ICS also led to their non-usage.
- **Limited after sales support:** The NPIC also failed to provide essential maintenance and after sales services, which are critical to enable sustained use of the improved stoves.

The National Biomass Cookstoves Initiative (NBCI) was launched in the year 2009 to extend the use of clean energy to all Indian households through the development of 'the next-generation of household cookstoves, biomass-processing technologies, and deployment models' (Venkataraman, Sagar, Habib, Lam, & Smith, 2010). NBCI's predominantly focused on enhancing combustion efficiencies, which could also lead to emissions and smoke reduction. Such a focus was distinctive from NPIC which only focused on removing smoke from the indoor space through the use of a chimney (Venkataraman et al., 2010).

The initiative stressed on establishing state-of-the-art testing, certification and monitoring facilities and strengthening R&D programmes. Three Biomass Cookstove Test Centres were established under this initiative. The standards of thermal efficiency and emissions for biomass cookstoves were revised by the Bureau of Indian Standards (BIS) under NBCI and published in August 2013. In keeping with commitments of the NBCI, the Ministry implemented pilot scale projects to demonstrate the use and study the impact of ICS on mitigating climate change and gather performance data.

Recently NBCI was reshaped into the Unnat Chulha Abhiyan, which was launched in June 2014 (Dhamija, 2014; MNRE, 2014b).

4.1.1 Technical Description

Natural Draft cookstoves improve combustion efficiency through better geometry, design and materials compared to a traditional stove. This is achieved by reducing the heat loss to the environment with the use of insulation in the design, and by improving air supply for cleaner combustion (e.g., use of grate). Thermal efficiency of natural draft stoves is typically in the range of 25% to 30%. Widely deployed natural draft models in India (e.g., Greenway GSSV3 and Envirofit stoves) are integrated with insulated combustion chamber as well as grate for the fuel bed to increase air flow and thereby increase the combustion efficiency. Some natural draft models (e.g., Envirofit ICS) are also found to use a pot skirt, which further augments the efficiency of the cookstove, as it channels the heat from the fuel to the cooking vessel in a precise and efficient manner (Envirofit, n.d.; Kshirsagar, 2009).

Forced Draft cookstoves typically employ a fan for supplying air into the combustion chamber, making it more efficient compared to natural draft ones. The thermal efficiency of forced draft models is typically in the range of 35% to 40%. Popular forced draft ICS models in India, such as Oorja K3DLX, TERI SPT 0610 and Ramtara, employ the principle of microgasification wherein combustion occurs in four steps – (i) drying (evaporation of moisture from biomass); (ii) carbonisation (formation of combustible gases and char from biomass by supply of primary air); (iii) char gasification (solid char is converted into carbon monoxide (CO) and carbon dioxide (CO_2) with excess supply of air leaving behind the ash content of the fuel) ; (iv) and, finally, gas combustion (reaction of combustible gases produced in the previous two stages by supplying secondary air).[3] This mechanism of separating the generation of combustible gas and its subsequent combustion leads to greater combustion efficiency and decreased emission of incomplete combustion products.

Micro-gasifier stoves are found to be most efficient when compared to other stoves. But the main obstacle with micro gasifier is that it requires a fan to inject air into the combustion chamber, which is driven by electric power, the supply of which is non-existent or unreliable in most rural areas. Newer designs such as one model of BioLite, are also entering the market, where the electricity to drive to the fan is generated in situ. These are priced slightly higher and are yet to be deployed at scale.

Based on their scale of on-ground deployment and popularity, two portable natural draft models and three portable forced draft models are selected for the analysis. Table 2 lists the ICS models that are analysed in this study, and Table 3 summarises certain key difference in features of natural draft (ND) and forced draft (FD) cookstoves.

[3] In micro-gasification stoves, air supply (e.g., through fans) is partially supplied into the combustion chamber from primary small openings located at the bottom of the stove. The remaining air supply is channelled to the top of the combustion chamber (and preheated) through secondary small openings

Table 2: List of Analysed Improved Cookstove Models

Cookstove Type	Model	Manufacturer	Thermal efficiency
Natural Draft	Envirofit M5000	Envirofit	29.7%
Natural Draft	Greenway GSSV3 Smart Stove	Greenway Grameen Infra	24.1%
Forced Draft	Oorja K3DLX	First Energy	37.26%
Forced Draft	TERI SPT 0610 (Unnat Chulha)	RBS Group	36.84%
Forced Draft	Ramtara	Ramtara	34.1%

Source: CEEW Compilation

Table 3: Features of Natural Draft and Forced Draft Cookstoves

Parameter	Natural Draft (ND)	Forced Draft (FD)
Smoke reduction	Smoke reduction is not as high as FD	Reduces smoke significantly in comparison to traditional and ND stoves
Cooking time	Reduces cooking time compared to traditional stove	Can reduce cooking time by approximately 50% (compared to traditional stove)
Cooking pattern/ habits	ND stoves are front and continuously fed, similar to traditional cookstoves	FD stoves are top and batch fed which is a cause of concern as it requires adjustment in cooking habits.
Ability to use multiple fuels	ND stoves are capable of using multiple fuels. However firewood has to be the primary fuel while, fuel such as cow-dung, agricultural biomass, can act as supporting fuel	At present most forced draft models are fuel specific (use either only pellets or processed firewood or rice husk)
Processing of cooking fuel	Requires minimally processed biomass	Fuel needs to be processed into pellets or into smaller pieces

Source: CEEW Compilation

4.2 Biogas

A little more than 1 million households in the country report the use of biogas as the primary source of cooking, as per Census 2011. A total of ~ 4.6 million biogas systems have been installed so far (CSO, 2014) over the course of the last three decades, since formal programmes to promote biogas were introduced. Clearly, a large fraction of the installed systems are defunct and efforts to promote biogas as a clean cooking energy solution have not yielded success. In order to understand the current status of biogas, it is necessary to trace the policies adopted so far and the implementation and follow up processes associated with various programmes.

The National Project on Biogas Development (NPBD) was launched in 1981 with the aim to bring clean cooking energy solutions to rural areas of the country. However, due to poor performance, failure and high non-functionality rates, it came under increasing scrutiny and criticism. The NPBD was revamped into the National Biogas and Manure Management Programme (NBMMP) with the objective of going beyond the provision of clean cooking energy.

Among other things, the programme recognises the potential role of biogas in reducing the drudgery of women engaged in collecting firewood; improving the state of sanitation and waste management in rural areas; reducing pressure on local forests; the ability to impact GHG emissions arising from better management of animal dung and the co-benefits to soil fertility by the use of digested products from a biogas plant (MNRE, 2014a). This holistic view of the role of biogas is conducive for the development of the technology and roll-out.

Despite the recognition of the potential and the role for biogas in catering to rural energy needs, the allocated budget and the resulting expenditures on the programme have been miniscule. In the last FYP (2007-12), the total expenditure over the period was a mere INR 440 Crore or 1% of the annual (FY 2013-14) expenditure on LPG subsidy (Lok Sabha, 2013). The ambition in terms of scale is clearly lacking.

Box 2: Performance Evaluation of the NPBD

A review of the NPBD was carried out in 2002 to provide suggestions on how to increase the adoption of family type biogas plants. Across all the states that were surveyed, between 40% and 70% of the installed plants were not functioning. The study documented reasons for poor performance of the programme, and these can be categorised under three broad heads (Planning Commission, 2002):

Administrative and Policy Problems

- The programme was driven top-down and there was limited participation of community organisations and local institutions in policy formulation.
- There were too many entities in the implementation chain in each state, which led to inefficiencies in ground-level planning and roll-out. A plethora of implementing agencies also meant poor monitoring, opportunities for collusion and unhealthy competition which allowed substandard quality of construction with poor performance of plants.
- Two-thirds of the training and research budgets were devoted towards salaries and contingency payments for the project staff. The meagre funding remaining for the core training activity meant that the quality as well as the number of the training sessions was lowered – both for users and for workers, thereby reducing the efficacy of the overall programme.

Technical Problems

- Out of 161 non-functional plants surveyed in the study, 99 were rendered dysfunctional due to various structural problems arising from faulty construction, thus, emphasising the need for improvement in the quality of training to the turnkey workers.
- Instead of feeding the digester daily, sometimes households tried adding a week's supply or more at once, which is against the basic design of the biogas system.
- Poor sizing of the system was also a reason behind poor performance of biogas plants. In most cases, the needs of the household or their ability to ensure enough feed to keep the plant running, was also not factored in.

Financial Problems

- With a relatively small budget of programme, a large portion was spent on just providing the subsidies, leaving little room for more monitoring, research and other key components of the project.
- There was a high dependence on subsidies, which prevented the beneficiaries from having a stake in the plant and developing a sense of ownership. This might have indirectly contributed to households defaulting on loans and poor performance of the plants.
- Amongst 600 beneficiaries surveyed, only 10% actually availed loans from banks; the majority did not apply for loans due to their inability to provide guarantees or show deposits as collateral. On the other hand farmers who took out loans could not repay these within the stipulated period and skipped interest payments.

4.2.1 Technical Description

Biogas is a clean, non-polluting fuel that contains about 55% to 75% methane (CH_4), which has high calorific value and is very similar to natural gas in combustion characteristics (National Academy of Sciences, 1977). It can be produced from cattle dung, human waste and other organic matter arising from household consumption through anaerobic digestion, in a biogas plant. The digested material or slurry, which comes out of the plant, is a form of enriched manure, when dried, and can be used for soil enrichment in farms.

Typically, a 1m^3 sized plant could serve a household of four to five members. This would on an average require ~25 kg of dung on daily basis (equivalent to daily produce of ~2.5 adult cattle). However as per an evaluation study of Planning Commission in 2002, the functioning biogas plants in the states examined were all in households where the average cattle holding was higher than 5.5 (Planning Commission, 2002). The requirement of water is in a 1:1 proportion with the quantity of dung, typically mixed thoroughly to create a fluid mixture (UNDP, n.d.). This can be a limiting factor in increasing the penetration of biogas digesters in areas, which are water-stressed or are likely to see periods with low water availability.

There are broadly two common types of digesters that are found; fixed dome and floating dome. A fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank. Floating-drum plants consist of an underground digester and a moving gas-holder. The gas-holder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored (UNDP, n.d.). The fixed dome model is the cheaper of the two as it relies on cheaper construction materials, but it suffers from poor implementation and quality issues in the construction process. It requires special sealants to ensure there is no significant leakage (UNDP, n.d.). The floating dome has a lower technical life as a result of the use of steel, which is prone to corrosion, especially when used in combination with the water jacket.

In recent years, pre-fabricated biogas plants are making their way into the market. Typically, these systems are made up of high density polyethylene (HDPE) material, which does not suffer from corrosion challenges, while being light-weight and easier to transport and deploy. HDPE based pre-fabricated biogas plants can also overcome the problems associated with poor design and construction quality, which have long plagued the traditional biogas plants, due to dependency on unskilled masons, and poor construction quality monitoring.

However, the production and use of biogas is determined by two important factors viz. ambient temperature and regularity of use. While the production can occur below 20°C (psychrophilic conditions), the optimal conditions for most methanogens, a type of bacteria that drives the conversion, is between 20°C and 35°C (Minde, Magdum, & Kalyanraman, 2013). India's geographic location in the sub-tropics makes it very conducive for the anaerobic process to thrive without much external intervention, such as external heating and activation of bacteria. However, in many parts of the country, a significant drop in temperature is witnessed during winters and external interventions are required to keep the plants functional.

The other important consideration in the use of biogas is that it is necessary for consumers to continually use biogas and prevent it from accumulating in the digester over prolonged durations. This can be done by either flaring or direct release. This last option can involve the release of large amounts of methane to the atmosphere, a very potent contributor to global warming (~21 times that of CO_2) despite its minor volume, and must be strictly avoided. Prolonged periods where the biogas plant is not loaded with fresh dung (or other feed) would require specific effort to re-start the anaerobic process and to attend the dried content within the digester.

4.3 Electricity-based Cooking

In the recent years, electricity based cooking is making inroads into the country, especially in urban areas. Due to erratic power supply with frequent outages in most of the rural areas, electricity based cooking has not witnessed any significant penetration in rural India. Electricity for cooking is used in many forms, from a simple electric stove or resistive hot plate to induction-based cooking to microwave ovens.

4.3.1 Electric Stoves

Electric Stoves (or hot plates) are typically used by consumers in cases where a normal sized kitchen stove would not be convenient or feasible due to space constraints or lesser cooking requirements. These offer a compact and emission free cooking alternative for urban dwellers, where adequate design for ventilation may also be difficult to provide. In addition, it helps avoid the inconveniences associated with the procurement of LPG for those living in urban slums or unofficial dwellings without legal status, since they do not possess necessary documentation to get subsidised LPG connection.

4.3.1.1 Technical Description

An electric stove or electric hot plate is a portable table-top stove that relies on electricity to power the appliance. Heat generated in the heating elements of a hotplate is used for cooking the food. The heating surface of a hotplate is made of a high performance, tubular element with a round cross section. Electric stoves/hot plates are available in two variants – with uncovered heating element and having a sealed tubular heating element. Both single burner and two burner models of hotplates are commercially available and can cater to a variety of cooking needs.

Essential requirements of an electric hot plate are that the stove body should be shock proof, stable, easy to handle and maintenance free. A heat regulator on the hotplate maintains a range of pre-set temperatures, automatically. Since the heating surface is flat, it is preferable to use flat bottomed utensils to minimise the heat loss. The electric stove/hotplates assessed in this study are listed in Table 4.

Table 4: Electric Stove/Hotplate Models Assessed in this Study

Model	Manufacturer	Capacity (watts)	Capital cost (INR)
Round Hot Plate N125	Nova	1,000	800
G.E. Coil Hot Plate With Rotary Switch (With Wire N Plug)	Warmex	2,000	2,366
SOGO Double Hot Plate 1500W + 1000W	SOGO	2,500	3,495

Source: CEEW Compilation

4.3.2 Induction Based Cooking

Indian households, particularly in urban areas, are showing greater demand for induction cookstoves due to factors such as limited time and space for cooking and difficulty in accessing LPG due to absence of proof of residence, a concern for those who are not permanent residents of the city (Consumer Voice, n.d.).

Presently, the Indian market is flooded with a variety of indigenous as well as imported (mostly from China) models of induction cookstoves with a majority of the manufacturers offering a warranty of one or two years.[4]

There are a number of manufacturers of induction cookstoves, offering a diverse range of products at various price points. Although there are no dedicated policies or subsidies for induction stoves, their demand seems to be affected by the price of alternatives. Sales of induction cooktops reportedly grew when government imposed a cap of six LPG cylinders per year per household in late 2012 (Mahajan, 2012).

4.3.2.1 Technical Description

Induction cooktops operate on the principle of electromagnetic induction. On supply of electricity, the induction coil within the stove generates a magnetic field causing circular current to be rapidly created in the base of the cookware resulting in the generation of heat, which then gets directly transferred to the food being cooked (Consumer Voice, n.d.).

Induction cooktops have a thermal efficiency of ~84% (Consumer Voice, n.d.). They are available in both single burner and double burner models, which offers consumers more variety to choose from, in accordance to their cooking needs. While other cooking methods use flames or red-hot heating elements, where the energy loss is more, induction heating only heats the vessel placed over it – so the air around the vessel does not become as hot, keeping the surrounding environment relatively cooler.

Induction cookstoves have a specific advantage in terms of safety, as the surface of the cook

[4] CEEW-Stakeholder interviews and desk research of market of induction stoves

top gets heated only if it is in contact with the vessel, reducing the possibility of burn injuries. There are certain key factors that reflect the heating performance as well as the economy of operation. These are the effective surface plate area, power rating of the stove, internal design of induction coil and the materials used in the fabrication of utensils. The induction cooktop models assessed in this study are listed in Table 5.

Table 5: Induction Cooktop Models Assessed

Model	Manufacturer	Capacity (watts)
Induction PIC 2.0 V2 – with remote	Prestige	2,000
Majesty ICX 3 Induction Cooker SKU: 740054	Bajaj	1,400
Majesty ICX 10 Dual Induction Cooker - SKU: 740017	Bajaj	3,300
Daily Collection Induction cooker HD 4929/00	Philips	2,100
EECO Cook	Inalsa	2,000

Source: CEEW Compilation

4.4 PNG

Piped natural gas (PNG) is natural gas distributed through a pipeline network, providing uninterrupted supply of gas for cooking to households (GAIL, n.d.). The provision of PNG as a domestic cooking fuel started a decade ago in India and is a relatively new entrant in many urban centres. The penetration of PNG is currently limited to 24 cities, which have a PNG network. As of November 2014, around 2.5 million Indian households have PNG connections with Gujarat alone contributing close to 50% of the total number of connections, i.e. 1.23 million (MoPNG, 2014a). As a comparison, there are more than 175 million LPG connections in the country, as of November, 2014 (MoPNG, 2014b). The provision of PNG as domestic cooking fuel is so far limited to only urban areas, where it is provided as a utility service by the city gas distributors (CGDs). CGDs operate and maintain the network and apart from domestic sector, they also provide PNG to small industries and commercial establishments, and compressed natural gas (CNG) for transportation.

4.4.1 Technical Description

PNG is mainly methane with a small percentage of other higher hydrocarbons. PNG distribution network is based on an on-line supply system that consists of safety valves and regulators that control and monitor the gas supply and pressure, and assist in identifying system leaks. Thus, an uninterrupted supply at a constant pressure is assured (MNGL, n.d.). A domestic PNG connection includes a PNG stove (same as an LPG stove), a piped connection to the high-pressure pipeline network, along with a pressure regulator and a meter.

5. COMPARATIVE ASSESSMENT

This section provides an in-depth analysis of each technology against each criteria of the multi-dimensional framework.

5.1 Economics - Unsubsidised Cost to Consumer

Economic consideration is usually the prime one, when it comes to a choice between various cooking energy options. An economic analysis of the different cooking energy options was carried out by employing the 'Levelised Cost of Energy' (LCOE) methodology. LCOE is assessed for useful energy delivered, and thus takes into account transformation efficiencies of the various technologies. There are multiple methods through which LCOE can be estimated by including (or excluding) various costs elements. For the purpose of this analysis, apart from capital, operational and maintenance cost, the cost of financing and depreciation of assets are also considered. It is important to note that the LCOE assessment is being conducted devoid of subsidies of any sort – be it consumptive subsidy on LPG or capital subsidy on biogas plants or improved cookstoves. While subsidies might continue, the purpose of this analysis is to compare these alternatives at factor costs (devoid of subsidies or taxes) which could skew the analysis. The outcome of such an assessment is also important to understand the level of economic support needed for different technology options to make them affordable to the end consumer. The LCOE is calculated in INR/GJ using real fuel prices at different price escalation rates. In order to get a sense of what a GJ of energy amounts to, an average household in India consumes around 3.3 GJ (~ 8.9 cylinders of 14.2 kg each of LPG) of useful cooking energy, annually (Jain et al., 2014). The following sub-sections provide a quick summary of the LCOE analysis and some of the inputs used in evaluating the LCOE for each technology.

5.1.1 Improved Biomass Cookstoves

ICS, particularly forced draft models, entail a significant upfront expenditure when compared to traditional cookstoves or *chulha*s. As of August 2014, two of the most commercially successful natural draft stoves in the country, Greenway GSSV3 and Envirofit M5000, were priced at INR 1,399 and INR 1,999 respectively. Commercially successful forced draft models cost between INR 3,000 and 3,200.[5]

On the operational cost front, fuel i.e. firewood price is the largest component of the LCOE. Notwithstanding the notional costs involved in terms of time and labour in procuring firewood, the price of the fuel alters the economics. Strikingly, NSS data over the years, along with other independent surveys, indicate that *more than 70% of firewood consumed in rural households across India is commercially procured*. Though there are significant local and regional variations in terms of quantity procured and price, the mean price for 2011-12 (as evaluated from NSS consumer expenditure data) turns out to be INR 3.67 per kg of firewood, in rural India. Moreover as per our analysis across three NSS datasets over the last decade, the aggregated market price of the firewood has witnessed a CAGR of 11% - 15%.

[5] Based on telephonic interviews with ICS manufacturers

Keeping this trend in mind, three different firewood prices were used in determining a range for the LCOE.

1) Base case: Firewood commercially procured at INR 4 per kg
2) Lower bound: Firewood collected free-of-cost without consideration of notional cost
3) Higher bound: Firewood priced at INR 6 per kg, which is the average price in urban areas

For forced draft cookstoves consuming pellets, the fuel prices levels assumed were INR 12 and INR 15 per kg.[6]

Apart from the fuel cost, the maintenance cost provisions are also taken into account. Forced draft cookstoves typically involve a higher maintenance cost because of moving and electronic parts. Based on the telephonic interviews with forced-draft ICS manufacturers, the annual maintenance cost is estimated to be in the range of INR 100 and INR 250. Stoves which employ batteries to run fans, provide task-light or phone charging point, entail additional expenditure in periodic replacement of the battery, which is also considered in the analysis.

5.1.2 Biogas

Biogas is certainly the most capital intensive solution among all the technologies. A typical household system of $1m^3$ costs between INR 18,000 and INR 20,000 depending upon the type of model and labour costs. This excludes the opportunity cost of the land used for building the plant. The capital costs for community level plant vary significantly with the size of the plant. As there are very limited functioning examples of community level biogas plants, the case considered for the analysis mimics the model system at Sumul Dairy in Bhitbudrak (in Gujarat) where a $170m^3$ biogas plant is being operated at the community level, since year 2004 (SUMUL, n.d.). The capital cost incurred in setting up this plant, which serves 121 households, was to the tune of INR 215,000 (Sharma, 2010)

As the feed stock – cattle dung or food waste – is available almost free-of-cost, the major cost operating costs of a biogas plant are the labour and maintenance cost. The household level plants need very little additional labour, over and above existing time and efforts spent towards management of dung or preparation of dung cakes, which can now be diverted towards preparation and handling of slurry and manure. Even though the reported maintenance cost for biogas plants is quite low (~ INR 400 per annum) the following three cases have been considered:

1) Lower bound: INR 400 per annum towards minimal maintenance and no specific labour requirements
2) Base case: Individual biogas plants under the enterprise-based service model, with

[6] Based on telephonic interviews with ICS manufacturers

professional oversight and periodic maintenance management, maintenance costs are assumed at INR 1,600 per annum[7]

3) Higher bound: Individual biogas plants under the enterprise-based service model, with daily functioning and periodic maintenance management entirely outsourced, maintenance costs assumed at INR 3,600 per annum[8]

5.1.3 Electricity Based Cooking

The capital cost for electric hotplates varies in accordance with the capacity (wattage) rating, the brand, covering of the heating elements and whether it is a single or double burner model. The upfront cost of a single burner (2000 W) electric hotplate is ~ INR 2,400 while a double-burner electric hotplate costs ~ INR 3,500. The cost of single-burner induction cookstoves (1400W -2100 W) ranges from INR 2,500 to INR 5,000. Double burner stoves (for example, Bajaj Majesty ICX 10 of 3300 W capacity) are priced at ~ INR 8,000.[9] For LCOE analysis, both single and double burner options are considered.

Induction based cooking also requires additional capital expenditure in buying utensils, as most regular use utensils are not compatible with induction cooktops. The expenditure can range between INR 1,500 and INR 2,500, depending on the requirement.[10]

Electricity costs form the largest component of the total expenditure, over the life of the stove. The quantity of electricity consumed (driven by respective efficiencies and rating) and its price determines the operational costs. For the analysis, the electricity price per unit is considered as INR 4.79, with real price escalation rate of 2% (Planning Commission, 2014).

Unstructured interviews with users indicate that there is no maintenance costs associated with both electric and induction based cookstoves (typically), which highlights the high resilience of the technology.

5.1.4 PNG

In terms of capital costs, as of November 2014, the upfront cost of acquiring a PNG connection in Delhi is a refundable deposit of INR 6,000, which is against the cost of piping, fittings and meter installation (IGL, n.d.). In addition, there is an expenditure of ~ INR 1,400 on the gas stove equipment (basic model).

Operational costs associated with PNG pertain to the cost of fuel. For the analysis, we have considered a price of INR 27.3 per SCM of gas, which was the price of domestic gas in Delhi, as of November 2014. Though it is very hard to determine the future pricing scenarios for PNG, two scenarios reflecting a real price escalation rate of 2% and 4% per annum have

[7] One personnel overseeing 100 biogas plants at monthly salary of INR 10,000 translates to INR 1,200 per household per annum; Additionally INR 400 annually towards maintenance parts/spares.

[8] For the case when even the day to day operation is managed by the enterprise at overall service charge of INR 10 per day per household.

[9] Interestingly, upfront costs of induction stoves are driven down drastically by e-commerce entities.

[10] Similar to induction appliance, the cookware is also available at heavily discounted price by manufacturers and e-commerce entities during certain part of the year.

been considered.

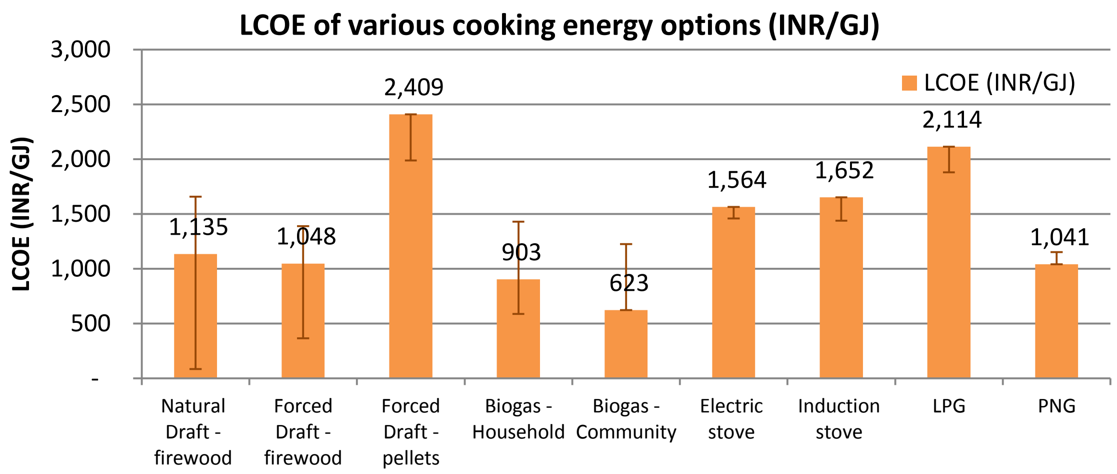
5.1.5 LPG

The capital costs associated with LPG include the security deposit for cylinder(s) and pressure regulator, as well as the cost of the gas stove and other administration charges, which together amount to ~INR 4,800, as of November 2014 (Indane, n.d.).

The operating costs for LPG based cooking, as in the case of PNG, comprises only the cost of fuel. Due to its direct linkage to the international market price and the associated price volatility, it is very difficult to predict variations in the price of LPG. A base price of INR 880 per cylinder (of 14.2 kg), which was the unsubsidised domestic price of LPG, as of September 2014, is considered for the analysis. For price variation, two cases with real price escalation rate of 2% and 4% are considered.

The tables in Appendix 1 summarise the key parameters considered in the economic analysis, including capital costs, efficiency, fuel price, escalation in fuel prices, useful life, O&M costs etc. A discount rate of 6%[11] and financial interest rate of 12% are uniform assumptions across all technologies. Capital expenditure over and above INR 1,000 was assumed to be financed at the rate specified above. The outcome of the comparative analysis of the economics of various options is depicted in Figure 1. The lower and the upper bounds for different columns (shown as error bars) in Figure 1, represent the sensitivity of the LCOE to changes in key attributes for each technology (as discussed in preceding paragraphs).

Figure 1: Comparison of Levelised Cost of Delivered Energy



Source: CEEW Analysis

[11] A real discount rate of 6% is evaluated as a the difference between average cost of capital and the prevailing inflation rate

The key outcomes emerging from the economic analysis are as below:

1) Improved cookstoves that are fired by 'free-of-cost' biomass are the most economical cooking energy solution (as shown by the lower bound in two leftmost columns of Figure 1). However, an analysis of data from recent NSS consumer expenditure surveys indicates that only 28% of Indian rural households, which use firewood, procure all of it, free-of-cost. More than 70% of firewood consumption (in quantity terms) for domestic cooking is commercially procured in India. Such a calculation, assuming 'free-of-cost' biomass, is applicable only to a limited proportion of population. Moreover, this does not take into account the time and the labour costs involved in fuel collection.

2) Biogas is the second most favourable solution for cooking energy in economic terms. LCOE for biogas ranges from INR 623 to INR 903 per GJ of useful energy, which is less than half of that for unsubsidised LPG, which stands at INR 1,942 per GJ.

3) The third in the list is PNG, which stands at around INR 1,041 per GJ. However, it must be noted that these cost estimates are based on certain assumptions of the price escalation of the fuel.

4) At the higher end of price assumption (of commercially procured firewood), the LCOE for improved biomass cookstoves is comparable or even higher than that of PNG. Even with conservative estimates[12], natural-draft cookstoves have an LCOE of INR 1,135 GJ, which is 10% higher than that of PNG.

5) Finally, the LCOE for improved cookstoves, based on pelletised fuels, is the highest and even surpasses unsubsidised LPG, which is the next most expensive option.

In summary, *on the economic front, with the exception of improved cookstoves running mainly on free-of-cost biomass, biogas emerges as the clear winner, and PNG comes in as a close second.* ICS emerges as a relatively expensive option, the economics of which are largely determined by the local firewood prices. Both electricity and unsubsidised LPG, neither of which are likely to see a downward trend in price in the long run, are significantly more expensive than others. These are also likely to be beyond the affordability limit for a majority of Indian households, unless supported through subsidies.

5.2 Smokeless Operations and Health Impacts Due to Indoor Air Pollution

The negative health impacts of indoor air pollution (IAP), caused by the traditional cookstoves, when used in poorly ventilated spaces, is one of the major drivers for national policymakers to promote clean cooking energy options. Thus, evaluating different technologies on this criterion is necessary to ensure that only effective technologies are promoted.

[12]Assuming firewood priced at INR 4 a kg, (20% of firewood using households pay a price higher than this) and at an annual real price escalation rate of 5% (CAGR for last 10 year, based on NSS data is ~11-15%),

Various studies attribute a significant burden of disease associated with household air pollution to the combustion of traditional biomass in *chulhas*. The main pollutants arising from combustion in these *chulhas* are fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO), followed by nitrogen dioxide, volatile and semi-volatile organic compounds (e.g., formaldehyde and benzo[α]pyrene) (Hude, 2014; Lim et al., 2012; Minde et al., 2013).

The *'clean'* aspect of cooking energy solutions was assessed using theoretical evidence from scientific studies as well as at the user perception level. The theoretical analysis is based on the reported emissions measurements (largely in controlled environments with limited on-field studies) of local pollutants (Jetter et al., 2012; Roden et al., 2009; Smith et al., 2007). The assessment of local pollutant emissions, especially CO and $PM_{2.5}$, which are the major causes of health burden due to indoor air pollution, provides the following key insights:

1) Cooking based on electrical or induction cookstoves has virtually no emissions in its end-use, thereby completely eliminating any adverse health impacts of indoor air pollution. However, electricity generation at its source can lead to increased pollution and result in morbidity and mortality, depending on the fuel and technology used for generating electricity. Coal based thermal generation already poses a significant public health issue in the country (Goenka & Guttikunda, 2013).

2) Gaseous fuels are the best in terms of limiting $PM_{2.5}$ as well as CO emissions.

3) Best in class estimates and field investigations suggest that natural draft cookstoves reduce $PM_{2.5}$ emissions by ~50%, whereas the forced draft cookstoves reduces the $PM_{2.5}$ emissions by 80% to 90% as compared to traditional cookstoves (Jetter et al., 2012). However, the impact of $PM_{2.5}$ exposure on health is not linear in nature, but rather supra-linear (Burnett et al., 2014). This implies that reduction in exposure to $PM_{2.5}$ is not linearly proportional to reduction in adverse health impacts of the exposure. In fact the marginal benefit of reducing exposure (or emissions) by 50% translates to less than 20% reduction in terms of health risk.

4) WHO guidelines on Indoor Air Quality standards recommend a complete transition to the use of gaseous fuels or electricity based cooking to eliminate health impacts from pollution arising from cooking (WHO 2014). The guidelines also indicate that the evidence from the field tests for ICS is very limited and the case for their improved performance is not a very strong one. The emissions from even the best-in-class models are not sufficient to reduce local pollutant levels to within safe limits, especially in poorly ventilated spaces. Researchers have also pointed out the significant difference in the lab and on-field performance of improved cookstoves (Roden et al., 2009).

5) Studies like Chafe et al., (2014) indicate that emissions from biomass cookstoves also contribute to ambient air pollution. Thus, unless there is a programmatic shift towards clean cooking in the entire area or location, it would be difficult to achieve the desired

improvements in public health by merely shifting a few households to cleaner cooking energy solutions.

The perception of experts, evaluated through a survey, also reflects that most technologies fare well on the 'clean' criterion barring improved biomass cookstoves, due to the inherent limitations of burning solid and mixed biomass. Significant improvements in the combustion process is needed should the ICS be viewed as a truly 'clean' cooking energy solution. Forced draft cookstoves are a step in this direction, but continue to have much higher emissions as compared to gaseous fuels.

Thus, from the perspective of reducing incidents of morbidity and mortality associated with indoor air pollution, *it is recommended to transition to gaseous fuels and electricity in the long term. Continuous improvements to the emission performance of ICS would serve as an interim solution, while the cleaner fuels become more affordable to the larger population.*

5.3 Assurance of Fuel Supply

Assurance of fuel supply on a sustainable basis is an important decision making criteria for both the households and the policymakers. In order to analyse how households perceive the assurance of various cooking energy sources, expert opinion was sought through an online survey. The fuel preferences emerging from the survey indicate that ICS has the most assured fuel supply and was rated so by more than 60% of the respondents. PNG, biogas and LPG were next in the rating, presumably indicating the inadequate supply of the fossil fuels in many parts of the country. Lower ratings for biogas could be explained by the poor performance of the existing stock of plants. Electricity based cooking received the lowest response and reflects the abysmal state of electricity supply – both in quantum and in reliability.

It can be inferred that the ranking stems from the current state of affairs in the country, where a significant proportion of households predominantly rely on biomass for cooking, and the state of electricity supply is extremely poor.

From a policymaker's perspective, a rudimentary analysis was carried out to estimate the growth in demand and the quantum of fuel supply required for each technology. These estimations assume that if the infrastructure to deliver a particular fuel to each and every household would be made available, what would the expected fuel demand mean, from the perspective of supply sustainability and energy security?

5.3.1 Improved Biomass Cookstoves

Most improved biomass cookstoves are primarily fuelled through firewood, apart from a few forced draft models which work on processed (pelletised) fuels. Even though biomass is largely regarded as a freely available resource, more than 70% of biomass consumption in rural households is commercially procured, as suggested by data from NSS consumer expenditure surveys over the years. The continued reliance and consumption of firewood by the largest proportion of population (~700 million), translates to 150-200 million tonnes of biomass use every year.[13] Though this consumption has been relatively stable (in absolute terms) over the past 10 years, there are underlying implications of seasonality, local and socio-cultural challenges associated with the availability of firewood.

At the national level, displacement of traditional stoves by ICS will reduce the net consumption of firewood, thereby improving overall availability. However, if improved cookstoves are to be considered as a medium term to long term solution for a large number of households, the sustainability concerns would be significant and better harvesting practices would have to be instituted. In the case of pelletised fuels, a shortage of locally manufactured pellets at a reasonable price is already proving to be a major constraint for forced draft stove manufacturers to increase their user base.[14]

5.3.2 Biogas

Secure and continuous supplies of feed (dung and kitchen waste) and operational availability of the plant are the only critical and necessary conditions to assure fuel supply for a biogas plant. These two conditions dictate that biogas should be promoted and adopted as a solution (i) in areas or households with livestock density (at the community level) and cattle ownership sufficient to meet the required biogas quantities; (ii) and in regions where ambient temperature and climatic conditions would not pose a significant barrier for the plants to function round the year.

Apart from the climatic considerations, the operational availability of the plant is dependent on the robustness of the technology and supporting maintenance services. Thus, from the policymakers' perspective on fuel supply assurance, targeted promotion and adoption of biogas should be facilitated, along with the efforts to improve the resilience and management of the technology.

In terms of overall availability of feedstock, the potential for biogas to serve as a cooking fuel is significant. Even though the livestock to human ratio has constantly declined over the years, there are still more than 300 million cattle in the country (Ministry of Agriculture, 2012). *As per our analysis, even if only 20% of the dung generated by the cattle and buffaloes alone, were to be used for biogas generation, it could potentially serve close to 30 million households in the country.* Earlier studies by the Planning Commission indicate that the potential is to the tune of 24 million households. However, the performance evaluation of biogas conducted by Planning Commission (more than a decade ago and focused only on family type biogas plants) suggests that the potential is significantly lower and could cover only 11.5 million households (Planning Commission, 2002).

5.3.3 Electricity based cooking (Induction or Electrical)

If the entire population were to derive all of its cooking energy from electricity, the average household consumption (equivalent to the current LPG consumption) would translate to an incremental demand for 335-375 billion units (BU) of electricity, depending upon the choice

[13] Estimated through NSS data and corroborated through existing literature (Venkataraman et al., 2010).

[14] Based on telephonic interviews with manufacturers

between induction and electrical heating. This is in comparison to 960 BU, which was generated in the country in 2013-14 (CEA, 2014). Such generation of 335 – 375 BU would mean an additional generation of 34% and 38% (over 2013-14 figures). Given that more than 80% electricity in India is based on thermal resources, of which more than 85% is from coal, if we assumed that this additional electricity was fuelled from coal, there would be an additional requirement of coal to the extent of 255 million to 286 million tonnes/annum (~ 50% increase from current coal consumption in the power sector).

At such a high penetration of electricity, for use as a primary cooking energy, the burden on the power sector cannot be understated. In an already power starved country, where 45% of the rural household do not have electricity even for lighting, it would be unreasonable to tie the cooking needs to the power sector as well. With the transition to renewable energy sources, the prices are also likely to increase, potentially, limiting this demand in the long run.

Generation of electricity is not the only challenge determining assurance of electricity supply. The reliable supply requires that additional generation is complemented by adequate strengthening and extension of transmission and distribution infrastructure to effectively electrify every household, while eliminating the existing practices of prioritising urban and industrial consumers over their rural counterparts (Palit & Chaurey, 2011). If electricity has to become a primary cooking option, reliable supply is a necessary condition.

Finally, from a resource efficiency and *overall* energy security point of view, the choice of electricity-based cooking is not the most optimal, as long as coal remains the major source of India's grid power. Given the energy losses, starting from generation, transmission, distribution and all the way to end use, the thermal efficiency across this supply chain drops to a mere 13% - 14%.

5.3.4 PNG

When it comes to fuel supply assurance for PNG, certainly India has very limited and low domestic reserves for natural gas. However, being a highly versatile fuel, natural gas has competing demands for electricity generation, fertiliser production, domestic cooking and as transportation fuel (in the form of CNG). Thus whether PNG can be used, and to what extent, as a domestic fuel for meeting cooking energy demands is a question which needs to factor in the national priorities accorded to these competing needs. The use of PNG for cooking by every Indian household is probably a distant reality, but certainly its use in urban areas is not. And even if we considered rising urban population, the domestic reserves of natural gas could cater to the cooking needs of urban India for as high as 80 years, if used exclusively for cooking. Complementing the supply with imports from international market is also an option, which could be cost effective with long-term procurement agreements. In the meantime, it is necessary for India to not only explore its own untapped gas resource, but secure other options of sourcing natural gas from the international market.

5.3.5 LPG

LPG is already a major cooking fuel. Although the penetration in terms of number of connections has reached close to 175 million (MoPNG, 2014b), our earlier analysis of NSS data suggests that only 50% of India's cooking energy is derived from LPG (Jain et al., 2014). Even at the current user base, the dependency on import is already as high as 89%. As per our estimation, the present annual consumption of 16 million tonnes would almost double to 32 million tonnes, if all households were to rely entirely on LPG for their cooking energy needs. This would lead to significant challenges in terms of sourcing LPG, as well as have implications on foreign currency reserves to procure the required crude or the product directly.

Apart from the sourcing, the end delivery of the product on a regular basis is also a challenge, which would limit the penetration, regular supply and adoption of LPG, especially in far-flung and poorly accessible locations in the country.

Along with the assurance of fuel supply, a related and important aspect is the 'ease of fuel procurement', which reflects the household's perception of the ease of obtaining fuel. This aspect is evaluated with the backdrop assumption that if fuel supply is assured for all technology options, how do they fare in terms of 'ease of fuel procurement'? Clearly, connected and delivered utilities like PNG and electricity have the highest ease of procurement, whereas LPG could have varying levels of ease, especially as in rural India, as it is not delivered at the door-step and households need to procure it from the distributor. For improved cookstoves, even though the assurance of fuel supply could be high, usually the ease of fuel procurement is low given the toil involved in firewood procurement. For biogas plants the effort associated with fuel collection is usually not as much as for firewood, but requires effort to maintain the plant.

5.4 Resilience of the Technology

Just as assurance of fuel supply on a continuous basis is a critical consideration to choose a particular cooking energy solution, the resilience of technology is an equally vital consideration for households before considering a shift of cooking energy technology. At the household level, the resilience of the technology fundamentally means how successfully the particular technology can be used as a primary cooking energy solution, without the need of a backup or alternative.

The resilience of the technology is assessed from the perspective of end-users, drawing on expert opinion, gathered through an online survey. PNG and LPG were (unsurprisingly) rated the most resilient technology on account of the minimal downtime they experience and little maintenance requirements on a periodic basis. Electric cooking solutions were a close second and offer similar characteristics. ICS and biogas plants fared the worst, indicating that there is still some way to go before end-users view these solutions on par with the rest.

Lowest rating for biogas, in terms of technology resilience, stems from the dominant view (and rightly so) that a majority of the plants that have been installed are in a state of disuse.

The quality of construction, design, the lack of user training and follow-up procedures from the technology providers have been cited as the primary causes for this (Planning Commission, 2002). A shift in focus, from mere provision of subsidy to the end-user to a holistic service based delivery model, would be necessary to ensure that this perception of unreliability is mitigated.

In a similar vein, for improved cookstoves, there is a need for technology development in terms of improving the durability of stoves. A strong push is also required to improve after sales and maintenance services. As forced draft stoves are equipped with moving parts, electronics and battery, maintenance and repair of these stoves poses serious challenges to the resilience offered by the technology. Drawing on the lessons from the failure of earlier programmes, ICS manufacturers are constantly making improvements in design and construction materials to make the product more robust as a whole. A well-established local network for repair and maintenance, complementing the dissemination or sales of these stoves, is essential for improving the resilience of the technology and the consumer's confidence in ICS.

5.5 Convenience of Cooking

This criterion is seldom given due importance, but for the final consumer, the choice of cooking energy solution is strongly influenced by the ease or convenience of using it (Atanassov, 2010; GIZ, 2014). There are multiple socio-cultural aspects and design needs, which collectively determine the overall convenience of using a cooking energy solution. Based on the literature review and experts' opinions, a range of sub-criteria were identified. The relative importance of these in determining the overall convenience of cooking, along with the performance assessment of various cooking energy solutions against these aspects, is determined through the experts' opinions using an online survey.

5.5.1 Ability to Accommodate Variety of Utensils and Food Items

The suitability of a cooking energy solution to accommodate a variety of cooking practices, including various cooking utensils and food items, is deemed as the most important criteria, as per the cumulative judgement of the experts. LPG and biogas received the highest scores on this front. Improved cookstoves and electric stoves were ranked third and fourth, respectively. Induction cookstoves were viewed poorly and deemed to be the least suitable option for accommodating the variety of cooking needs. The low rating for electric and induction based cooking solutions also corroborates the fact that only flat bottom utensils work best with electric cookstoves, whereas utensils of only ferromagnetic material can be used on induction cooktops. Absence of flame, required for cooking certain food items, is also a limitation for electric and induction cooking.

5.5.2 Ease of Control of Flame or Heat Intensity

The ease with which one can control the flame or heat intensity of the cooking energy solution is believed to be the second most important criteria influencing the choice of cooking energy solution. LPG, PNG and biogas, with common characteristics of gaseous fuel, and using similar (if not identical) stoves, were rated as the best solutions in this regard. Induction and electric stoves were rated below the gas based solutions. Primary research conducted for the study indicates that electric cooktops, unlike gas or induction stoves, heat and cool slowly, making them less responsive in terms of temperature control. Improved cookstoves were rated the lowest for their controllability of heat intensity.

5.5.3 Ability for Quick Start-Stop Operation

Ability of a cooking energy technology to be used in quick start and stop operations is a desirable feature, especially when it comes to short cooking durations for certain items such as tea, snacks etc. Unsurprisingly, the three gas-based cooking options (LPG, PNG and biogas) were rated as the most suitable for such cooking practices. Induction and electric stoves were also viewed to be suitable with a high rating. However, primary research indicates that electric cookstoves have long response times, as compared to induction, which are instantaneous in response. Improved biomass cookstoves, again, were poorly rated. It is a documented drawback of these cookstoves, where the fuel continues to burn even after the cooking operation has ceased.

5.5.4 Time Taken for Cooking

The time consumed in the cooking process is also considered as an important factor by the experts, which influences the choice of cooking energy solution. Fundamentally, the rate of heat intensity determines the time of cooking. For most cases, the higher the heat intensity, the lower would be the time of cooking. All the technologies except improved cookstoves were considered as 'fast' in terms of the time taken by the solution to cook a meal. The improved cookstoves got the lowest rating.

5.5.5 Ease of Management of the Technology

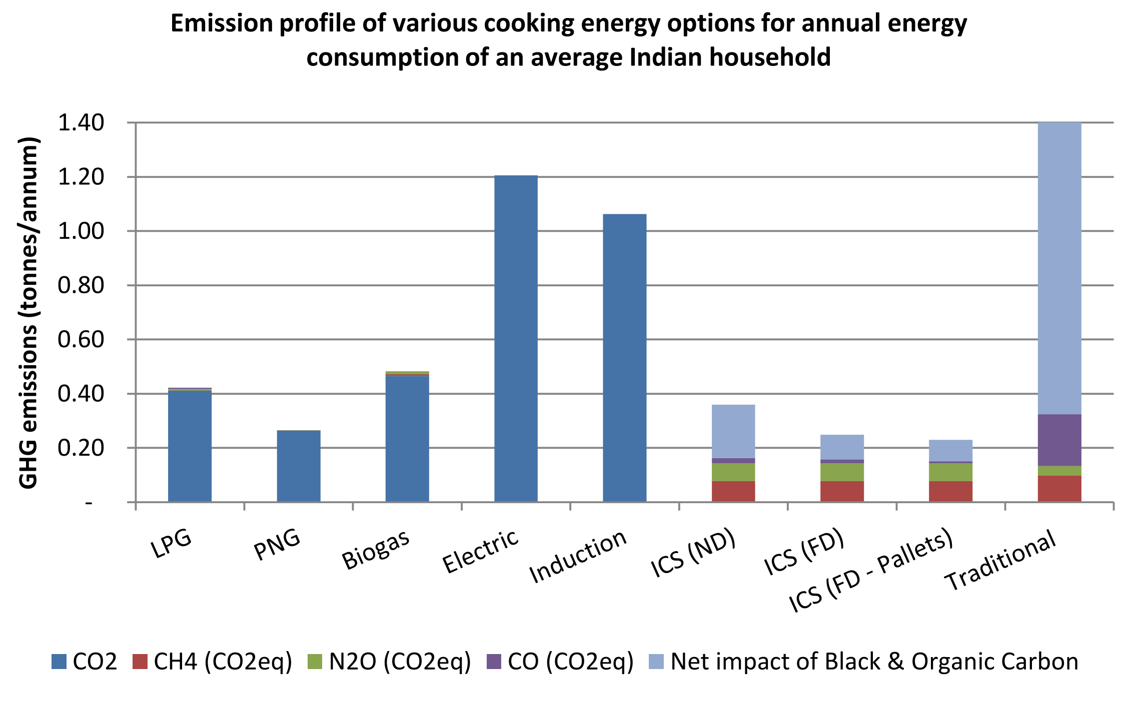
Another important factor is the ease of managing the technology to ensure sustained and reliable performance. This alludes to activities like regular cleaning of cookstoves, daily management of biogas plant (in case of household level plant), etc. LPG and PNG were considered the easiest to manage, based on the cumulative opinion of the experts from the survey. The management of improved cookstoves was not deemed as easy. Household-level biogas plants were considered as most difficult in terms of their management, as compared to other technologies, reiterating the common perception of their difficulty in use and daily management.

5.6 Cumulative GHG Emissions

The consideration of global environmental impacts, especially on climate change, is probably not an important factor in the choice of cooking solution for a household, but it is certainly an important one for policymakers wanting to promote clean cooking technologies. The greenhouse gas emissions (net climate forcing) of each technology are calculated as tonnes of CO_2-equivalent (CO_2eq) emissions corresponding to the annual cooking energy needs of an average Indian household. CO_2eq are calculated by the summation of emissions of each GHG multiplied with its respective Global Warming Potential (GWP).[15]

It is important to note that for GHG emissions estimation, the analysis boundary for the case of LPG and PNG is limited to the end-use i.e. combustion. Lifecycle emissions starting from extraction and from the refining and transportation process are not considered. For estimating emissions from the use of electricity , the effective emissions associated with the generation mix is considered through the use of an average emission factor of 0.98 kg CO_2/kWh (Central Electricity Authority, 2014). For biomass-based cookstoves (traditional or improved), direct CO_2 emissions are not considered in the overall GHG calculations[16]. However, actual combustion in cookstoves also results in non-CO_2 emissions, which are accounted for in GHG estimations. The annual GHG emissions estimated for the different cooking energy technologies are shown in **Figure** . This is based on the typical cooking energy requirement of an average Indian household (~3.3 GJ of useful energy).[17]

Figure 2: Shifting Away from Traditional Cookstoves has a Co-Benefit of mitigating climate change



Source: CEEW Analysis

For the purpose of providing a comparison with the most commonly used cooking energy solution in India, Figure also indicates the GHG emissions from traditional cookstoves for equivalent energy delivered. Certainly, all the cleaner cooking energy options perform better

[15] Emissions of pollutants from each technology and GWP values have been outlined in Appendix 2

[16] Biomass is assumed to be sustainably harvested and thus CO_2 emissions from its combustion are assumed to be carbon neutral.

[17] Estimated from NSS data on consumer expenditure survey for the year 2011-12.

than the traditional stove, providing a clear case to promote clean cooking energy solutions. The gain is mainly driven by significant reduction in emission of black carbon (also known as elemental carbon), which is a result of incomplete combustion and is often the major constituent of soot. Elemental carbon from combustion has a GWP 900 times that of CO_2 (Bond et al., 2013). This can also make a strong case for India's mitigation actions against climate change.

Given the carbon neutrality of biomass, ICS have the lowest emissions per unit of delivered energy. They have significantly lower black carbon and CO emission as compared to the traditional cookstoves.

PNG, LPG and biogas, all consist of small chain hydrocarbons and hence have similar impact on GHG emissions. PNG has lower emissions as compared to LPG, which is corroborated by evidence from literature (Gautam et al., 2013). CO_2 is the primary GHG contributing to the carbon footprint for both LPG and PNG based cooking. Biogas has only a marginally larger footprint than LPG and PNG, as the emissions associated with transport and processing of these fossil fuels are not accounted. If such emissions would be taken into account, LPG and PNG could have higher lifecycle emissions as compared to biogas. The indirect emissions associated with the generation of electricity mean that it is the most polluting one, from the perspective of GHG emissions. With increasing contribution from renewable energy or non-fossil sources, this could come down in the future.

6. SUMMARISING THE ASSESSMENT OUTCOMES

The assessment across multiple dimensions provides a comprehensive view of each of the cooking energy options considered. Table 6 qualitatively synthesises the outcomes of the comparative analysis as elaborated in the preceding section.

Table 6: Summary of Evaluation Across all Considered Attributes

	Affordability - LCOE	Health impacts	Assurance of fuel supply	Convenience of cooking	Resilience of the technology	Environmental Impacts/ GHG emissions
Biogas	Best in class	Good	Neutral	Good	Worst in class	Neutral
Improved Cookstoves	Neutral	Worst in class	Best in class	Worst in class	Bad	Best in class
Electric stove	Bad	Best in class	Bad	Neutral	Neutral	Worst in class
Induction stove	Bad	Best in class	Bad	Bad	Good	Worst in class
LPG	Worst in class	Good	Neutral	Best in class	Best in class	Neutral
PNG	Good	Good	Good	Best in class	Best in class	Good

Legend:

Best in class	Good	Neutral	Bad	Worst in class

Source: CEEW Analysis

PNG emerges as a strong overall contender for clean, affordable, and sustainable cooking energy for the coming decades. Whether PNG will realise this potential and contribute to a large share of the cooking energy needs of India (at least the urban areas) is dependent on national priorities, but certainly it provides the best in class convenience of cooking, technology resilience, has one of the lowest GHG emissions, and is economically viable, both for the consumer and for the exchequer. However, the low domestic reserves of natural gas are a significant deterrent to the universal promotion of this option.

It is quite evident that biogas is a competitive and clean cooking energy option when it comes to economics, cooking convenience and improved indoor air pollution conditions. While its GHG emissions are higher than LPG and PNG, it saves on transportation and production costs and associated emissions. Depending upon where we put the boundary for GHG emission analysis, the effective GHG emissions for LPG and PNG could be higher than that from biogas. With moderate impacts on the ambient environment, the major area where biogas lags behind is the 'resilience of technology' and the challenges associated with plant management. The historic experience with biogas plants in the country has marred the perception of the technology and eroded confidence in the technology amongst rural households. This makes a strong case for innovation in technology design and management, to revive the image of biogas as a sustainable technology as well as to realise the massive untapped potential of this option.

For improved biomass cookstoves, the outcomes are mixed. It ranks high in terms of fuel supply assurance and decreased GHG emissions. In terms of indoor air quality improvements, the benefits of switching to improved cookstoves, although significant, are still limited. Also, ICS fares low on cooking convenience and technology resilience. Evidence from multiple primary surveys, including NSS consumer expenditure surveys, indicates high reliance on commercially purchased firewood in the rural areas, as opposed to the common perception of easy availability of free-of-cost biomass. As a consequence, ICS fares poorly on economic considerations, depending upon the choice of cookstoves and the price of fuel (firewood or pellets). The pellet-based cookstoves, which have a very good performance in terms of emissions and efficiency, are by far the most expensive technology to adopt. The overall assessment indicates that much needs to be done on the technology improvement front, in terms of emission reduction, enhancing cooking convenience and technology resilience. Technology resilience improvements could also be achieved in part with better service models. But any government programme towards large scale deployment of ICS should give consideration to economics for the end-user against the accrued benefits, while promoting such solutions.

Electricity-based cooking solutions excel in the 'clean' aspect because of zero point of use emissions. Apart from the moderate ranking in terms of cooking convenience and technology resilience, electricity-based cooking does not fare well on any other criteria. The assessment also points to its inability to accommodate various cooking needs. This calls for technological innovation to tailor the solution to suit prevailing cooking practices and needs. Unless there is a significant improvement in providing a reliable electricity supply to every Indian household, the use of electricity as primary cooking energy source would be limited.

Finally, LPG fares high on cooking convenience, technology resilience and a significantly lower impact on health. However, it has major drawbacks on the economic and supply assurance front. Given the high dependence on imports, the high cost of LPG use is likely to continue. In terms of affordability, it poses a significant burden on the individual and this could translate to a higher fiscal burden on exchequer (on account of the large subsidy provided).

7. RECOMMENDATIONS

The government is pursuing multiple solutions through various programmes such as promoting city gas distribution networks for PNG, the NBMMP for biogas plants, the *Unnat Chulha Abhiyan* for improved cookstoves, and RGGLVY and LPG subsidy to improve LPG penetration in the country. These programmes must be pursued in order to reduce the public health impact of indoor air pollution and drudgery associated with the collection and use of traditional solid biomass, especially for women and children in rural India. In their present form, however, these programmes and schemes are being implemented in isolation. Though these have been in place for many years, the results are not very encouraging, with 80% of the Indian households continuing to use some form of traditional fuels for cooking. In order to allocate adequate resources towards these options of clean cooking energy, **there is a need to unify these government efforts with a vision (and mission) to provide clean, affordable and sustainable cooking energy to every Indian household**.

The most pressing need for such a mission is to create awareness about the negative consequences of utilising traditional fuels for cooking energy. Awareness generation is important to create bottom-up demand for clean cooking energy solutions. Such awareness generation activities should be technology neutral, and should provide a clear picture of relative merits and de-merits of various options. An ideal approach would be one that factors in the needs of the household as well the national goals of energy security and sustainability. The decision-making should be a combination of top-down and bottom-up estimations (driven by the nature of technology). Local-level decision-making authorities should play a critical part in deciding best possible technologies to cater to the local cooking energy needs and are in line with resource endowment. The following points could serve as initial guiding principles while making appropriate choices for the long-term:

1. Promote biogas (under the service-based enterprise models) in areas with suitable climatic conditions, resource feasibility, and community acceptance, by creating the necessary ecosystem and a favourable environment for its roll-out.

2. If the necessary conditions for biogas do not exist:

    a. For remote and far-flung areas with poor LPG access, forced-draft ICS using firewood should be promoted while ensuring after sale services to facilitate sustained use. Simultaneous efforts on technology development front must be undertaken to improve emission performance, technology resilience and suitability to accommodate mix biomass fuels.

    b. For areas with adequate connectivity and a reasonable population density – LPG should be promoted in a programmatic manner, i.e. covering entire area rather than individual households, starting with areas having low availability of free-of-cost biomass. For areas where socio-economic conditions and higher availability of cheap or free biomass do not favour LPG (the more expensive option), ICS should be promoted as an interim solution. Simultaneously, sustainable harvesting of biomass should be promoted in these locations. In addition, the planning for newer LPG bottling units should reflect this geographic shift in the demand for LPG, so as to minimise transportation costs and increase its availability in 'smaller-towns'.

3. Promote PNG in urban areas beginning with the densely populated Tier-I and Tier-II cities. It would also be necessary to develop medium and long term strategies for natural gas procurement and delivery to as many sections of society as can be covered with a PNG network in a cost-effective manner. PNG (for cooking) constitutes a small portion of the demand for natural gas today, but is likely to grow the fastest in the years ahead.

Pursuant to the *'next-steps'* proposed above, recommendations specific to each technology are provided below, with the view to achieve universal coverage of clean affordable cooking energy. India needs to tap into all the available options, if it is to meet the large demand from a diverse user base, which is yet to see formal provision of clean cooking energy solutions.

7.1 LPG

Given the multiple challenges associated with the large scale (and time-bound) deployment of the alternatives that have been considered in this study, LPG will continue to cater to clean cooking energy needs of a large section of the population. However, there is a need to rationalise the subsidy provided for domestic consumption to ensure that there is enough fiscal room to expand access of LPG to non-users. Some of the recommendations made to this effect, in a related study[18] by the authors are worth reiterating:

1. Reduce the limit on subsidised LPG to 9 cylinders per annum per connection, in order to drive efficient use of the commodity and allow for a larger user base.

2. Introduce differentiated subsidy for domestic LPG, to align the prices with affordability. It would also be a prudent move to exclude the well-to-do category (top 15 per cent population by income) from LPG subsidy net.

3. The supply of LPG to rural areas has been a challenge so far. It is necessary to leverage existing institutions in rural areas (such as self-help groups and rural supply chain networks) to sustainable delivery models for LPG. Simultaneously, the costs of delivery must be shared across all consumer categories and burden must be made uniform across the country.

[18] (Jain et al., 2014)

7.2 PNG

4. PNG for household cooking should continue to remain as a high-priority sector in the allocation of domestically produced gas.

5. Expansion of PNG network in the urban areas should be aggressively promoted and facilitated.

6. In order to generate demand and shift towards PNG, LPG supply in areas that have connectivity to the gas network must be phased-out in a time bound manner.

7.3 Biogas

1. Facilitate innovation and technology development in order to improve the design, construction quality and resilience of biogas plants. There is also a need for innovation in low cost technologies to ensure safe and hygienic handling of dung, slurry and manure.

2. Biogas must be aggressively promoted in areas or households with favourable conditions, i.e. areas where the ambient temperature for large parts of the year is in the range of 20^{0}C – 35^{0}C. In addition adequate land availability, livestock number and livestock to human ratio are important criteria to keep in mind. These are necessary but not sufficient drivers for success. Community/household awareness, keenness and ownership are other important parameters to be gauged while promoting biogas as a cooking energy solution. While the government has spared no bills in the provision of LPG at subsidised prices to consumers, the budgetary allocation for biogas needs to be increased significantly to signal such an ambitious programme. This is not merely to provide the capital subsidy but to strengthen the entire implementation process.

3. Promote service-based enterprise model for both community and family type plants. The major challenge associated with biogas is technology resilience and technology management. Both of these can be adequately addressed with innovations in implementation models. An enterprise based model is proposed, where even the household level plants could be operated and managed by a local enterprise with trained personnel, ensuring plant uptime and performance. Based on the choice of business model, this could also eliminate the need of initial capital investment by households in a pay-as-you-go model. The household would be required to only supply the necessary feed of animal dung and wastes.

4. Such implementation models have significant employment generation potential at the grassroots level and this would be an important co-benefit of running a biogas programme. There is a need to provide financial support and facilitate capacity building to promote enterprise-based models for both household level and community level plants.

7.4 Improved Cookstoves

1. Policymakers need to focus on incentivising research and innovation to improve the (i) emission performance; (ii) convenience of cooking; (iii) and technology resilience of ICS.

2. Until the emission performance improves further to match that of gaseous fuels, promote ICS as transitional solution, particularly in areas with cheap, freely or easily available biomass.

3. In order to increase the adoption, facilitate service based enterprise models, which can provide regular servicing to improve resilience of the technology, ensuring continued use of ICS.

4. Spur technical, financial and business innovation to bring down the cost of pelletised fuel for forced draft cookstoves.

5. Develop and impose rigorous quality standards to regulate the influx of low quality products. Such standards should be multi-dimensional, rather only based on efficiency and emissions performance, with commensurate testing and certification procedures.

6. Further studies and research are required to evaluate the on-ground emission performance of ICS, while also monitoring and apportioning the ambient air pollutant, in order to confidently estimate and effectively achieve the desired health benefits.

7.5 Electricity Based Cooking

1. Given the perpetual power deficit, unfavourable economics, predominant reliance on thermal generation, and the competing needs for electricity, there is little rationale to support large-scale cooking energy provision through electricity.

8. CONCLUDING REMARKS

This study provides concrete recommendations which could be pursued at a macro level based on the current state of affairs. In addition, it proposes a framework that synthesises multiple criteria for decision-making, which must be considered for determining optimal cooking energy choices.

As technology evolves, the outcomes of this framework may also change, which in turn would lead to different choices being made, even as the framework to assess the alternatives remains the same. The framework would be useful for national policymakers as well as local level decision makers to determine and prioritise the endeavours needed to achieve clean cooking energy for all. Finally, the need for a unified approach for planning and roll-out of clean cooking energy solutions cannot be overstated. Besides providing a decision making framework for pursuing such an approach, the study highlights the need to expand the horizon of public debate and efforts around clean cooking energy beyond LPG.

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10. APPENDICES

Appendix 1

Key Inputs in Economic Analysis of Clean Cooking Options

Cooking Technology	Efficiency	Calorific Value of Fuel	Fuel Price	Fuel Price Escalation (CAGR)	Lifespan	Capital cost	Annual O&M costs (not including fuel cost)	Other costs incurred over lifetime
Natural Draft	24.1%	3,500 kCal/kg	Firewood: INR 0, 4,6 per kg	5%	5 years	INR 1,399-1,999	Nil	Nil[19]
Forced Draft	34.1% - 37.3%	3,500 - 4,000 kCal/kg	Firewood: INR 0, 4,6 per kg Pallets: INR 12, 15 per kg	5%	5 years	INR 3,000-3,200	INR 100-250[1]	INR 300-800[20]
Biogas-Household	57.4%	4,800 kCal/m^3	-	5% - for O&M cost	20 years	INR 19,500	INR 400 ; 1,600 ; 3,600[21]	INR 1,500[22]
Biogas-Community	57.4%	4,800 kCal/m^3	-	5% - for O&M cost	20 years	INR 2,150,000	INR 120,000 ; 360,000[23]	INR 261,995[5]
Electric stove	74%	-	Electricity: INR 4.79 per kWh	2%	10 years	INR 800; INR 3,495	Nil	Nil
Induction stove	84%	-	Electricity: INR 4.79 per kWh	2%	10 years	INR 2,695; INR 7,995	Nil	INR 2,000[24]
PNG	57%	10,000 kCal/scm	INR 27.3 per scm	2% ; 4%	15 years	INR 7,400[25]	Nil	Nil
LPG	57%	10,870 kCal/kg	INR 880/14.2 kg	2%; 4%	15 years	INR 4,800[26]	350[27]	INR 350

Source: CEEW Analysis

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[19] Based on telephonic interviews and discussions with stakeholders including manufacturers
[20] Towards battery replacement
[21] Corresponding to different O&M models – Self maintained (Reported in literature), Service based model with outsourced maintenance (CEEW analysis); Service based model with both operations & maintenance outsourced (CEEW analysis)
[22] Stove replacement
[23] Corresponding to different operating model – INR 120,000 reported by Sumul Dairy in telephonic interview for their operational plant
[24] Cost of induction compatible cookware
[25] Out of this INR 6,000 is refundable, but assumed to lose to its value over lifetime of 15 years
[26] Out of this INR 2,900 is refundable, but assumed to lose to its value over lifetime of 15 years
[27] Towards hose replacement

Appendix 2

GHG Emissions of Various Cooking Energy Options

Cooking technology/ fuel	Annual fuel quantity /useful energy	CO2	CH4 (tonnes CO2 eq.)	N2O (tonnes CO2 eq.)	CO (tonnes CO2 eq.)	Elemental carbon (tonnes CO2 eq.)	Organic carbon (tonnes CO2 eq.)	Annual CO2 eq. emissions (tonnes)
Natural Draft	3,276 MJ	-	0.08	0.04	0.00	0.24	-0.04	0.32
Forced Draft (using firewood)	3,276 MJ	-	0.08	0.04	0.00	0.11	-0.02	0.22
Forced Draft (using pellets)	3,276 MJ	-	0.08	0.04	0.00	0.09	-0.02	0.20
Biogas	3,276 MJ	0.47	0.01	0.01	0.00	-	-	0.48
Electric stove	1230 kWh	1.21	-	-	-	-	-	1.21
Induction stove	1080 kWh	1.06	-	-	-	-	-	1.06
PNG	4,851 SCF	0.26	0.00	0.00	-	-	-	0.26
LPG	3,276 MJ	0.41	0.00	0.00	0.00	-	-	0.42

Source: CEEW Analysis

Global Warming Potential (GWP) of Gaseous and Particulate Emissions

GHG	GWP as 100 year carbon dioxide equivalent	Source
Carbon dioxide (CO_2)	1	http://www.ipcc.ch/ipccreports/tar/wg1/249.htm
Carbon monoxide (CO)	2	http://www.ipcc.ch/ipccreports/tar/wg1/249.htm
Methane (CH_4)	21	http://unfccc.int/ghg_data/items/3825.php
Nitrous Oxide (N_2O)	310	http://www.ipcc.ch/ipccreports/tar/wg1/249.htm
Particulate matter elemental carbon	900	Bond et. Al. 2013
Particulate organic matter	-50	Bond et. Al. 2013

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