Appendix B

This is an appendix of the report

'Fuelling the Transition'

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प्रयास

आरोग्य, ऊर्जा, शिक्षण आणि पालकत्व
या विषयांतील विशेष प्रयत्न

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Appendix B: The CEFTI Model

The appendix describes in detail aspects of the CEFTI model which were not covered in the report. This includes key assumptions, treatment of costs and health benefits. However it should be read in conjunction with section 2.4 of the main report.

In order to estimate demand, the population for every age group considered and gender and household projections for every state for the time period in the model needed to be utilised. As there are no projections for population and households from a single source which are compatible and consistent with the methodology for estimating costs and health benefits, these projections have necessarily been derived from multiple sources. The methodology used for this purpose is described in Section B.1.

Section B.2 describes the methodology for estimating energy demand and magnitude of fuel requirement for each year of the projections based on the useful energy requirement, fuel penetration trajectories in the scenarios, projections of number of households, and stove efficiency trajectories.

Section B.3 provides a detailed description of the methodology used in CEFTI for estimating the health benefits of a transition to cleaner fuels.

B.1 Population and household projections

All India population projections by gender and for children on an annual basis for the considered time period are as per the World Population Prospects projections (United Nations, 2015) for compatibility with the disease burden projections. As the analysis also makes use of state-wise rural, urban populations and household projections, further disaggregation of the UN (United Nations) projections was required. At the subnational level, there are no recent, consistent, publically available projections suitable for this analysis. The Office of the Registrar General and Census Commissioner of India (ORGI) publishes state-wise population projections for a 20 year period with age, gender and rural-urban disaggregation on a decadal basis, with the most recent projections being for the period 2001–2026 (Census, 2006).[1] Using this data, state-wise, gender-wise and age-wise population proportions were arrived at for every year till 2026 and extrapolated for the next 4 years till 2030.

The age and gender wise population proportions in each state from the ORGI were applied to the all-India projections from the World Population Prospects to estimate state-wise, age-wise and gender-wise population used in this analysis. As these state-wise proportions were based on the 2001 Census data rather than the 2011 Census data, there are small discrepancies between the estimated numbers and actual figures for 2011.[2]

Much of the analysis, such as fuel penetration and associated costs, is done at the household level. The numbers of rural and urban households for the respective states were estimated by dividing the

1. There is no publication for projecting populations till 2036 using Census 2011 data as of April 2018.
2. For the year 2011, the discrepancies range from 4% underestimation of the population of Bihar to a 6% overestimation of the population of Kerala. For all the states considered, the average discrepancy in population is 0.7% or 7.6 million higher than Census 2011 estimates.

population projections by the average family size projections. As average family sizes have been varying, the state-wise rural and urban average family size was projected based on the average family size trends between 2001 and 2011 as per the Census as it was the best available source.[3]

B.2 Estimation of energy demand

The fuel preference of households in 2015 is estimated based on the primary fuel used by households as reported in Census 2011, and the trends of fuel usage between 2001 and 2011 (Census, 2011). The projection of fuel adoption or penetration rates for the years 2016 to 2030 are described as part of the developed scenarios. The fuel penetration rates form the basis for demand estimation, cost estimation and assessment of health benefits.

Useful energy demand from a particular fuel is estimated by multiplying the number of people using that fuel with the annual 1046 MJ per-capita norm. Total energy demand for a fuel is arrived at by factoring in the efficiency of the corresponding cook stove. The magnitude of each fuel required is necessary to estimate costs, and is derived by dividing the fuel-wise total energy demand by the energy content of that fuel. The following formula captures how magnitude of fuel demand in a year is estimated:

$$\textit{Fuel Demand} = \frac{(\textit{\%Households Using Fuel} \times \textit{Number Of Households} \times \textit{Household Size} \times \textit{Per Capita Useful Energy Reqd})}{(\textit{Fuel Energy Content} \times \textit{Stove Efficiency})}$$

The efficiencies of various cook-stoves and energy content of various fuels are based on a review of various studies (Malla & Timilsina, 2014). For simplicity, it is assumed that all cooking based on electricity happens using efficient induction cook stoves. There is no improvement in efficiency of solid fuel traditional stoves over the analysis period, while there is a small improvement in the efficiency of kerosene stoves, and greater improvement in efficiencies of modern technologies such as gas-based and induction cook stoves. The efficiency trajectories do not change across scenarios. The efficiencies of stoves in 2015 and 2030 and the energy content of fuels used in the analysis are presented in Table 1.

Table 1: Fuel energy content and stove efficiencies assumed

Fuel specific cook stove	Stove Efficiency (2015)	Stove Efficiency (2030)	Energy Content
Biomass[4]	14%	14%	15.6 MJ / kg
Coal	10%	10%	17.5 MJ / kg
Kerosene	35%	39%	43 MJ / kg
LPG	55%	64%	45.5 MJ / kg
PNG	55%	64%	38 MJ / scm
Biogas	55%	64%	22.8 MJ / scm
Electricity	78%	91%	3.6 MJ / kWh

Source: (Malla & Timilsina, 2014) and Prayas projections

3. Similar to population projections, there is also a small discrepancy in projected household numbers. For the year 2011, the discrepancies range from 5% underestimation of households in Bihar to an 8% overestimation of households in Kerala. For all the states considered, the average discrepancy was a 3% underestimation of households compared to Census 2011.
4. In the case of biomass, the energy content is a weighted average of firewood, crop residue and dung. This is calculated separately for each state. The energy content for each biomass fuel is weighted with the state-wise number of households using fuel in 2011 to arrive at the average energy content for that state. It is assumed that the proportion of use of firewood, crop residue and dung will not change over time as people may not switch between traditional sources of fuel. The figure reported here is the weighted average for the country.

There are wide variations in estimations for useful cooking energy requirements in the literature due to differences in measurement, methodologies and dietary practices. Note that useful energy required is largely independent of fuel used, energy content of the fuel and stove efficiencies, though it is likely to vary across socio-cultural and economic classes and across regions (Ravindranath & Ramakrishna, 1997). It can also change over time as cooking and eating habits change, and incomes and use of cooking appliances (e.g. pressure cookers) change. There are no recent estimations in the Indian context which could have been used, and the best available Indian estimate is 947 mega-joules (MJ) per capita per year from 1985 made by the Advisory Board of Energy (ABE, 1985). Therefore, the estimate used in this analysis is an average of studies in developing countries which comes to 1046 MJ per capita per annum (Sanga & Jannuzzi, 2005). It is assumed that this average applies across the country and does not change over the period of the analysis. More granular and dynamic estimates can be arrived at as more data becomes available with more field studies. However, indicative analysis based on the average number of cylinders consumed by households using data from LPG service providers and informal surveys suggests that the useful energy required is likely to be somewhat lower than 1046 MJ.

B.3 Estimation of health benefits

B.3.1 Key Assumptions

While estimating the level of exposure to particulate matter pollutants from incomplete combustion of traditional fuels, the following assumptions have been made.

1. The level of HAP is affected by various factors such as the type of kitchen, ventilation, time of the day, quality of fuel and season. However, due to unavailability of data and for simplicity reasons, standard assumptions have been made about these factors across the country and over time.[5]
2. This analysis only considers the health impacts from using solid fuels for cooking, namely firewood, agricultural residue, coal, charcoal and dung cakes. The health impacts of kerosene use are not estimated. Similarly, health impacts of other uses of solid fuels (e.g. for space heating or water heating) are also not accounted for.
3. In the absence of data regarding particulate emissions for the different types of solid fuels, they are treated similarly and considered as one class, hereafter referred to as SFU (for solid fuels).
4. Diseases may take several years to develop after exposure to particulate matter. The model assumes cessation time lag where 30% of DALYs occur in first year of exposure, 50% are distributed evenly between years two to five, and the remaining 20% are distributed evenly between years six to fifteen. This assumption is based on the model proposed by US EPA (U.S Environmental Protection Agency, 2015)
5. The analysis does not control for altered risk of disease due to pollutant exposure before 2015 due to solid fuel use.
6. Emissions are only for cooking and not for other biomass burning in the house (space heating, water heating, preparation of cattle-feed, etc.)

5. It also depends on whether food is cooked indoors or outdoors. However, it is assumed that all households cook indoors as only 11.5% of rural households in the country reported cooking outdoors in 2015–16 (Ministry of Health and Family Welfare, 2017, p. 27)

B.3.2 Estimates of background disease burden for India

The Global Burden of Disease (GBD) projections provide health trends for baseline, optimistic and pessimistic scenarios for this period (Mathers & Loncar, 2006). The baseline scenario which considers 'business as usual' assumptions and derives its projections based on past trends was used for calculating annualised background DALYs for the diseases under consideration.

Since the DALY projections are available only at the WHO regional level, the population proportions of India in the South East Asian Region (SEAR) were applied to SEAR DALY projections to derive India specific DALY projections. This was done using the age- and gender-specific World Population Prospects projections for 2015 and 2030 (United Nations, 2015). In the absence of India-specific data, this is a good proxy since India contributes about 70% of the SEAR population.

B.3.3 Estimates of $PM_{2.5}$ exposure level

A single zone model, as illustrated in WHO's indoor air quality guidelines, has been used to estimate the 24-hour steady state concentration of $PM_{2.5}$ in the kitchen area from the emission rate of solid fuels (WHO, 2014; Johnson, Edwards, Morawska, & Smith, 2014). The single zone model had been used as early as the 1980s by (Smith, Aggarwal, & Dave, 1983) to predict kitchen concentrations from particulate matter resulting from cooking with solid fuels in India. The model is a simple construct requiring few assumptions and has been used widely in air pollution research (Johnson, Smith, Edwards, Nicas, Morawska, & Chiang, 2014). The model also accounts for parameters such as volume of air in the kitchen and fresh air rate from natural ventilation, compiled in the WHO guidelines from studies including India specific studies. Our analysis assumes that there is no direct ventilation mechanism with the stove and no loss of particulate matter onto room surfaces.

The $PM_{2.5}$ emissions from solid fuels is computed using the quantum of solid fuels used for cooking (whose estimation is described in Section B.2) and the $PM_{2.5}$ emission per kg of solid fuel used (SFU) from the WHO guidelines (Johnson, Edwards, Morawska, & Smith, 2014). These values are used in the single zone model to estimate steady state 24 hour $PM_{2.5}$ concentration. However, exposure to $PM_{2.5}$ is much greater for women and children than for men. Thus the exposure levels for men, women and children from 24 hour $PM_{2.5}$ concentration is estimated using average rates of exposure for men, women and children to $PM_{2.5}$ as reported in the Global Household Air Pollution Database Version 2.0 (Smith, et al., 2014).

The single zone model for estimating $PM_{2.5}$ concentration and most of the assumed parameter values are based on (Johnson, Edwards, Morawska, & Smith, 2014). CSS is the 24 hour steady state concentration of $PM_{2.5}$ in μg / scm, which is estimated as:

$$CSS = \frac{(1 - \varepsilon) \times G}{Q + \alpha \times V}$$

where

$\boldsymbol{G}$ is the emissions rate which is estimated from the amount of fuel needed for cooking, the emissions from the fuel and the time exposed to such emissions. In this analysis, it is assumed that 5.2 g of $PM_{2.5}$ is emitted per kg of biomass used. As most cooking is done at home, it is assumed that the time exposed to emissions is 24 hours.

$\boldsymbol{\alpha}$ is the Loss parameter due to particle deposition onto upper room surfaces. It is assumed that there is no particle deposition and $\boldsymbol{\alpha}$ is taken to be 1.

$\boldsymbol{\varepsilon}$ is the parameter which accounts for the presence of a chimney on the stove. In this case, it is assumed that the traditional stoves do not have chimneys and thus the value assumed is 0.

$\boldsymbol{Q}$ is the air exchange or air replacement rate which assesses the number of air exchanges per minute. For the purpose of the model, this is assumed to be 0.42 standard cubic metre (scm) per minute.

V is the volume of the room which is assumed to be 20 scm, which roughly corresponds to an 80 square feet kitchen with an 8-feet high ceiling.

B.3.4 Estimates of attributable disease burden under a scenario

Estimation of relative risks using Integrated Exposure Response (IER) curves

The burden of a disease attributable to Solid Fuel Use (SFU) is the portion of background DALYs of that disease that can be directly attributed to $PM_{2.5}$ exposure resulting from combustion of solid fuels. It is dependent on the proportion of population exposed to SFU and the risk of contracting the disease due to the exposure, measured in terms of the relative risk (RR) of the disease. Relative risk is the ratio of the probability of an event occurring in an exposed group to the probability of the event occurring in a non-exposed group. The IER curves discussed in the report are used to estimate the RR to particular diseases due to SFU for cooking. IER functions were first used as part of the Global Burden of Disease 2010 study (Lim, et al., 2012). They model risk data across a wide range of exposure to $PM_{2.5}$ from four sources of pollutants (ambient air pollution, household air pollution, active tobacco smoking and second hand tobacco smoking). For the purposes of this analysis, the risk of disease outcome at different $PM_{2.5}$ exposure values linked to household air pollution is used. IER based estimations are shown to have superior predictive power as compared to relative risk derived from systematic review and meta-analysis (Burnett, et al., 2014). Additionally, use of IER allows estimation of RRs for IHD and stroke, where such estimation is difficult if based on evidence from epidemiological studies. Based on the data from the Global Burden of Disease 2010 study, a model for IER curves for various diseases was developed in (Ochir & Smith, 2014). Table 2 presents these equations, where PM is the $PM_{2.5}$ exposure of women, children or men. There have been other estimates which also model IER curves for various diseases, but do not cover gender specific risks for all diseases considered in this study, and hence have not been used (U.S Environmental Protection Agency, 2015).

Table 2: Relative Risk Equations

Disease	Relative Risk Equation
IHD	RR = 0.9564*log (log (12.98+PM))
COPD	RR = sqrt(1.398+(0.00638*PM)+(-24.08)/(54.74+PM))
ALRI	RR = (9304+(27.36*PM)+(3.328*PM^2))/(8704+(38.75*PM)+(PM^2))
Lung Cancer	RR = 1.015+(0.00596*PM)+(1.781e-8*PM^3)+(5.276e-15*PM^5)+ (-1.047e-5*PM^2)+(-1.557e-11*PM^4)
Stroke	RR = 2.125+(-172.9-19.42*PM)/(227.9+PM^2)

As family sizes in urban and rural areas in different states are different, the RRs for urban and rural areas for different states are different. Over the years, the relative risks also change since the amount of solid fuel burnt changes. Hence the model estimates relative risk for each year in the analysis. Similarly, as the $PM_{2.5}$ exposure is different for men, women and children, there are different RR estimates for each of these categories. Thus using IER curves, the model is able to arrive at disease and gender specific relative risks on an annual basis for rural and urban areas in each state for men, women and children.

The national average RRs for all the diseases in 2015 and 2030 are given in Table 3. As can be seen, the RRs for women to get Lung Cancer, and children to get ALRI are highest, while for any given disease, RR for women is higher than for men given their greater exposure to the particulate emissions.

Table 3: National average of Relative Risk ratios for various diseases by gender in 2015 and 2030

	2015			2030		
Disease/Gender	**Men**	**Women**	**Children (0-4)**	**Men**	**Women**	**Children (0-4)**
IHD	1.74	1.82	N.A	1.72	1.80	N.A
COPD	2.09	2.52	N.A	1.99	2.38	N.A
Lung Cancer	2.73	3.51	N.A	2.55	3.26	N.A
Stroke	2.08	2.10	N.A	2.08	2.10	N.A
ALRI	N.A	N.A	3.14	N.A	N.A	3.11

Note: N.A. denotes not available

Estimation of the Attributable Fraction and Attributable Burden

Population Attributable Fraction (PAF) is a fraction of the disease burden attributable to SFU for the entire population, exposed as well as unexposed (Wilkinson, Smith, Davies, Adair, Armstrong, & Barrett, 2009). PAF is derived from the proportion of population exposed to SFU and the RR of the disease due to the exposure. When PAF is applied to background DALYs, it provides the attributable burden of the disease (i.e DALYs of a disease attributable to solid fuel use) in the entire population. The following formula is used to calculate PAF for each disease, state and year by rural and urban regions (Desai, Mehta, & Smith, 2004), where the proportion of population exposed to SFU in a particular year and rural or urban area of a state is based on the particular scenario under consideration.

$$PAF = \frac{((\text{Population exposed } (\%) \times RR + \text{Population unexposed } (\%))\text{-}1)}{(\text{Population exposed } (\%) \times RR + \text{Population unexposed } (\%)\ )}$$

The burden of disease in terms of DALYs attributable to SFU is then calculated by applying PAF to background disease burden.

$$DALYs_{\text{attributable to SFU}} = PAF \text{ x } DALYs_{\text{background}}$$

Annualized averted DALYs (aDALYs) for each scenario are calculated as the difference of DALYs attributable to solid fuel use between an intervention scenario and the Baseline scenario for that year.

$$aDALY_{\text{intervention scenario}} = DALYs_{\text{Baseline scenario}} - DALYs_{\text{intervention scenario}}$$

Aggregate aDALYs for a scenario is just the sum of aDALYs for the scenario over the analysis period.

CEFTI accounts for the cessation lag in the DALYs of IHD, COPD, lung cancer and stroke attributable to SFU as done in previous health literature. (U.S. Environmental Protection Agency, 2010; Ochir & Smith, 2014).

B.4 Estimation of costs

For most fuels, a national level fuel cost is estimated with some exceptions. In the case of biomass, an assumption is made about the share of households purchasing biomass, and cost calculations only include the households buying biomass. In the case of biogas, two kinds of systems — either family type or community type — are considered. For biomass, cost estimations have been made separately for rural and urban categories and for the states being analysed, while the cost of electricity is estimated separately for each state.

Only two of the cost assumptions vary based on the scenario, with the price of biogas being lower for the Multi-Fuel and SDG scenarios while the price of PNG is higher in the SDG scenario due to a greater share of imports. Costs of other fuels do not vary across scenarios.

There are two major components to the costs incurred — fixed or one-time costs and recurring or annual costs. The former refers to costs that are incurred at the time of switching to a new fuel and includes elements such as connection costs, capital costs and stove costs[6]. The latter refers to the costs incurred on purchasing the required fuel (including the distribution cost of the fuel). These two categories are described in detail below.

B.4.1 Fixed costs

This includes the one-time lump sum connection cost, payments for cook stoves depending on the lifespan of the stove, and any additional capital expenditure.

B.4.1.1 Stove Cost

Except in the case of LPG, where a large number of connections are being disbursed which may not translate to primary fuel use, stove costs are determined for the primary fuel used for cooking. It is assumed that households have only one cook stove for primary fuel consumption. The stock of stoves in the base year (2015) is expected to retire over the lifespan of the corresponding stove. For example, if the lifespan of a PNG stove is 15 years, then 1/15th of the current stock will retire each year for the next 15 years and addition of new primary users will add to the stock of stoves. The number of LPG stoves added in a year is estimated to be the same as the number of new connections (not users) in that year plus the number of new stoves purchased to replace the stoves that retired in that year.

The lifespan and price of various stoves considered for the analysis in the base year are specified in Table 4. All estimations are based on price and product information from various manufacturers and vendors in India. The most popular stove models were often used to estimate prices. For example, a basic two hob gas-based cook stove is assumed for LPG, PNG and biogas stoves as most households own such stoves. Similarly, in case of electricity, biomass, coal and kerosene, stove price was estimated for a single hob stove.

Table 4: Price and lifespan of stove by stove type (2015)

Stove type	Price of stove (Rs.)	Lifespan of stoves (years)
Biomass	120	1
Coal	200	3
Kerosene	900	5
LPG	1500	15
PNG	1550	15
Biogas	1550	15
Electricity	1500	10

Source: Authors' compilation from various sources

It is assumed that real prices of stoves will change over time based on material prices and technological changes. For projecting future prices, the price increase for all stoves, except biomass

6. Stove costs are strictly not one-time as stoves need to be replaced once their lifespan is over. This is accounted for in the model but for simplicity they are mentioned as fixed costs here.

stoves, is linked to the projected increase in base metals price index as per the World Bank as they are mostly assumed to be metallic. Due to the lack of a better estimate, the biomass stove price is linked to the increase in the non-energy commodities price index (World Bank, 2015).

The total cost of stoves for any year in the analysis was estimated by multiplying stove prices with the number of new stoves and replacement stoves purchased in that year.

B.4.1.2 Connection costs

In addition to the stove costs, a switch to fuels such as LPG, PNG and electricity would also involve a one-time connection cost. The connection cost entails the network investment costs recovered for the additional connection.

With the advent of PMUY, the Government of India has targeted the disbursal of 10 crore new LPG connections (of which 5 crore would be subsidised) by 2019. This massive push to increase connections will have cost implications. However, mere roll-out of connections may not translate to sustained use due to price, access and availability of alternate fuels (Dabadge, Josey, & Sreenivas, 2016). In other words, the connection costs will be incurred even though they may not translate to sustained use and commensurate health benefits. In order to estimate the costs due to connection rollouts, trajectories for LPG connection rollout were projected separately from its use as a primary fuel. These projections were based on the actual number of connections in 2015 and 2016, and the possible increase in the number of connections due to PMUY (PPAC, 2015b). The connection numbers vary slightly between the Baseline and intervention scenarios depending on the extent of success of PMUY, and whether there are focused efforts on supply infrastructure after PMUY. The increase in connections will impact overall costs through connection costs and number of LPG stoves.

As electricity is a fuel with multiple uses, it is safe to assume that households would have availed of an electricity connection irrespective of their preference to switch to cooking with electricity. Therefore, connection costs are not considered for electricity. Similarly, setting up a city gas distribution network involves significant costs. However, not all of these costs are counted in the PNG connection costs, as the city-wide network can also support other uses (for example, CNG for transport and commercial PNG use), and it is assumed that such investments are made by city gas operators to extend their network through the urban area. In the case of LPG, which is distributed using trucks running on roads, the cost of roads is not counted as part of the connection costs, since the road has many other uses of which LPG transport is just one. Therefore these elements of capital requirement are not considered in the analysis.

Connection cost for LPG in 2015 is assumed to be Rs 1,900 based on what is charged by the Oil Marketing Companies, which are the predominant LPG service providers (PIB, 2015). In 2015, the average cost of a PNG connection was assumed to be about Rs 6,500 based on connection charges published by various service providers in 2015. Future projections of both LPG and PNG connections are linked to the projected price index for base metals (World Bank, 2015).

B.4.1.3 Capital cost for biogas

The methodology for estimating fixed costs for biogas is different as this is the only fuel which does not require a large network to operate but is still reasonably capital intensive. They also incur operation and maintenance expenditure on an annual basis. This is estimated as a proportion of the capital expenditure of the plant which needs to be incurred on an annual basis. The cost estimations are made separately for community and family size plants. For both types of plants, the capital expenditure and operation and maintenance (O&M) expenditure together account for fixed costs. The estimated capital expenditure is annualised over the lifespan of the plant as bank credit is available for the investment needed for such projects and payments can be made on an annual basis. This annualised amount is translated to a per standard cubic metre (scm) cost based on the requirement of biogas in the households that the plant can serve, to make further calculations simpler. Table 5 summarises estimates and assumptions made to assess these costs for 2015, based on estimates provided by biogas plant developers. Future projections are linked to the projected real price index for base metals, as metals are expected to be one of the significant inputs in biogas infrastructure (World Bank, 2015).

Table 5: Assumptions for biogas capital cost in 2015

Particulars	Unit	Family size plant	Community size plant
Capital cost	Rs	26,000	16,00,000
Lifespan	Years	20	30
Biogas needed per HH per day (approximate)	Scm	1.06	1.06
Annualised cost assuming 10% discount rate	Rs	3,054	1,69,727
Number of households served	Number	1	80
Annualised capital cost per unit	Rs / scm	7.88	5.48
O&M as a % of capital cost	%	2%	10%
Total fixed cost per unit	Rs / scm	8.04	6.02

In the Multi-Fuel and SDG scenarios, due to a significant technology push, policy focus and the emergence of a robust supply chain, the capital costs of both family and community sized biogas plants are assumed to be lower than those for the Baseline and PMUY scenarios, with SDG scenario costs being lower than those for the Multi-Fuel scenario. With a greater policy push and uptake of community sized projects, the potential for reducing costs will also increase. Thus, while the total fixed cost for biogas plants in 2030 increases to Rs 10.9 / scm and Rs 8.2 / scm for family sized and community sized plants respectively in the Baseline and PMUY scenarios, they only reach Rs 8.05/ scm and Rs 6.55 / scm respectively in the Multi-Fuel scenario, and Rs 7.4 / scm and Rs 6.11 / scm respectively in the SDG scenario.

B.4.2 Running costs

Annual running costs include variable costs such as fuel costs and distribution costs for fuels with large network infrastructure (e.g. LPG, PNG and electricity). The cost of fuels required is determined by the quantity of each fuel required and the price of fuel estimated for the year based on real price growth assumed for each fuel till 2030. Future price projections for all fuels except biomass, coal and biogas are based on various global real price indices projected by the World Bank till 2025, potential variation in exchange rates between the dollar and the rupee, and other relevant parameters (World Bank, 2015). The projections in the 2025–2030 period are based on the annual growth rates in the 2020–2025 period. As the World Bank projections are in US dollars, the model needs to also assume how exchange rates would vary over the model period. The long-term inflation target differential between the two countries[7] is used to estimate long-term exchange rate variations. Thus, an annual 2% depreciation in the Indian Rupee - US Dollar exchange rate is assumed annually till 2030. Modern fuels with network infrastructure like PNG, LPG and electricity also have significant distribution costs. The treatment of these costs for the various fuels is explained in the sections below.

B.4.2.1 Biomass

In case of biomass, it is assumed that only a proportion of households purchase biomass for cooking. It is assumed that about 66% of urban biomass users and 56% of rural biomass users resort to market purchase for fuel supply in 2015 (Desai & Vanneman, 2016; CEEW, 2015). Given increasing alternative uses of biomass, likely loss of forest cover and considering its limited supply, the proportion of biomass users who purchase the fuel will increase over time. Therefore, it is assumed that the proportion of biomass users purchasing it increases to 81% of urban biomass users and 74% of rural biomass users by 2030 in all scenarios. There are separate rural and urban price estimates for each state. The estimates used are based on rural and urban average of firewood prices for different states reported in the 68th NSS consumption expenditure round for the year 2011–12 (NSSO, 2014). The prices were adjusted to 2015 real price estimates based on the price indices released by the Central Statistical Organisation (CSO) (CSO, 2012). Firewood prices were considered as there is no consistent, disaggregated data available for the price of agricultural residue and dung, which are also less likely to be traded for direct domestic consumption. Moreover, as firewood accounts for 74% of biomass based cooking fuels, this price is a good proxy (Census, 2011). The inflation adjusted average annual growth rate of price of firewood between 2004–05 and 2011–12 was about 2.4% (NSSO, 2014) (NSSO, 2007). This was used to arrive at the annual price of biomass for the 2015–2030 period.[8]

B.4.2.2 LPG

LPG fuel costs for the year 2015 are based on the price break-up provided by the Petroleum Planning and Analysis Cell (PPAC)[9] for supply in Delhi (PPAC, 2015a). This price includes fuel price as well as freight and import charges. Future projections are linked to the projected price index for crude oil by the World Bank (World Bank, 2015) and adjusted for rupee-dollar exchange rate variation.

The other running costs include the costs of transport of fuel via pipeline and freight, bottling expenses, transportation cost and distribution costs. These were accounted for as per estimates of the PPAC for Delhi (PPAC, 2015a). Future projections of distribution costs are linked to the projected real price index for base metals (World Bank, 2015).

B.4.2.3 Biogas

In the prevailing situation, dung is also typically not purchased. Thus, biogas projects in the past have relied on the ownership of cattle and the use of dung available to the households. However, most projects including family sized projects have not been sustainable due to a lack of consistent and adequate supply of dung. Therefore, for this analysis, dung for biogas is assumed to be purchased from a viable dung market. This is because cattle ownership will otherwise restrict penetration of family sized biogas plants to only affluent farmers. The average cattle holding of owners of functional biogas plants is about 5.23 cattle (Planning Commission, 2002), which is beyond the reach of the majority of rural households.[10]

The estimation also looks at the uptake of two types of biogas systems— the family sized system with a capacity of 2 m^3, and the community sized plant with a capacity of 85 m^3 which can meet the needs of about 80 households.[11] Family sized systems are predominant today but the share of cheaper community sized systems can increase with the right institutions, business models, policy

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7. India has a long-term inflation target of 4% while the US has a long-term inflation target of 2%.
8. The growth rate is assumed to be constant to account for the interplay of factors which could influence prices. Factors such as overharvesting, poor rainfall and agricultural distress can drive prices up, while the formation of organised biomass markets and its increased availability due to reduced use in cooking and for other purposes can reduce prices.
9. Petroleum Planning and Analysis Cell is the data and analysis wing attached to the Ministry of Petroleum and Natural Gas.

interventions for behavioural change and investments. The model provides a different cost treatment for the two biogas plant types.

The price of dung may be lower for community sized projects than family sized projects due to bulk procurement. Currently the price of dung for community sized plants is almost half the price for family sized plants. However, with the increase in the uptake of family sized biogas plants, it is assumed that increased demand will broaden, unify and deepen dung markets, thus reducing the retail price as well. The price of dung for family sized projects for 2015 is based on the estimates provided by project developers, while for community sized projects, it is based on prices reported by operational biogas projects (Jamwal, 2003; Vijay, 2014). These are about ₹ 1 / kg for the family sized plant and ₹ 0.5 / kg for community sized plants.

For the Baseline and PMUY scenarios, the price of dung for both family sized and community sized projects till 2030 is linked to the overall inflation-adjusted projected growth rate of dung prices. The growth rate used is based on the growth rate of the price of dung as reported by the CSO in the recent past, and adjusted for overall inflation using the Consumer Price Index (CPI) (CSO, 2012). In the Multi-Fuel and SDG scenarios, which have a significant uptake of biogas, the maturing of markets and increased uptake through bulk procurement result in no increase in the price of dung for community sized plants. For family sized plants, the price of dung in the Multi-Fuel scenario in 2030 is 20% lower than the price in 2015, while in the SDG scenario, the price of dung for family sized plants in 2030 is 40% lower than the price in 2015.

B.4.2.4 PNG

PNG prices are based on natural gas prices as decided by the Government of India based on benchmark international natural gas prices on a gross calorific basis in US dollars per Metric Million British Thermal Unit (MMBTU) (PPAC, 2014). The price per volume of gas is estimated in Rs / scm terms. To this price, the approximate average cost of pipeline and transportation of gas to the city network is added. This cost is estimated on the basis of the pipeline transportation costs of the Hazira-Vijaipur-Jagdishpur (HVJ) pipeline as charged by GAIL from June 2014 to June 2015 (CERC, 2015). Future projections are linked to the projected World Bank price index for natural gas and long-term variation in the Rupee-Dollar exchange rate.

The supply and distribution cost and marketing margin is as per proportions reported by Gujarat Gas, India's largest PNG distributor (Gujarat Gas, 2015). Future projections of PNG distribution costs are linked to the projected price index for base metals (World Bank, 2015), since the bulk of PNG network costs would relate to the cost of metals for laying the distribution network.

In the SDG scenario, there is a significant penetration of PNG, and given India's limited domestic gas reserves, the country would have to import natural gas for PNG supply too. Therefore, this scenario assumes an increasing proportion of imports for meeting PNG demand over the years, reaching around a quarter of total PNG demand in 2030. The 2015 price for imported natural gas is based on the average price of LNG imported in 2015–16 (Ministry of Petroleum and Natural Gas, 2016), and projections are based on the natural gas price index adjusted for exchange rate variations (World Bank, 2015).

10. Per household ownership of cattle and buffalos is low in India at 1.71 per rural household (DAHD, 2014). Further, the distribution of livestock is unequal with only 25% of landless farmers owning cattle whereas about 70% of farmers with a landholding greater than 2 hectares own cattle (Jumrani & Birthal, 2015)
11. Even though plant sizes are assumed to be standard, shrinking household size would imply that biogas requirements per household will reduce correspondingly. This is accounted for in the model.

B.4.2.5 Electricity

The per unit cost of electricity was estimated by projecting power procurement and distribution costs in each state based on data collated by the erstwhile Planning Commission (Planning Commission, 2014). The projections for each cost component was done separately as power procurement growth rates depend on fuel prices and can be volatile, whereas distribution costs show a lower, steady increase. Future projections for power procurement costs are linked to the growth in projected price index for energy commodities, and distribution costs are linked to the growth in the projected real price index for non-energy commodities (World Bank, 2015).

B.4.2.6 Coal and Kerosene

As coal is predominantly used for cooking in the states of Odisha, Jharkhand, Chhattisgarh and West Bengal, the weighted average price for coal in these states was used for national prices. These prices for 2011–12 were as reported by the National Sample Survey Organisation (NSSO) (NSSO, 2014). The 2015 prices were estimated from the 2012 prices using the coal and charcoal combined CSO price indices (CSO, 2012). It is assumed that real coal prices stayed the same in the medium term after 2015, as recent price trends show a negative growth after adjusting for inflation (Ministry of Coal, 2016; CSO, 2012). Long term projections for coal were not used, as the use of coal for cooking is assumed to reduce drastically in all scenarios.

Kerosene costs for the year 2015 are based on the price break-up provided by the PPAC for Mumbai (PPAC, 2015a), while future projections are linked to the projected price index for crude oil (World Bank, 2015) and the likely variation in the Rupee-Dollar exchange rate.

B.4.3 Determining cost-effectiveness

In order to assess cost effectiveness of a particular scenario, the incremental cost per aDALY is calculated across the years for rural and urban regions in the country. The CHOICE threshold used in the model cannot be used to assess cost-effectiveness at the state level due to the lack of state level GDP projections and disease burdens in India. Therefore, this analysis is only done at the national level. The cost-effectiveness methodology and the CHOICE model have some limitations (Eichler, Kong, Gerth, Panagiotis, & Bengt, 2004; WHO, 2003), but given data availability constraints, this was the best available option for this analysis. The GDP estimate for calculating the CHOICE threshold for the year 2015 was taken from the Central Statistical Organisation (PIB, 2016; RBI, 2016). The GDP was then projected till 2020 based on growth rate projections as per the International Monetary Fund's World Economic Outlook (IMF, 2017). The projections in the 2020–2030 period were based on the trend in the 2015–2020 period.

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