Scenario Analysis of GHG Emissions from the Built Environment of Developing Countries



The Indian residential sector as a case for illustration

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Front cover images from left to right:

1. A slum upgrading building under construction in Mumbai
   City/Town: MUMBAI
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2. An LPG cylinder now costs Rs 883
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   Posted by Paige McClanahan, in New York
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Preface

I would like to thank my supervisors for all the help and support, especially Donovan for all the good advice and friendship. Also, I own a lot to Martina for its guidance and the whole Department of International Climate Polices and Buildings at Ecofys Cologne for being really good mates and support my research with their skills. Thanks to Ecofys for granting me to work with such an outstanding group of professionals.

Thanks to Martin and Evert, my supervisors from the Utrecht University, for the patience and valuable insights into the Indian reality. Also to Vassilis, for all the information he has provided to me.

I want to thank my friends for all the good moments we share and, finally, to my family who has always stood by me.

This thesis is for all of you.

Abstract

Buildings are one of the main end-uses of energy and are responsible of roughly a third of total GHG emissions. Although the building sector presents the largest and most cost effective emission reductions possibilities, this sector is currently characterized by an oversized carbon footprint. Following current trends, GHG emissions from building are expected to double by 2050. Developing countries lead the growth of the building sector as it is closely coupled with demographic and economic drivers. These and other variables can be evaluated by their influence on energy demands and thus, can project trends on GHG emissions from the use-phase of buildings.

Especially in developing countries, the residential sector accounts for most of the energy consumed in buildings. Three different categories of mitigation measures can be used to make this sector more energy efficient: a better insulation of buildings, fuel switching to more convenient fuels and more energy efficient technologies. Different indicators are used for understanding their potential impact for curbing GHG emissions.

India presents a large increase of population coupled with a high, although unequal, economic growth. Due to this fact the Indian residential sector could harvest important results from the implementation of the three categories of measures. Three different scenarios were constructed in order to first evaluate how Indian buildings energy demands could develop in the absence of mitigation measures. Other scenario shows the most important government initiatives targeting the residential sector. A third scenario evaluates further possibilities for curbing the expected high increase of GHG emissions from the Indian residential sector.

Contents

List of Figures

List of Tables

Abbreviations

GHG:	Green House Gases	LPG:	Liquefied Petroleum Gas
MDG:	Millennium Development Goal	NG:	Natural Gas
SWH:	Solar Water Heaters	CDM:	Clean Development Mechanism
ICL:	Incandescent Bulb	FL:	Fluorescent Tube Lamp
CFL:	Black Carbon Lamp	LED:	Light-emitting Diode
HDD:	Heating Degree Days	CDD:	Cooling Degree Days
U-value:	maximum thermal transmittance [W/m2/K]	SHGC:	Solar Heat Gain Coefficient
BC:	Black Carbon	PM:	Particular Matter
ICS:	Improved Cookstove	COP:	Coefficient of Performance
MEPS:	Minimum Energy Performance Standards	EEI:	Energy Efficiency Index
LCDs:	Liquid Cristal Displays	SEER:	Seasonal Energy Efficiency Ratio
CRT:	Cathode Ray Tube		

Conversion Units

1 MJ =	10^6 Joules	specific heat of water =	1,163 Wh/K/litre
1 Kgoe =	41.868 MJ	1 Kg of Wood =	17.6 MJ (Bailis et al., 2007)
1 KWh =	3.6 MJ	1 Kg of Coal =	18.4 MJ (Bailis et al., 2007)
1 litre Kerosene =	37.6 MJ (Mills, 2003)	1 Kg LPG =	47.3 MJ (Blok, 2007)

1 Introduction

The building sector is responsible for 32% of global energy use and contributes to 30% of global GHG emissions. At the current pace, GHG emissions from buildings will more than double by 2050 (IEA, 2012). Developing countries were historically characterized by low economic growth which resulted in low demand for energy services in this sector. Still, these countries accounts for most of the energy consumed in buildings and, due to economic and demographic growth, some developing countries are now seen as main contributors to energy consumption and GHG emission upsurges (IEA, 2011e).

In Industrialized countries, the amount and intensity of energy services demanded in buildings are reaching saturation levels, in the sense that human and, in the case of the service sector, economic energy needs are fully satisfied. For the sake of a more equal international development, developing countries should keep progressing as to finally reach a convergence with industrialized countries turning into a similar energy performance of buildings.

Considering this framework, how developing countries shape the development path of this sector has become a global concern. Although the Fourth Assessment Report of the IPCC (2007) shows buildings as the main contributors in the medium term to the largest and most cost-effective mitigation measures, most of the currently existing building stock has an oversized carbon footprint. This fact means that this sector has plenty of room for improvement. A recently published report of the UNEP (2011) estimates the total emission reduction potential of the building sector to 1.4 to 2.9 GtCO2e/year.

Developed countries are complying with this potential mainly through the retrofitting of existing building stock and regulation of technologies performance. In the case of developing countries, showing high building construction rates, the lack of energy conservation policies could bring about a “locking in” effect whereby new buildings are not as energy efficient as it could be achievable with the implementation of building energy standards (UNEP, 2009). Therefore, it could be missed a great opportunity for curbing GHG emissions.

This concern boosts initiatives helping developing countries to set new policies and other measures promoting a more sustainable development of the building sector. Green growth can be embodied in the case of buildings in better insulation materials, fuel switching to more convenient fuels and energy efficiency regulations. A comprehensive strategy for their implementation must be backed up by meaningful indicators defining energy and GHG emissions intensity of technologies as well as projecting buildings performance.

The main objective of this report is to explore how the building sector of developing countries could develop based on the expected trends in economic and demographic growth. This report tackles three different energy and GHG scenarios. A baseline scenario departs from historical data compiled and projects the outcomes as keeping the same track of development of the last years. The first mitigation scenario comprises the most important actions that are being undertaken by the government and based on their expected impact it constructs a more realistic, and probably optimistic, scenario for the building sector of the analysed country. A more aggressive third scenario is been underpinned by best case examples as the means for aligning the case study to international best practices.

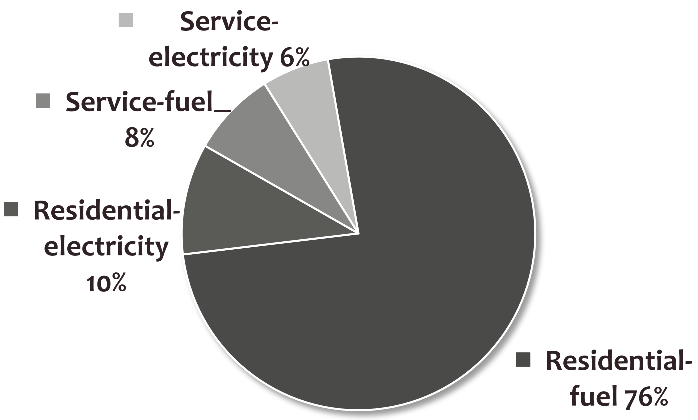

Figure 1 Breakdown of primary energy use in buildings of non-OECD countries. Adapted from IEA Energy Balances, 2009

The increase on energy and GHG emissions from the building sector is observed in both the commercial and the residential sector. The non-residential sector, hereafter expressed as the service sector, consumed in 2005 approximately a third of the world total primary energy (ECOFYS; 2008) and tends to have a more important role in advance stages of economic development. Among developing countries, however, the residential sector represents the lion share of buildings energy demands. Figure 1 shows that the residential sector accounts for more than 85% of the primary energy flowing to buildings. Therefore, this report is focused on the residential sector as presenting the highest potential for reducing GHG emissions.

Also, the IEA Energy Balances (2009) shows that over half of the fuel used in the residential sector of developing countries is biomass and waste. The use of biomass as the main fuel in households is, along lack of access to electricity, the main indicator of energy poverty (IEA, 2009). China and India population are typical representations of this phenomenon. In rural areas of India, almost 90% of the population rely on biomass as the main fuel for cooking and heating energy demands (Pachauri and Jiang, 2008).

In India, at least two tiers of development can be extracted from the analysis of the residential sector. On the one hand, the demand for better living standards of a growing middle class is represented by the penetration of modern forms of fuel, mainly LPG, and impressive market sales of electric appliances. However, energy poverty is an acute problem for the vast majority of Indian households. Moreover, the impressive building construction rates pose a unique opportunity for the long-lasting benefits of building insulation measures.

Therefore, the Indian residential sector is presented as the case for illustrating the advantages and some barriers that may be encountered during the implementation of the three major categories of mitigation measures that can be undertaken in the built environment of developing countries: Built envelop, fuel switching and energy efficiency measures.

This research paper intends to show demographic and economic factors as the main drivers of energy consumption from the built environment. Building occupants uses different technologies as means for satisfying energy needs. Therefore, the technology effect plays an important role on how benefiting from energy services will affect future energy demands and, consequently, pollutants emitted to the atmosphere. In this context, the different scenarios constructed, in this case for the analysis of the Indian residential sector, can be used for defining an ambitious strategy which includes a universal access to modern forms of fuel and identifies measures lowering the demand of energy and promotes the use of low carbon technologies in the built environment.

1.1 Problem definition and research questions

This report tackles the use of energy in the built environment and how GHG emissions may develop from its use. Therefore, the main research question represents the expected output of this research:

- **How could greenhouse gas emissions for the built environment develop in developing countries?**

In order to answer it, other sub-questions describe the expected development of my research:

  - How can the built environment be modelled?
  - What variables have the biggest impact on CO2 emissions from buildings in developing countries?
  - How can CO2 emissions be reduced by the use of different mitigation actions?
  - How can mitigation scenarios be constructed in relation to the variables and mitigation actions studied?

The main outcomes of the report were analysed in an excel template in which I am gathering main input data required for predicting the expected energy and GHG emissions developments in the residential sector. This input data represents the main variables affecting energy demands of buildings. Also, this template has been populated with main technologies used for the conversion of energy into energy services and main indicators of their performance. Mitigation measures can be modulated with regards to the year of implementation and their expected outcome. As a result of the analysis of those technologies, it can be addressed the potential impact of different mitigation measures.

1.2 Structure of the Report

Chapter 2

Chapter 2 presents the methodology followed for fulfilling the requirements of this research. It reviews the type of information compiled and its presumed effect in the energy analysis of the built environment. It also explains how the fuel mix used in the analysed country is expected to develop in the future and how mitigation measures are expected to impact GHG emissions paths.

Chapter 3

Chapter 3 is an overview of the main characteristics describing the residential sector of developing countries. The different energy services which are met in buildings are analysed with the objective of disaggregating the energy analysis into the different uses of energy in buildings.

Chapter 4

Chapter 4 describes the GHG mitigation measures for the building sector, thereby distinguishing three different categories. These categories are described in order to better understand the different impact from their implementation.

Chapter 5

Chapter 5 presents the Indian residential sector as a case study for the GHG scenario analysis. In this chapter, main characteristic of the Indian residential sector are presented as a prior step before the impact of different mitigation measures can be analysed

Chapter 6

Chapter 6 presents the results of the GHG scenario analysis conducted for the Indian residential sector.

Chapter 7

Chapter 7 discusses meaningful outcomes of the mitigation actions constructing the mitigation scenarios. Also, it is presented different indicators for analysing the impact on energy and GHG emissions intensity. Also, this chapter presents the sensitivity analysis of the main variables used for studying the Indian residential sector.

Chapter 8

Finally, chapter 8 presents the main conclusions extracted from this report. Thereby, the research questions are answered and also it is recommended further research possibilities.

2 Methodology

As most of the bottom-up statistical models, this research uses regression techniques in order to compute the relationship of energy trends and economic and demographic variables. Different mitigation measures are presented in order to increasing the efficiency of the energy system and achieve GHG emission reductions. The analysis of energy consumed in Figure 2 shows a schematic representation of the blocks used for constructing the different scenarios presented in the report.

2.1 Energy trends

Energy requirements are affected by exogenous factors as a result of the, so called, ASI equation, composed of three different effects –Activity (A), Structure (S) and Intensity (I) effects– (Isaac and van Vuuren, 2008), and the efficiency of conversion to the energy services demanded by building occupants. The equation representing the final energy use in buildings is expressed as follows:

Equation 1 $$E = A * S * I_{ij}/\eta_{ij}$$

Where the subscript i refers to the type of fuel used and j represent each energy service.

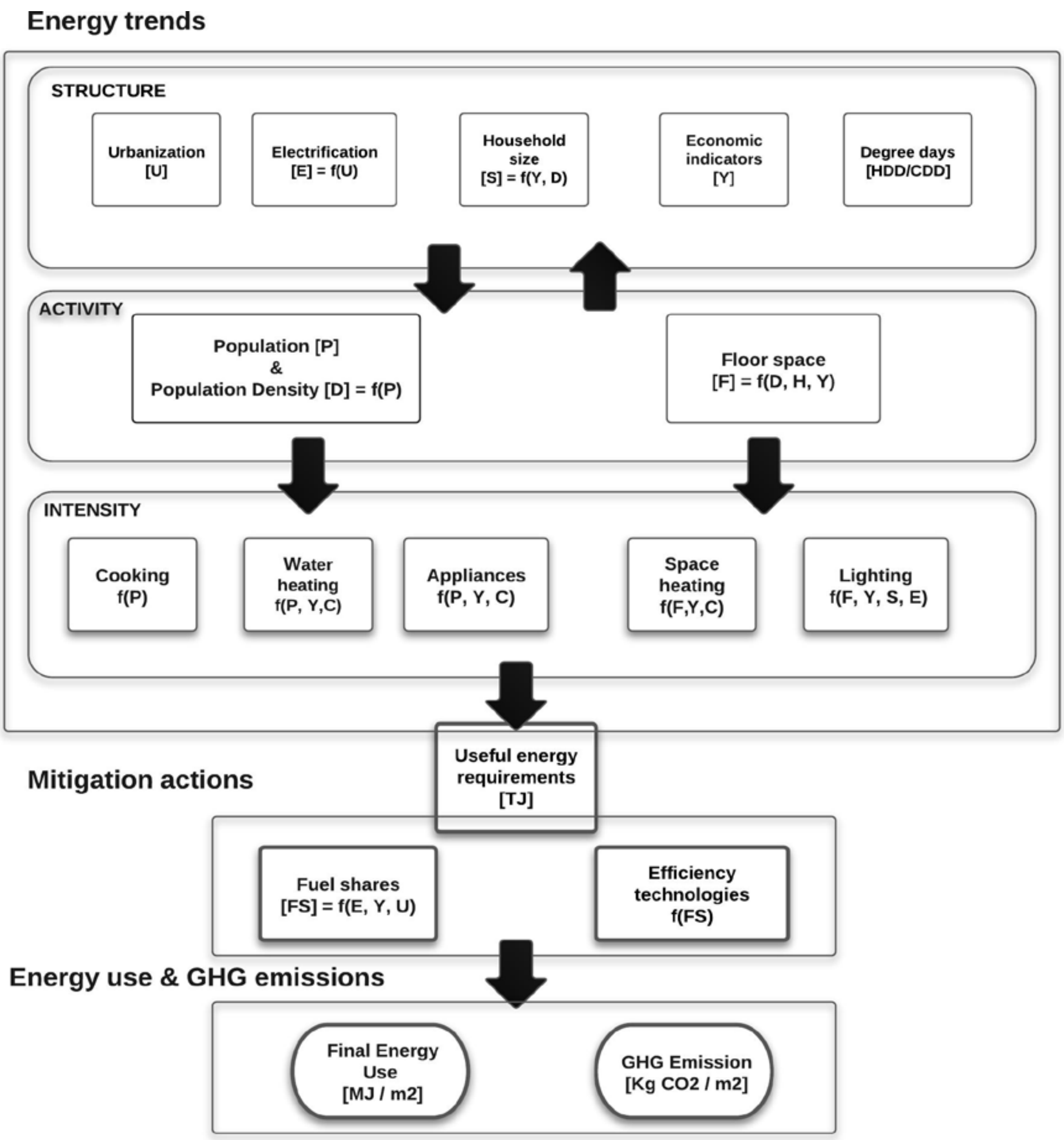

Figure 2 Schematic representation of main factors analysed. Adapted from: van Ruijven et al., 2011

2.1.1 Activity effect

Activity effects (see Figure 2) are indicators of the overall volume of activities in the sector (Blok, 2007). Population is used in this report as the main indicator of the level of activity as they dictate the expected growth of the building stock and defines the energy intensity required. Other indicator used for analysing the activity effect is floor area

(Figure 2), measured in square meters. These two factors are expected to influence functional uses of energy in the residential sector. Cooking energy use is treated as a constant against population. In this report, energy used for lighting and space heating is determined by the total floor area to be either illuminated or heated. All other functional uses of energy are analysed by their respond to synergies between activity and structural factors.

2.1.2 Structural effect

Structural effect (see Figure 2) represents exogenous factors explaining how the volume of activity is expected to change over time. Some of the most important indicators are presented in monetary terms. Household income growth is expected to influence other important variables used to model the residential sector. Therefore, economic growth is used as the pattern for projecting changes in other structural effects. Measured in income per capita, or household expenditure, economic indicators are used for forecasting changes in floor space availability, household size, and the expected increase on the demand for hot water and affordability of new appliances. This correlation is differenced by income quintiles as this method represents, with a higher certainty, different lifestyles. The PovCalNet, managed by the World Bank, has been used as the source for sorting rural and urban population in groups of similar income levels.

Household size is the number of people living in the same dwelling. Except for highly density populated countries, the observed trend leads towards less occupied households which can turn into higher household income and more floor area per capita available.

Other important effect is the amount of households with access to electricity and thus, the access to energy services such as electric lamps and appliances. Climate conditions, measured in heating and cooling degree days, are expected to dictate heating and cooling requirements.

Finally, all the factors affecting the residential sector show important differences in relation to urban and rural environment, especially in developing countries. This factor is expected to contribute to the fuel mix used in households as the result of the high accessibility of modern fuels in urban centres.

2.1.3 Intensity effects

Intensity effects (see Figure 2) embody the amount of useful energy required per unit of activity (Isaac and van Vuuren, 2008). Useful energy is that minimum required for providing tap hot water or cooking a meal. It differs with the other term many times repeated in this report which is final energy use. Final energy use is the total energy entering the device rendering an energy service. Therefore, it is discounted the fraction of energy loss through its conversion to an energy service. This discounted value is defined as the technology effect which describes technologies' energy efficiency.

2.2 End-use energy & GHG emissions

This report disaggregates energy flows to energy services rendered in the residential sector which are: cooking, water heating, space heating and cooling, lighting and the use of other electric appliances. Different approaches are used for calculating final energy use for each of those functional uses. These are explained in the Sectoral Analysis Chapter whereas main equations applied are provided in the appendix to this report.

The way to analyse energy services can also depend on the type of fuel used. Types of fuel considered in this report are: electricity, liquefied petroleum gas (LPG); natural gas (NG); biogas; kerosene; coal and traditional biomass such as charcoal, wood, crop waste and dung. LPG and NG were aggregated into a Gas fuels group. Fuels emission factors were extracted from the IPCC (2006) and are presented in the appendix 4 of this report. Table 1 summarizes all fuels that have been considered in the research.

Table 1 Energy carriers available for each end-use function

Cooking	Water heating	Space heating	Lighting	Appliances
T. biomass	T. biomass	T. biomass	Electricity	Electricity
Coal	Coal	Coal	Kerosene	
Kerosene	Kerosene	Kerosene	Renewable	
Gas	Gas	Gas		
Electricity	Electricity	Electricity		
Renewable	Renewable	Renewable		

Information about fuel shares for cooking is readily available from different sources. The UNDP & WHO (2009) conducted a research of main fuels used for cooking in developing countries. Also, national surveys are used in order to find more complete information of the fuel mix in households. Information about water and space heating fuel mix is scant and it was mainly extracted from the expected penetration of different technologies such as electric boilers, solar water heaters (SWH) and similarities to cooking fuel mix. The information about fuel shares were filled in for three different years and fuel shares projections for the baseline scenario are assumed to follow the same linear trend as seen in historical data and were calibrated each five years.

Renewable energy source considered in this report are biogas and solar energy. Some authors referee biomass as either a renewable or a non-renewable source. Biomass combustion has been treated in some cases as a zero emission source as, for instance, in the Fourth Assessment Report, Climate Change 2007 of the IPCC. In order to the implementation of fuel switching projects for biomass cook stoves as CDM projects the UNFCCC elaborated a definition of renewable biomass (UNFCCC, 2006). Five conditions were posed for treating biomass as renewable which are related with the sustainable management of the land. Other organizations developed similar indicators for treating biomass as non-renewable based on, for instance, time spent for gathering wood, fuel wood prices or changing trends in the type of cooking fuel used (GTZ, 2010).

2.3 Mitigation actions

A broad array of mitigation actions are taken into account in this report. This measures aims at rendering more convenient forms of fuel, increase standards of living, reduce energy needs and curb Greenhouse Gases emissions. Following the Fourth Assessment Report of the IPCC (2006), these measures are sorted in three categories:

- Building shell: Useful energy requirements for heating and cooling can be reduced by enhancing buildings envelopment with insulation materials.
- Fuel switching: This measure targets the shift to more convenient fuels for the accomplishment of functional uses of energy in the built environment. In the case of fuel combustion for cooking and water and space heating, the convenience of the fuels is related with its heating content and thus it is recommended the use of natural gas or LPG. The promotion of renewable sources of energy, such as solar water heaters and biogas, is also highly encouraged.
- Energy efficiency: The last group of measures describe best practices on the phase-out of obsolete technologies such as traditional cook stoves and other low performing technologies. Different types of legislation are expected to increase market sales of more energy efficient technologies.

The mitigation scenarios presented in this report are underpinned by these three types of measures. This impact of this initiatives are expected to differ as regards of the year of its implementation and the expect goals of their fulfilment. The modelling of the residential sector is projected until 2035. The first mitigation scenario includes major initiatives promoted by the Indian government. The second mitigation scenario describes further initiatives that could align India with some best case examples.

PART I
SECTORAL ANALYSIS

3 Overview of the residential sector in developing countries

Highest demographic rates of growth take place in developing countries and this fact results in an increase of the building stock. China, India and South Mediterranean Countries (SMCs) are the most prominent cases. China adds 1.6 billion square meters per year while 220 million m2/year are added in SMCs (WEC, 2010). In the case of India, a 70% of the building stock in 2030 is still to be constructed (Williams and Levine, 2012). This sharp increase is expected from both the residential and commercial sectors.

Economic and demographic effects drive the increase on buildings and appliances stock and the affordability of more energy services and intensity of their use. Other variables have an impact on energy trends in the built environment whereas, far from being independent, they are interrelated between them and with other parameters with an indirect effect such as floor space and household size. This chapter analyses the relation between those variable and the expected increase in energy demands.

3.1 Development of the residential sector

There is a global trend towards moving into urban areas. The World Bank estimates that over 90% of urban growth is taken place in developing countries. In China, for instance, the 70% of the population will live in urban areas by 2020. The two poorest regions of the world, South-Asia and Sub-Saharan Africa will double their urban population during the next two decades. Therefore, urban building stock in developing countries is expected to double by 2030 (Liu et al. 2010)

An urgent challenge for governments is to reduce the proliferation of people living in slums which has been estimated as a third of the urban population of developing countries by the UN-HABITAT (2010). The proliferation of slums has been attributed to income inequalities and the migration to urban areas (Arimah, 2010). In order to improve living standards, properly equipped dwellings should substitute for these settlements. This challenge posed by the 7.d target of the Millennium Development Goals (MDGs) aims at improving the lives of at least a 100 million slum dwellers by 2020 (UN, 2010). It can be expected that economic growth will help poor people to move into proper dwellings and thus, even more new housing stock may be constructed in urban areas than the extracted from population growth and urbanization rates.

Although no MDG is focused on energy issues, access to energy services is now recognized as a priority for realizing each of the eight MDGs (UNDP, 2012). Energy services are essential for satisfying basic needs such as cooking, and water heating, while lighting and the use of appliances may set the grounds for basic health, education and economic take-off as the result of, for instance, more time available for undertaking economic activities.

An important share of the population still suffers from energy poverty which has been defined by the lack of access to electricity and the reliance on the traditional use of solid fuels –biomass and coal– for meeting their cooking and space and water heating needs (IPCC, 2006). This fact is frequently represented by the energy ladder whereby fuel choices are explained as a function of economic development (IEA, 2010a). On the first stage, basic needs for cooking and heating are satisfied by traditional biomass (IEA, 2009). The fuel mix represented in the upper rungs of the ladder is more convenient for each functional use: fuels with a high calorific value -liquid and gases- are used for heating and cooking and electricity for most other uses (UNDP, 2007). This process is also called “Fuel switching” (Heltberg, 2003).

Following IEA recommendations, a minimum energy access threshold was stated as approximately 100 KWh of electricity and 100 Kgoe (equivalent to 1200 KWh) of modern fuels per person and per year for both consumption and productivity use, this last one related with lowering the time and effort that people requires to meet their energy needs (AGECC, 2010).

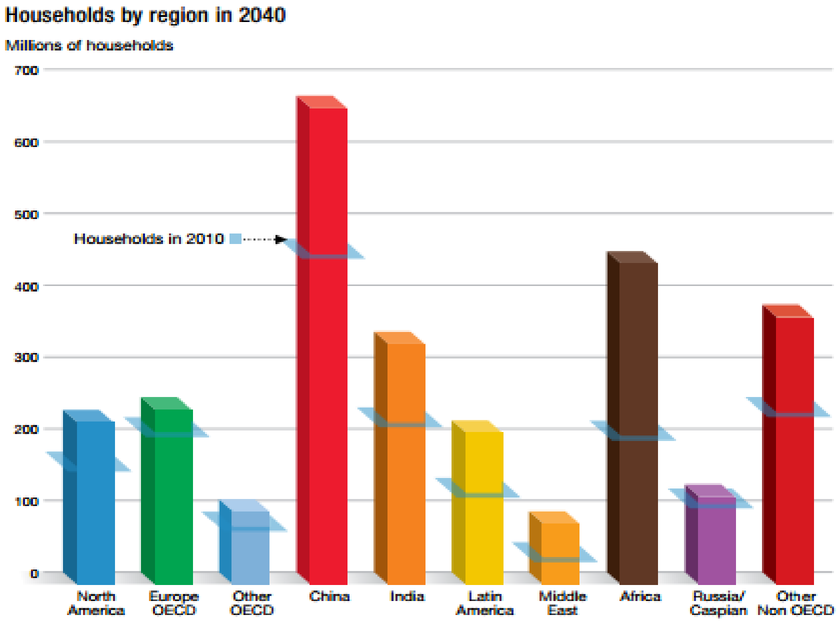

Figure 3 World trends of the residential sector by 2040. Source: Exxon (2012)

As given in figure 3, all world regions are expected to increase the household stock by 2040. Non-OECD regions experience the strongest growth in household demands. In Africa the increase of the residential sector is explained by demographic factors. In China, it is explained by economic growth which enables fewer multifamily and shared households. In India and Latin America is a combined effect of both demographic and economic growth (Exxon, 2012).

Population growth drives total energy demands from the residential sector but the intensity of its use is explained by socio-economic factors. Economic growth is expected to drive energy demands as the increase of household income makes affordable more and of a better quality energy services and leads to a more energy intensive lifestyle. The expected economic growth has been related to more living area demanded per capita and decrease of number of occupants per household resulting in an increase of the total floor area constructed. As household income increases, more energy is used for energy services such as water and space heating and higher appliances ownership rates.

When analysing household size and floor area per capita, it seems that both variables keep a correlation to household expenditure. This relation can be explained by the higher income per capita of less occupied households. With the exception of areas with a high population density, living area demanded by consumers tends to increase along income per household. Floor area has an important effect in energy demanded from buildings as a larger area of the building must be space conditioned and lit. For instance, almost a 40% energy efficiency gains in the EU is offset by the fact that dwellings are becoming larger (ODYSSEE, 2009).

3.2 Energy trends in the built environment of developing countries

Household incomes in developing countries are reaching, in absolute terms, levels where more and of better quality energy services become affordable. Previous studies, such as Rue du Can et al. (2009) and Isaaac and van Vuuren (2008) have found a correlation of this parameter with energy consumed for all functional uses of energy with the exception of useful energy for cooking which does not seem to respond to exogenous factors (Daioglou et al., 2011). Therefore, energy intensity of different energy services is expected to increase leaded by the influence of economic growth.

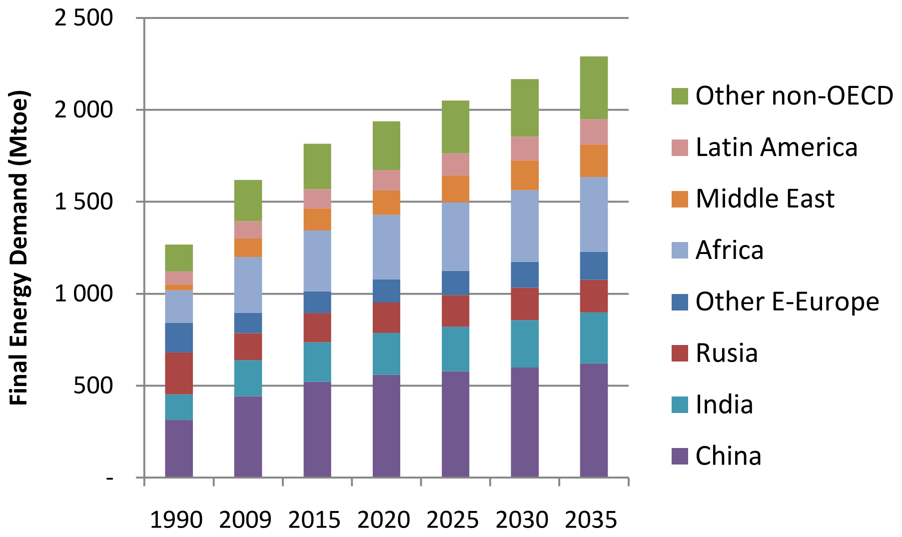

Figure 4 Projections of buildings energy demand. Adapted from: WEO 2011

Figure 4 represents the expected growth on energy demanded of the whole building sector in non-OECD countries. These countries accounts for more than half of energy demands from the building sector and, representing the largest growth rate, the share of energy use arises to a 60% in comparison to OECD countries by 2035 (WEO, 2011). Moreover, this growth is marked by a decrease on the use of biomass and waste and increase of modern forms of fuel specially electricity with annual growth rates of around 5% in China and India, 4% in Africa and 2% in Latin America during the period 2010-2035 (WEO, 2011).

The growth in the demand for modern forms of fuel is the result of urbanization rates, economic growth and the access to more and proper energy services. Energy services in the residential sector are aggregated in five categories: cooking, water heating, space heating, lighting and use of other electric appliances. Space cooling energy service is included in this report in the category of electric appliances.

3.2.1 Cooking

While cooking tends to account for a decreasing share of the domestic energy use, it remains the most common end-use of energy in those regions with low income levels. The low heating value of traditional fuels and poor energy performance of cook stoves increase the amount of final energy required. For example, rural energy use per capita in China was three times as much energy use in urban areas due to the low efficiency of coal and biomass combustion (UNEP, 2009). In India, households substituting LPG for fuelwood require a 22% less energy for cooking (Balachandra and Reddy, 2006).

Useful energy use for cooking (MJue/cap) is the minimum amount of energy that a person requires in a daily basis for cooking meals. This energy end-use does not seem to be affected by structural effects as it has not shown a clear dependence to any of those drivers (Daioglou et al., 2012). However, it varies significantly between countries or even in a sub-national level.

3.2.2 Water heating

In some developed countries water heating energy consumption has been estimated as 5 times as much as the required for cooking (Zhou et al. 2007) and it uses to represent the third or second most energy consuming service of the residential sector (UNEP, 2009). In the case of Chile, for instance, water heating is the most consuming energy service in dwellings (CDT, 2010). The use of water heating in households is a basic condition for meeting human needs. Yet it is satisfied with rudimentary technologies, i.e. cookstoves, by a large share of the population living in developing countries.

Water heating is expected to increase along household income. In poor households relying on stoves, the use of water heating is a small proportion of the energy used for cooking, and usually not larger than 0.5 MJ/Cap/Day (de la Rue du Can, 2009). Therefore, the demand of hot water depends also on the type of technology as well as on a good distribution system of tap hot water in better equipped households. It is expected that households at higher income rungs can afford better hot water energy service as developing countries shown an upward trend for water heating energy intensity.

Obviously, households' hot water demand has to reach a saturation level. Some research papers observed a reduction of hot water consumption during the hottest months of the year (Maithel et al., 2010). In order to take this fact into consideration, Daioglous et al. (2012) have included climate conditions for setting a benchmark for the saturation level of hot water demands.

Therefore, households' energy use for water heating can differ as result of climate conditions and economic development. VHK (2007) estimated that the hot water demands, at 60 °C, ranges from 10 to 50 litres per person among EU member states. A mean value of 24 litres or 59 litres per household (roughly 2.5 cap/hh) was equated to a useful energy consumption of 1246 KWh/hh per year (specific heat of water = 1,163 Wh per K per litre). While southern countries presents relative lower useful energy demands, countries such as Latvia and Lithuania lie far behind the European average and this fact highlights economic factors as the main driver for water heating energy demands.

3.2.3 Lighting

In European countries lighting ranges from 7 to 35% of total electricity consumed in households (ECBS, 2010). This share is even larger for developing countries where the use of other electric appliances is not so extended (IEA, 2006). The use of more efficient lamps is an important factor for the decrease of lighting energy demands.

The most common electric lamps used in the residential sector are traditional incandescent bulbs (ICL), fluorescent lamps (FL), compact fluorescent lighting (CFL) and Light-emitting diode (LED). Each of them shows better energy performance than the precedent based on their luminous flux (lm) per input energy (W). LEDs are the most efficient type of bulb but it is not extensively deployed in developing countries (WEO, 2010).

The use of more efficient lamps in households could trigger a rebound effect whereby lamps are switched on for more hours as the consumer perceives that operating cost has decreased (Maxwell and McAndrew, 2011). Lighting hours in the US were estimated more than 40% higher by the use of more efficient lamps (ECBS, 2010).

Electricity used for lighting has been studied by different authors as an estimation of the number of bulbs used per household and market shares of each type of lamp in the analysed country (Letschert, 2010; McNeil et al., 2007). Rather than following this approach, I have assumed a minimum illuminance in dwellings in order to correlate energy consumed with lighting power density (LPD), expressed in W/m2. Minimum illuminance requirements are domestically established for the accomplishment of different tasks. These requirements are described as lumens/m2 or Lux, thus measuring the illuminance on a surface. For example, the Illuminating Engineering Society of North America (IESNA) provides recommendations for different activities ranging from more than 500 lux for demanding tasks to a minimum of 54 lux in areas where it is not expected to strain the eyes (IEA, 2006).

LPD levels are calculated from the equated luminous efficiency (lm/W) and energy losses in the overall lighting system. Finally, lighting hours was set to 2 hours and the possibility of a rebound effect is deemed irrelevant. The final equation for calculating energy use for lighting, as well as the other equations used for the modelling, is included in the appendix to this report

On the other hand, households depending on fuel-based lighting are assumed to use kerosene with a rate of consumption ranging by a factor-of-ten among developing countries in relation to consumers behaviour and type of lamp used. Mills (2003) studied four different fuel lamps. Therefore, kerosene for lighting is depended to country characteristics, consumers' behaviour and the type of kerosene lamp used.

3.2.4 Space heating

Space heating and cooling have the greatest influence on buildings energy consumption among developed countries and some developing countries such as China (Zhou et al., 2007). In developing countries, space heating market is immature and the demand is expected to grow significantly (IEA, 2011a).

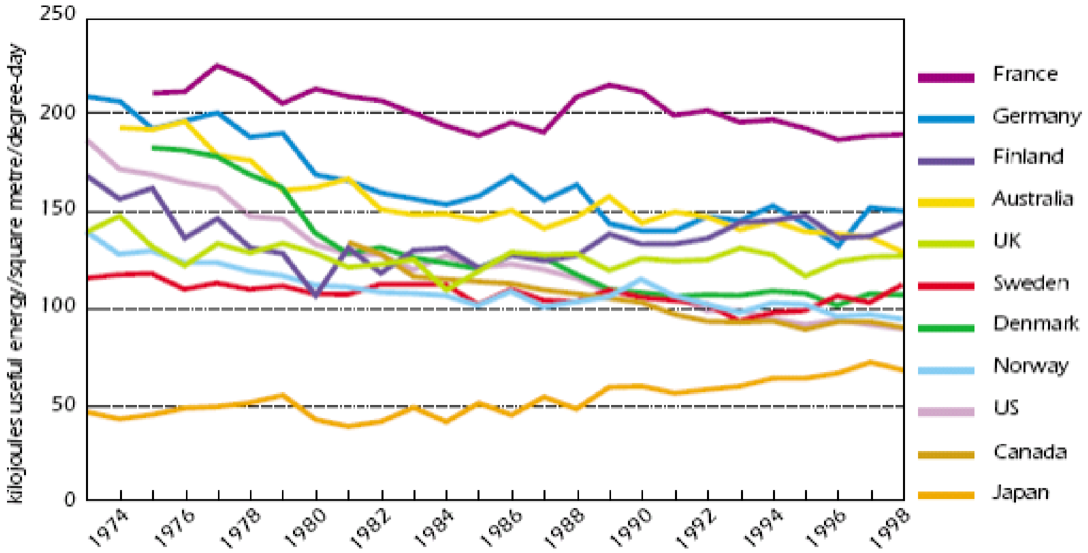

Figure 5 Space heating energy Intensity provided by the IEA (2004); Source: Zhu and Pan (2007)

Figure 5 shows historical data about useful energy requirement for space heating. It was estimated by the IEA for a number of developed countries on basis of heating degree days (HDD) and living area (m2). The energy intensity of those countries in 1998 ranged from 80 KJ/m2/HDD to 150 KJ/m2/HDD and it seems to follow a trend towards 100-130 KJ/m2/HDD for all the countries studied (Zhu and Pan, 2007). Several underlying factors can explain the differences found among countries:

- Building insulation: A low insulated building conducts more heat through its surface and this fact increases heating and cooling demands.
- Building physics: Single family houses have a larger exterior surface per square meter and, thus the heat conduction will be larger.
- Climate conditions: Far for being heating degree days the only climate condition determining heating requirements, solar irradiation, humidity levels and other factors can influence indoor temperature.
- Human behaviour: This factor includes different characteristics such as the comfort level perceived by building occupants or the trend to heat the whole or just part of the living area.
- Use of heating devices: Centrally heated dwellings uses to heat up larger areas of the house than portable devices which are plugged in for their use in just a room.

- Technologies performance: the average values were calculated under the assumption of equal energy efficiencies for each type of fuel (Zhu and Pan, 2007) but the energy performance of the same technology can differ largely between countries.

- Household income differences: This factor is responsible for the perceived cost of fuels. A case was studied in Jordan where 60% of surveyed households heat just one room (Jaber, 2002). Also, in poor household comfort temperatures may not be met with energy services.

Analysis of space heating energy demands in developing countries has been studied in other research papers as developing from an assumed heating energy intensity which is expected to fit with the values exhibited by industrialized countries (Isaac and van Vuuren, 2008). Due to the above explained factors, I found this approach to shed uncertainty in the space heating analysis. As I expect to study individual cases rather than general trends in developing countries, I aim to find reliable information about the share of final energy use which is used for space heating in the analysed country.

The next step is to discount the technology effect in order to come out with a value describe heating energy intensity (KJ/m2/HDD). Following the same procedure as Isaac and van Vuuren (2008), energy intensity is assumed to develop towards an average value of 100 KJ/m2/HDD in the year 2100.

3.2.5 Electric appliances

Residential electricity demands is expected to boom among developing countries as a result of a more extensive use of domestic appliances (Letschert, 2010). In OECD countries, a 59% of the total residential electricity consumed in 2005 was for appliances. In general, most of this energy is used for five large appliances: refrigerators & freezers, washing machines, dishwashers and televisions. However, other small appliances, such as computers, fans and personal audio account for an increasing share of the total end-use electricity in dwellings among developed countries (IEA, 2008).

A different picture is expected in developing countries where the market share of large appliances is not saturated yet. Large appliances, with the exception of dish washers, are considered as the first devices chosen for increasing living standards (WEO, 2009). Due to this fact, refrigerators, washing machines and televisions rates of ownership are studied by its relation to household expenditure.

Also, Cooling demands are expected to increase in warm regions such as India and the Middle East and in countries with high living standards. Energy use by air conditioning has been explored in several research papers (Isaac and van Vuuren, 2008; McNeil & Letschert, 2007; van Ruijvan et al., 2011). These researchers have estimated air conditioning as a function of cooling degree days (CDD) and household income. The expected increase of this last factor results in more operating hours and higher energy intensity of these devices over time.

Also, fans and air coolers are treated in this report as they can account for an important share of the cooling energy requirements. Air conditioning, fans and air coolers are treated in the category space conditioning appliances.

Different functional units are applied for the assessment of each technology performance and they are explained in chapter 4 of this report. Also, stand-by energy losses are important for some large appliances and all small appliances. Small appliances can account for an important share of electricity consumption and thus, the most relevant are generally included in a country analysis.

4 Mitigation options in the built environment

Polices and other initiatives for ensuring a better use of energy in buildings can be implemented as part of a building energy code. This code can set the minimum performance for envelope and equipment components. Building codes has different enforcement regulations. In India, building codes are voluntary and Japan just recently enacted penalties for no compliance to the previously voluntary standards. China has enacted a national regulation of building codes which is, in most of the cases, regionally enhanced with stricter requirements (Liu et al, 2010). In the EU building codes are determined at the country level as in the case of other countries such as the United States, Australia and Canada.

However, mitigation options for the residential sector are treated separately in order to assess their specific mitigation potential. Different measures for curbing energy and GHG emissions from the use of buildings have been sorted in three different branches: Building insulation, Energy efficiency, and Fuel switching measures (IPCC, 2006).

Table 2 Opportunities for energy and CO2 emissions savings in buildings. Source: IEA, 2012a

Major savings areas	Relative importance over next decade
Building shell measures	
New residential buildings in non-OECD countries	Medium to large
Retrofits of residential buildings in OECD countries	Large
New commercial buildings	Large
Retrofits of commercial buildings	Medium to large
Energy efficiency	
Lighting	Medium
Appliances	Large
Water-heating systems	Large
Space-heating systems	Medium to large
Cooling-ventilation systems	Medium to large
Cooking devices	Small to medium
Fuel switching	
Water-heating systems	Medium to large
Space-heating systems	Medium to large
Cooking devices	Small

As seen in Table 2, building shell measures can have a high impact in lowering the energy used for heating and cooling. Due to the fact that most developing countries are located in warm regions, this report is focused on the potential impact of insulating buildings for reducing energy used by cooling, in this report called space conditioning, devices.

Fuel switching and better performing stoves measures have an important role in developing countries in which an important share of the population lacks access to modern forms of fuel. These measures are increasingly drawing the attention of development funds. The bulk of capital investment estimated in the year 2009 was around US$ 9 billion in order to provide 20 million people with access to electricity and to supply 7 million improved cook stoves (IEA, 2011d)

In relation to energy efficiency measures, different legislation can be enacted as an information instrument encouraging the purchase of more efficient devices. There are several factors influencing consumers´ choice of new appliances. The capital cost of the appliance is generally the most relevant factor. Operating costs can also be deemed important especially in relation to very energy intensity technologies. An information instrument such as energy efficiency labelling is expected to contribute to the final choice. Also, new regulation can set minimum energy performance standards banning very inefficient products

4.1 Building insulation

The expected increase on new buildings in developing countries offers an opportunity for implementing building codes as to incorporate minimum insulation requirements. Countries postponing their implementation of building codes are losing the opportunity to achieve an important energy conservation measure. To address energy reduction of buildings through retrofitting is more costly and difficult and thus, the booming of the building sector provides an opportunity to lock in energy savings for the whole use-phase of new buildings (UNEP, 2009).

Building heat losses occurs through roofs (30%), walls (25%), windows (15%) and air ventilation (25%) (ETSAP, 2012a). A reduction of the heat transmittance of more than 70% can be achieved in relation to a poorly insulated building (Petersdorff et al., 2006). In order to achieve that savings, envelope insulation standards should be enhanced. These standards indicate the maximum thermal transmittance through different components of the building envelope, usually called U-values [W/m2/K].

Table 3 Insulation requirements for buildings in hot and cold world regions

U-values (W/m2K)	Roof	Walls	Floor	Windows
cold[1]/hot[2] climates	0.13 / 0.31	0.18 / 0.56	0.15 / 0.67 [3]	1.2 / 3
Indian conventional building[4]	2.34	2.07	--	5.65

1. Mandatory standards in Sweden (EPBD, 2008); 2.Mandatory standards in Darwin (Australia) except for windows requirement that is mandatory in the Chinese region of Hainan (Evans et al., 2009).
3. These standards are also applied to suspended floors in vertical buildings.
4. Source: (Singh and Garg, 2009). U-Value of floor surface is not provided.

Table 3 presents different legislation for the construction and retrofitting of households under different climate conditions and a building in India constructed with brick and cement (Singh and Garg, 2009). A better overview of main materials composing the building physics of Indian households are provided by the National Census of India (2011). The most stringent standards have been issued in the coldest climates of Europe such as Sweden and Norway (EPBD, 2008). Also, hot regions, such as in Darwin (Australia) and Hainan (China), have implemented very strict buildings standards.

All those measures can be used as guidelines for the provision of insulation packages targeting increasingly aggressive building standards. They may be applied as regards of the most cost-effective level of insulation under local conditions. For instance, a moderately insulated building could be enough in regions dominated by a mild climate whereas more aggressive measures may be necessary in regions where heating and/or cooling energy consumption represents a larger fraction of the total energy consumption.

Three different packages of measures are developed for modelling the impact of building insulation measures. In this report, It is used the soft and medium package of measures assuming that the soft package could reduce a 15% and the medium 25% of heating transmittances within buildings. Due to the fact that the majority of developing countries are located in warm climate regions, these packages of measures are assessed by their potential for reducing cooling energy demands.

These packages are mainly extracted from other papers reviewed (KFW, 2010; CONAVI, 2011) and it has not been modelled per se for any type of building. Yet some indications can be highlighted as regards of the type of heat transfer taking place on buildings:

- Building orientation is fundamental as it takes into account solar irradiation and thus, it has been included in several countries´ building codes (ETSAP, 2012).
- It is fundamental to have a balanced insulation between the different buildings envelop components (Roof, façade, floor and windows).
- Shading of the building is encouraged for reducing solar radiation on solar facing facades (Petersdorff, 2006). The capacity of reflecting materials to reduce solar irradiation is measured by the solar heat gain coefficient (SHGC).
- Roof insulation is especially important as it mitigates heat gains by solar radiation in hot climates and heat losses in cold climates (ETSAP, 2012a; EPBD, 2008). In hot climates, roof insulation is the most cost-effective measure (KFW, 2010). The so called cool roofs can improve solar reflectance by 60% (Akbari et al., 2009). For instance, a dark roof has a SHGC of 80% whereas a white painted roof has a reflectance of 0.7 to 0.8 (GCCA, 2012).
- In the case of windows, there are marketable units which just a 15-20% of the heat loss of a single-glazed windows (Levine et al., 2007). Coated glazing is efficient for reflecting solar radiation, thus reducing cooling demands. Electricity savings of up to 28% in households replacing single with double glazing windows were reported in hot & dry regions of India (Singh and Michaelowa, 2004). Also, solar control window seems to be very effective in reducing cooling requirements (Singh and Garg, 2009).

- An excessive insulation on floor surface can hinder the reduction of cooling demands because of the relative cool temperatures on the ground (Boermans and Petersdorff, 2007).

- To control air tightness within buildings is important for reducing energy demands. For instance, in hot climates it is recommended to allow air ventilation at night and reduce it during the hottest hours of the day (Boermans and Petersdorff, 2007).

- Minimize internal heat load from inefficient appliances has a large influence on cooling requirements (Petersdorff, 2006) but it can have a backfire effect on heating requirements. This concept is known as the Heat Replacement Effect (HRE) (van den Bergh, 2010).

- The implementation of insulation standards is estimated to increase the construction costs in just a small percentage of the total cost of the building (Levine et al., 2007) For example, a 0.25 U-value can be achieved in external walls by a 15 cm insulation wall of mineral wool at a price of 4.4-7.8 €/m2 (AEA, 2010).

The commitment to building codes has not harvested the expected results in other countries and its enforcement is especially low in rural areas (UNEP, 2009). Therefore, it is recommended to create a government agency in charge of the monitoring, compliance and enforcement of the new legislation. Also, the agency could have the role of developing new legislation enhancing building insulation codes over time.

4.2 Fuel switching to modern forms of fuel

In 2000, about half of the world's households use unprocessed solid fuels (biomass and coal), ranging from almost zero in developed countries to 80% in China, India and Sub—Saharan Countries (Smiths, 2002). More recently, the IEA (2008) estimates than the 59% of the energy use in non-OECD countries is from renewable sources, mainly traditional biomass.

The 2010 edition of the World Energy outlook defines the access to modern forms of fuel as: *"a household having reliable and affordable access to clean cooking facilities, a first connection to electricity and then an increasing level of electricity consumption over time to reach the regional average"* (IEA, 2011d). The same report sets a threshold level of energy consumption in rural areas of 250 KWh and 500 KWh of electricity per year in urban areas.

Burning biomass for cooking and water heating emits substances such as CO, CO2 SO2, NOx H2S, TSP1, and particular matter of 2.5 to 10 micrometres of diameter (PM2,.5 andPM10) (ASTAE, 2008). Figure 6 shows the contribution of different sectors to global emissions of SO2, NOx and PM2.5. Health studies have linked the indoor pollution from these substances with premature death due to diseases such as pneumonia, chronic obstructive pulmonary disease (COPD) and lung cancer (WHO, 2010). 420 thousands premature deaths in India were attached to indoor pollution based on data available in 2000 (Venkataraman et al., 2010) while acute respiratory illness accounts for a fourth of under-five children deaths in India (Mathew et al., 2011).

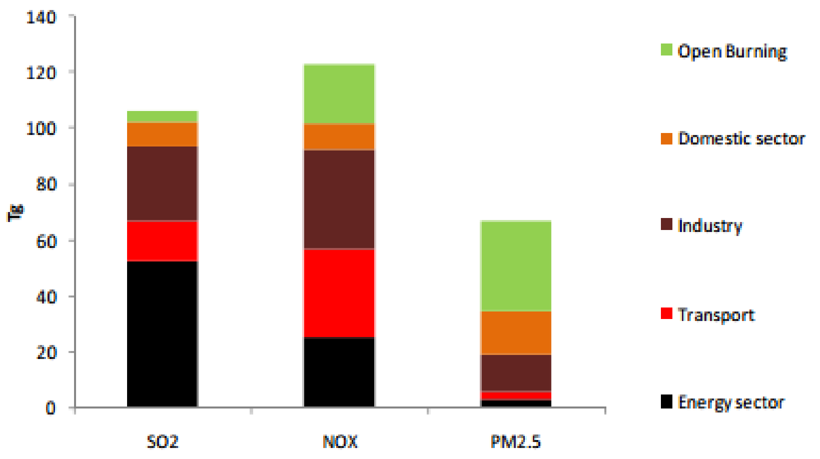

Figure 6 Global Emissions of SO2, NO and PM2.5 (Tg) Source: Rao et al. (2011)

Figure 6 shows the contribution of different sectors to total emissions of SO2, NOx and PM2.5. The residential sector presents significant shares for all of them. Black carbon (BC), also called soot, is a component of PM and, besides inducing health problems, it is the greatest anthropogenic aerosol absorber of sunlight and the second larger contributor to global warming after CO2 (Foell et al., 2011).

The global warming potential of BC has been estimated as 680 times that of CO2 (MacCarthy et al., 2008). BC darkens snow and ice surface which is accelerating glaciers meltdown (UNEP, 2011). Soot has a shorter lifespan than other pollutants and thus, most prejudicial effects may be paid off locally. For instance, BC is seen as a major responsible for the retreat of the world largest non-polar ice masses in the Himalaya (Meitiv, 2010).

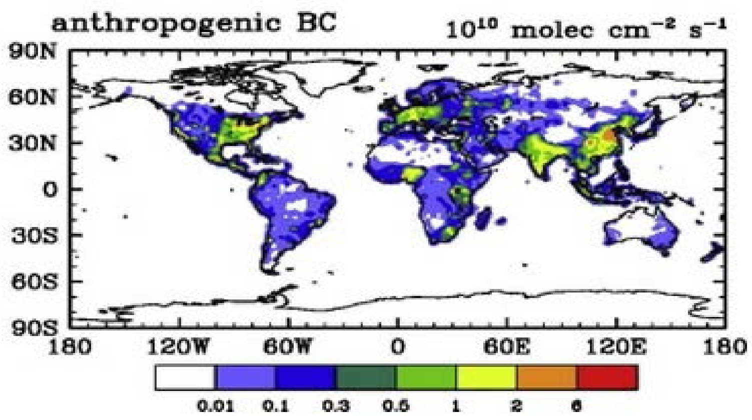

Figure 7 Surface emissions of soot in 2000. Source: Saikawa et al., 2009.

Due to the fact that soot is formed by an incomplete combustion of diesel fuel, coal and biomass, this pollutant`s concentration is particularly high in countries where a considerable share of the population relies on those fuels for cooking and heating (Wallenstein, 2003). The residential sector, mainly combusting biomass for cooking, is responsible of around 30% of the soot globally emitted. India and China account for roughly 40% of soot emissions (USEPA, 2012). Figure 7 shows that the radiative forcing attribute to soot is much significant on those regions.

LPG is seen as a more convenient fuel for its use for cooking and heating purpose. The WEO 2010 in their Universal Modern Energy Access Case showed that the switch of 1.2 billion people to LPG cooking stoves by 2030 would increase world oil demand by less than a 0.9% of the projected total demand in that year (Foell et al., 2011). In addition, the increase of GHG would be negative if a 20% of the biomass used in cook stoves is deemed as unsustainable.

Also, the Universal Modern Energy Access Case of the WEO 2010 presented biogas as a feasible alternative for providing clean cooking means to low income households. In regions where the electricity or gas grids can find difficulties to reach, especially in rural areas, it may be a good alternative the promotion of bio-digesters for generating methane-rich biogas (Ecofys, 2011). This option reduces GHG emissions by capturing and burning methane which contributes 25 times as much as CO2 to global warming (IPCC, 2007).

The shift to more efficient fuels may bring along some kind of financial stimulus such as subsidies to the premium cost of modern fuels and technologies. For instance, LPG stoves are much more efficient than wood stoves but its annualized cost is higher (Bhattacharya and Croppe, 2010). On the other hand, replacing LPG with biogas in Thailand yielded cost savings of $70 per year and household (AGECC, 2010). The cost of achieving universal access to modern forms of fuel for cooking to 2.8 billion people would require $56 billion from 2010 to 2030, or approximately $2.6 billion per year (Foell et al., 2011).

4.3 Energy efficiency measures

The measures explained in this section are related to the increase of the energy efficiency of the appliances used in the residential environment. The technologies analysed account for a fair market penetration or are expected to achieve it in the forthcoming years. Those technologies can save energy and thus, GHG emission reductions. Better fuel combusting technologies can also bring about health benefits for the consumers. This section also identifies meaningful indicators for analysing technologies performance.

A market transformation towards more energy efficient devices can be achieved by the implementation of energy standards (CLASP, 2010). This report is focused on standards and labelling systems as to account for the phase-out of obsolete technologies. In order to develop MEPS it is necessary a process for testing energy performance of appliances, analyse the potential impact of the labelling and develop effective directives. Therefore, this process requires the involvement of the government, manufacturers and research experts and can take 18 to 24 months depending on the analysed product (Zhou et al. 2010).

The implementation of MEPS is a continuous process in which MEPS becomes stricter over time. In this report, it is expected the review of the legislation each 4-5 years (Zhou et al., 2011). The degree to what the standard is raised depends on the technology analysed. Also, it is assumed that MEPS would never surpass the energy performance of currently best available technologies.

In the case of electric lamps and cook stoves, instead of the development of energy labelling or design standards, some government initiative can either incorporate a strategy for the roll-out of more convenient technologies or plan the complete phase-out of inefficient models.

4.3.1 Cooking stoves

The deployment of more efficient cookstoves is identified as a readily and feasible solution for reducing energy use and health risk from indoor pollution (Heltberg, 2003). Cooking with traditional biomass or coal in cookstoves without a system to vent pollutants to the outdoors can result in detriment effects for household occupants. The advantages of improved cook stoves (ICS) are related to conserving biomass and coal fuels as well as reducing the time and effort people needs to meet their energy needs. In addition, it could be a government strategy for modernizing the consumption of traditional fuels in order to delay demand growth for fossil fuels (Bailis et al, 2007).

Improved cook stoves (ICS) can be two to three times more efficient than traditional cooking devices (AGECC, 2010). However, some studies in developing countries stressed that most of the ICS technologies in the market are not as effective as promoters were claiming in reducing undesirable pollutants (US EPA, 2012). Among ICS, fan mechanisms are top-performing as, for instance, can reduce black carbon emissions by a factor of 4 (MacCarty et al., 2008; Kar et al., 2012). This type of cookstove is assumed to be implemented as ICS for its domestic use.

Table 4 Stoves performance and pollutant emission factors (g/MJ) of wood, coal and LPG.

Cookstove		Efficiency[1]	BC	CO	CH4	N2O	CO2 [5]
Wood	Traditional	15%	0.034 [2]	3.92 [2]	0.284 [2]	0.005 [2]	112
	Improved	35%	0.005 [3]	0.308 [3]	0.000 [3]	0.000 [3]	112
Coal	Traditional	22%	0.29 [2]	14.95 [2]	0.429 [2]	0.013 [2]	94.6
	Improved	45%	0.04 [4]	1.175 [4]	0.000 [4]	0.000 [4]	94.6
LPG	Conventional	60%	0.000 [3]	0.091 [3]	0.000 [3]	0.001 [3]	63.1

Conversion factor: 17.6 MJ/Kg Wood; 18.4 MJ/Kg Coal. (Bailis et al., 2007)
Adapted from:
1. Isaac and van Vuuren, 2008. 2. Venkataraman et al., 2010
3. IIT & TERI, 2010 4. Own estimations based on correlation 6. IPCC (2006)

Table 4 shows the technology performance of traditional cookstoves and compare it to a LPG fuelled one. The research conducted by IIT & TERI (2010) provides results based on energy delivered to the cookstove. Therefore, the results presented in table 4 were adapted in order to provide pollutant emissions per fuel (MJ) fed to the cookstove. Venkataraman et al. (2010) shows that cooking with dung and crop residues have similar emission factors as wood. CO2 emission factor are presented in this table following IPCC guidelines and thus, the potential of ICS to mitigate CO2 emissions relies on the thermal efficiency of the equipment.

4.3.2 Lighting

Making lighting more energy efficient is often seen as the most cost effective way to curb CO2 emissions at negative costs for governments (McKinsey, 2009b). This is explained by the high energy intensity of ICL and the costs of subsidizing electricity. ICL is very inefficient as a 95% of the emitted energy is in the invisible infrared (heat) while just a 5% produces light. A fair amount of developing countries are undertaken measures for the phase-out of ICL (e.g., Bangladesh, Bolivia, China, Cuba, Ethiopia, India, Mexico, Philippines, Rwanda, South Africa, Sri Lanka, Thailand, Uganda, and Viet Nam) (UNEP, 2012).

Table 5 Analysis of electric lamps

	IL	FL	CFL	LEDs	LEDs $_{2020}$
Lamp Power (W)	60	36	15	6	6
Efficacy (lm/W) [1]	12	31	51	75	200
Power density (W/m2)	16,67	6,45	3,92	2,67	1,00
Lifespan (1000 hours)	1	15	10	100	100
Cost of lamp (US$ $_{2005}$)	5	8	11	30	5
Cost savings (US$ $_{2005}$) [2]	-	66	84	74	99

[1] The efficacy of fluorescent lamps is reduced as it is assumed a loss of 15% efficiency by the use of ballast (IEA, 2006).

[2] Cost savings for lamp as assuming 0,1 $USD/KWh after 10000 operating hours (IEA, 2006)

Sources: Own elaboration; based on: IEA, 2006; ETSAP, 2012.

Table 5 shows main characteristics of ICL bulbs and other alternatives with a better energy performance. The cost of each lamp is presented in Indian rupees. Even though there is a market transformation towards more efficient lighting lamps, ICL is still predominant in almost all world regions. An effective way to explain the impact of shifting to modern electric lamps is by analysing the average luminance efficiency of the residential market. In the case of India, it is estimated in this report as15.45 lm/W. As shown in Table 5, FL has a luminous efficiency of 31 LM/W while the efficiency of CFL is 51 and current LEDs has around 75 LM/W. Therefore, these types of bulbs can render a higher luminous flux while consuming less energy than ICL.

4.3.3 Water and space heating

Regular (or dedicated) water heaters are devices which only provide drinking or sanitary hot water. However, this energy service can also be performed by a space heating boiler or "combination boiler". This report is focused on this technology, hereafter referred as boiler. The system is normally designed in EU as a central heating boiler that circulates hot water through a radiators system. In case of simultaneous hot water use in large houses, water demand can be backed up by small heating units (secondary water heater) installed in close proximity to hot water use (Kemna et al., 2007a).

Boilers fuelled by oil, gas or by electric resistance elements provide energy to a heat generator that is often regulated by a thermostat. These systems can either heat water directly before it is used or store it in a tank. The first type is called demand (tankless or instantaneous) system and they avoid standby energy consumption required for offsetting heat loss through the external walls of conventional storage boilers. Some instantaneous boilers have a small internal water store in an attempt to take advantage of both systems (USDE, 2012).

Table 6 Energy performance and estimated costs (Rupees) of boilers

Boiler Type	Efficiency	Life span (years)	Installed Costs (Rs.)	Fuel Price (Rs./GJ)[7]
Conventional electric storage [1.5]	50%	13	2000	**415**
High efficient electric storage [1,6, 5]	97%	13	2800	**415**
Conventional Gas storage [1,6]	41%	13	2000	**270**
High efficient Gas storage [1,2,6]	80%	13	2500	**270**
Conventional Gas tankless [1,6]	62%	13	2750	**270**
High efficient Gas tankless [1,3,6]	96%	13	3500	**270**
Kerosene stove [1,5]	55%	8	250	**282**
Coal stove [5]	65%	8	250	**85**
Wood Stove [5]	50%	8	250	**62**
Solar Water Heater [6]	100%	20	30000	**0**

Standing losses affects low performance of storage boilers. Same price is assumed for coal and wood stove. SWH costs for a 3 m2 collector area.
Adapted from: 1. ACEEE (2011); 2. Navigant (2011); 3. toptenUSA.org (2012); 4. Kemna et al. (2007); 5. Reddy (2004); 6. Maithel et al. (2010); 7. Ekholm et al.(2010)

The technology performances of most important devices used as boilers in the domestic environment of India are represented in Table 6. The energy efficiency of the boiler is defined as the ratio of the heat transferred to the water and the energy content of the fuel. The energy efficiency depends on the amount of water (nominal input) and the flue gas temperature. Gas fired boilers for both demand and storage systems can apply either a standard process of heat transferred to a piping system or a condensing system taking advantage of the latent heat of flue gases, thus improving boilers energy performance (Blok, 2007). Larger hot water demands induce the purchase of larger capacity and, generally, less efficient water heaters. Especially in the case of storage systems, the low energy performance is explained by heat losses through poorly insulated walls.

High efficient boilers have achieved efficiencies close to fuel thermal efficiencies and modest efficiencies can still be achieved. In the case of storage devices, the addition of better insulation materials has reduced heat losses. Rather than focus on a type of boiler system, the labelling scheme implemented in this report aggregates different water heating systems, storage or instantaneous, by the type of fuel used.

An alternative device is solar devices which use solar energy to heat fluids which transfer energy to water via a heat exchanger. It can also make a contribution to space heating demands in a bivalent system by using two heat generator types (Kemna et al., 2007). China leads world installed capacity with 87,5 GWth capacity installed in 2008 (IEA, 2011a). In 2009, India ranked in the third position of world capacity added (REN21, 2011) and it is forecast that India will follow China which a 10% of the 975 GWth capacity installed by 2030 (Bloomberg, 2011).

Other systems ramping up market shares are electric and gas engine heat pumps in which heat is absorbed from a heat source (for instance, geothermal or air) and driven through a Carnot cycle. This device is used for air heating and cooling but can also provide hot water. The ratio of the supplied heat to the electricity input is expressed as the coefficient of performance (COP) achieving values on the range of 4 to 6.

Although its use is promoted in developed countries and in China, heat pumps should advance in marketable price and it is not expected to be a feasible alternative for most developing countries in the short-term (IEA, 2011a). Furthermore, Due to the large energy losses (typically 60–65%) in the generation, transmission and distribution of electricity, heat pumps are particularly advantageous for heating when they replace electric-resistance heating, but may not be preferable to replace the use of fuels for heating (Levine et al., 2007).Thus, it has not been included as a target for boiler’s MEPS in this report.

The US Government has a labelling voluntary scheme for water heating in place since the 1980`s and it has paved the road for developing similar system in other countries (Kemna et al. 2007). Therefore, US standards set the basis for the labelling system applied in this report. In the US, most of the current installed boilers just meet MEPS but standards will be increased by. Some examples of the new standards are an increase of 13% for gas and 9% for oil storage boilers while standards for gas tankless water heaters will increase 20% (Navigant, 2011). A European regulation on boilers is still under development (Ökopol, 2012).

4.3.4 Appliances

This report assesses the energy used for washing machines, refrigerators, air conditioning and televisions. The mitigation measures for appliances implies the use of labelling systems of different energy efficiency indexes (EEI), this indicator is constructed taking a given device efficiency of conversion as benchmark. In the case of air conditioning Seasonal Energy Efficiency Ratio (SEER) is usually applied for rating the cooling output during the cooling season to the input electricity. The EEI and SEER values have been extracted from the EU Directive 2010/30/EU for energy labelling of appliances.

Table 7 Technologies energy indicators and efficiency potential.

Product	Energy performance indicators	Functional unit	Best available technology	EE Index
Refrigerator	Compartments volume; temperature	Total Cooling volume	0,57 KWh/l/year	22%
Washing machine [1]	Programme time at standard temperatures; Kg capacity	Kg capacity at 60° C	0,11 KWh/Kg /cycle	38,9%
Television [2]	On-mode and standby power use; Screen diagonal size	Screen area	0,4 W/cm2 ; 0,25W standby	16%
Air conditioning [3]	Cooling and heating capacity per type of device	Input energy to cooling output	N/A	5,1

1. Washing machines with a laundry capacity of 7 Kg.
2. Screen area TVs in the order of 80 to 100 cm; Best available technologies for on-mode and standby losses
3. Just considering cooling capacity of a multi-split device; energy performance is measured in EER

Source: EU Directive 2010; 2. Topten.eu; Young Park et al., 2011; Siderius et al., 2011

The labelling system applied is related to energy consumed per functional use under test conditions (Siderius et al., 2012). Different indicators are used during the testing phase of new technologies before it is decided their labelling level. Table 7 summarizes those indicators and other assumptions accounted for. Also, best available technologies are presented as the “efficiency frontier” in this report. Therefore, energy efficiency would not surpass those values in any review of MEPS.

4.3.4.1 Refrigerators

Refrigerators ownership rates have increased along household income and electricity access. It has been identified as one of the main reasons for the sharp increase in energy consumption of the residential sector in some developing countries such as China, Indonesia and Philippines (Calwell, 2010).

The volume is the main indicator of combined refrigerators and freezers energy intensity. The last one requires more energy as it operates at lower temperatures and its compartment occupies 30-40% of the total volume. In The EU, the average fridge volume is 213 litres plus 78 litres of freezer and this value is applied for the average Indian refrigerator. The biggest models are found in the US with twice the volume of the EU average size, while Chinese refrigerators are a third of the volume of US models (Siderius et al., 2012). The equation for calculating the adjusted total volume of refrigerators can be reviewed in the appendix to this report:

Current models use 25% the energy intensity of models in 1975 and 40% of a model in 1992 and this efficiency gains offset the increase in energy demands from size growth and unit sales in the EU market (Calwell, 2010). The Energy efficiency of refrigerators varies from more than 1.5 KWh/adjusted litre of inefficient models to less than 0.6 KWh/Adjusted litres on average in countries with most efficient models. I applied the first value as benchmark for establishing the EEI.

Refrigerators energy intensity is similar among developed countries which a plateau in EEI over the last years. This EEI is around 60% and some countries with historical bad energy performance refrigerators such as 140% in Australia are rapidly catching up with other industrialized countries (IEA, 2010c). In the EU, refrigerators labelling system will stretch the legislation of MEPS from the current 55% to 42% EEI in 2014 (EU Directive, 2010).

4.3.4.2 Washing Machine

Energy savings of washing machines are achieved by energy required by Kg of capacity and hot water requirements. The level of labelling for washing machine is dependent on its laundry capacity. The IEA (2012b) shown that laundry capacity has increased from around 4 to 6 Kg. Market preference is normalized to 6 Kg per cycle in this research. Energy consumption per year ranges between 0.8-1.3 KWh for a standard wash (IEA, 2010d).

Baseline energy consumption is stated as 1.3 KWh per wash or 0,22KWh per Kg of capacity. A hurdle for estimating energy consumption of wash machines is to come out with a realistic number of cycles per year. In developing countries, even households with a washing machine may wash some clothes by hand, particularly in hot climates. I assume that one person uses the washing machine once each ten days and thus, washing machine energy consumption depends on household size.

Washing machines are in an advanced stage of development. Label G appliances has been almost entirely removed from the global market (Letschert, 2010). The European Eco-design regulation for washing machine entered into force in December 2011 with MEPS of 0.68 EEI and it will be lowered to 0.59 EEI in December 2013 (Josephy et al., 2011).

4.3.4.3 Televisions

Televisions market is suffering a transition towards Liquid Cristal Displays (LCDs) which may capture more than 75% of global new sales by 2014. LCD models in general and LCD LEDs in particular are the most efficient models in the market (IEA, 2010b). Cathode Ray Tube (CRT) televisions will almost be phased out by 2014 (Young Park et al., 2011). The most energy intensive TVs are plasma models rated to an EEI of 0.64 for the best case examples (IEA, 2010b).

TV is the only appliance that could be more energy intensity in 2030 (McNeil et al., 2008) as a result of consumers´ choice of TV with bigger screen area. Young Park et al. (2011) estimates a global average increase from 82 cm to 87 cm, close to the estimated saturation level, in 2014. I assume that, in developing countries, diagonal screen size will develop along the substitution of LCD for CRT models. In other words, diagonal screen size will increase from 50 cm in the middle 90´s to around 87 cm by 2015.

There is a lack of information about energy efficiency of TVs in developing countries. Average EEI was estimated in a sample of OECD countries in the order of 0.8 – 1.2 for both CRT and LCD models. The baseline efficiency in developing countries is set to the most inefficient case which is an EEI of 1.2 (Young Park et al., 2011).

Stand-by losses have decreased from more than 5W/h to less than 1 along efficiency gains (World Bank, 2008). I decided to state baseline stand-by losses as 1W/hr. Finally, the amount of daily hours spent watching TV differs among countries from 3.7 hours in Switzerland to 7.6 hours in Australia or the US (Young Park et al., 2011). These values have been explained by the ownership of more than one device per household. In line with TERI (2006) estimations, average watching hours in India were set equal to 3.1 hours/household.

The European Commission has TV¨s labelling system in place since January 2010. A new tier of requirements will be enforced in January 2013 setting MEPS at 0.84 EEI. A more drastic legislation will be enacted in California where the MEPS could be set at 0.42 EEI in 2013 (Toptep.Info, 2012).

4.3.4.4 Space conditioning

The average SEER found among developed countries is larger than 3 (IEA, 2010c). More efficiency devices are increasing their market shares in countries with their own manufacturers while those countries importing them tend to show average EEI around 2.5 (IEA, 2007b).

China embodies the best example on Air conditioning standards as MEPS were reviewed from a 2.6 SEER in 2005 to 3.2 SEER in 2009 (Jin and Fridley, 2007). In India, air coolers are covered by a star rating band similar to air conditioning. The 1 star rating in 2010 was established at a 2.3 EER (w/w) and it will be raised to 2.7 in 2015 while the 5 star rating will be recast in 2015 at 3.5 EER from a value of 3.1 in 2010 (BEE, 2012). Letschert (2010) estimated fans to achieve 40% improvement of average energy efficiency by 2020.

The Indian Bureau of Energy Efficiency has developed guidelines for the labelling of fans and air coolers (BEE, 2012). Fans energy performance is measured in terms of volumetric airflow delivered per watt of electric power (Yu & Evans, 2010) whereas air coolers use the same benchmark as air conditioner (input energy to cold output).

Based on the information provided, it is possible to achieve an efficiency improvement of a 30% as an average value for al space conditioning appliances before 2020. Also, new technologies are expected to bring along further energy savings (IEA, 2007b; Yu and Evans, 2010).

PART II
Case Study: Indian Residential Sector

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5 The Context of the Indian Residential Sector

India's building sectors consumes around 45% of national final energy and the residential sector accounts for more than 80% of this demand. However, much of this energy is biomass and just a 15% of other sources of primary energy are used for domestic purposes (Williams and Levine, 2012). Biomass consumption is much higher in rural areas. National Indian Census (2011) indicates that more than 80% of people in rural areas use biomass as the main fuel for cooking. This fact can be explained by lower economic development and lack of incentives for moving away from traditional fuels.

The impressive rate of GDP growth, around an 8%, recorded in recent years is seen reflected in households' lifestyle. Especially in urban areas, households are shifting to LPG as the main cooking fuel and market sales of electric appliances show an almost exponential growth. This economic development, combined with high population growth rates, explain demands for modern forms of fuel and, consequently, GHG emissions upsurge. The Indian economy is expected to keep growing until 2035 with an average economic development rate of 6.6% (IEO, 2009).

The access to modern forms of fuel is more generalized in urban areas of India. Therefore, urbanization rate is an important factor contributing to energy consumption and GHG emissions. The World Bank predicts that, by 2030, 40% of the total Indian population will live in urban centres.

The Indian building stock is expected to be a 70% larger in 2030 (Williams and Levine, 2012). As well as by population growth, building construction rate can be explained by socio-economic factors. According to Indian National Surveys, household size has decreased in the period 2001-2011 from an average value of 4.53 to 4.17 in urban areas and from 5.19 to 4.6 in rural areas. I assume a development along economic growth and, as a result of this, household size decreases by 26% in urban areas and 15% in rural areas in 2030. This fact contributes to the increase of new buildings stock.

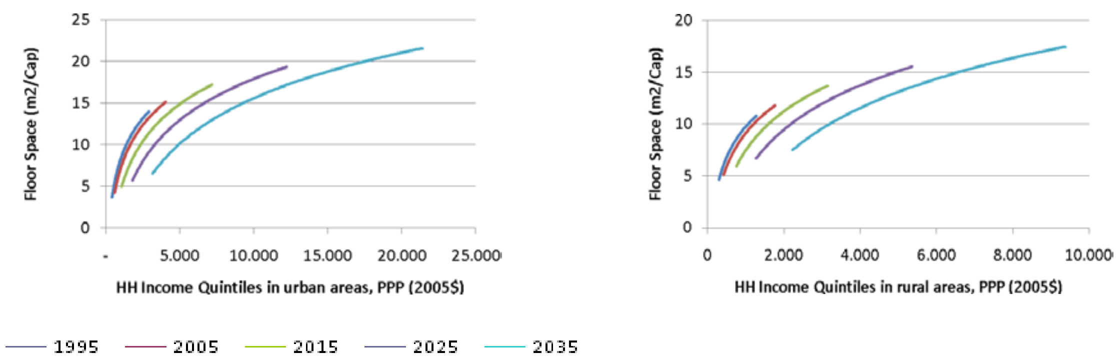

Figure 8 Floor space by income quintiles in urban and rural areas of India. Adapted from National Surveys and own calculations

Also, floor space constructed is also increasing as a result of demographic and socio-economic factors. The increase on household income is pressing the demand of floor area per capita. Trends on floor space were constructed from National surveys (NSS 58th round, NSS 63rd Round, NSS 65th round) and are presented in Figure 8. In order to project space availability I have assumed a logarithmic increase along household expenditure. This process results in an increase of floor area per capita of 33.3% in urban areas and 31.9% in rural areas by 2030. The highest quintile of urban areas shows the fastest growth. Economic factors are not modelled per se in this report and thus, differences between quintiles are expected to remain constant. Slum settlements in urban areas of India present special characteristics which are tackled in Box 1.

Box 1. Slum Settlements in India

The UN-habitat definition of slum highlights the lack of: a proper built envelop protecting from climate conditions, sufficient living space, safe water, adequate sanitation such as toilettes, durable shelter and tenure security against eviction. Slums are part of the urban landscape in India. A 50% of Indians in some metropolis (GIPC, 2006) and on average a 29% of urban population in 2009 lived in these settlements (UN, 2012).

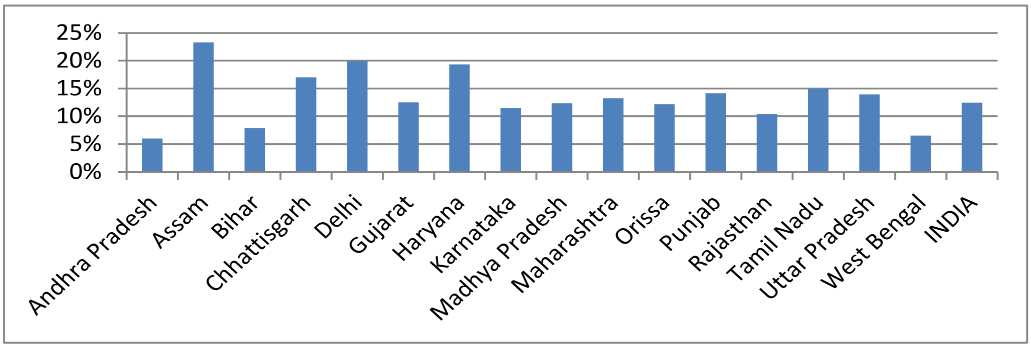

Figure 9 Projected growth of urban slum population in major states, 2011-2017. Adapted from: SCUPC (2011)

Slums have more than doubled from 42.6 million people -in 8.3 million Households- in 2001 to 93 million people in 2011 (MHUPA, 2011). Around 49 thousand slums were estimated in India in 2008-09. The proportion of notified (by the municipalities) slums differ by region and the Indian average was 50% in 2008 (NSS 65th Round, 2010). Figure 9 represents the expected development of Indian states which account for a 95% share of slums population. Around 105 million Indians are expected to live in slums, a 25% of the urban population, by 2017.

The rural exodus to urban centres results in the proliferation of slums where people become trapped in squalid living conditions. The lack of sanitations is normal and 21% of notified slums and 29% of non-notified slums in 2009 lacked access to tap water (SCUPC, 2011). The majority of households are built with construction (pucca) materials in 64% of notified and 50% of non-notified slums whereas katcha structures (e.g., grass, bamboo) were predominant in 7% of notified and 21% of non-notified slums in 2009 (NSS 65th, 2010).

In 2004-2005, a 26% of the urban population was below the poverty line with less than Rs. 538.6 per month (Government India, 2007). The urban poverty gap is deeper in Indian urban areas than in rural areas. Also, the GINI coefficient, which measures consumption inequalities, has increased in urban areas explaining the large inequalities among the population (SCUPC, 2011). On the other hand, the NSS 58th in 2002 showed half of the population living in slums were above the poverty line and 20% households had monthly per capita expenditures over RS. 1000. This fact indicates that some people rather live in tax exempt slums areas.

Electrification rates are also an important difference between urban and rural areas of India. The Indian census (2011) indicated that just a 55.3% of rural population has access to electricity while in urban areas the electricity grid covers the 93.2% of the population. Future projections about the use of electricity go in line with the ones provided by the Energy for All Report of the IEA (2011d) which predicts electrification rates of 98% in urban areas and 84% in rural areas by 2030.

5.1 Energy services

This section of the report analyses the different energy services demanded in the residential sector.

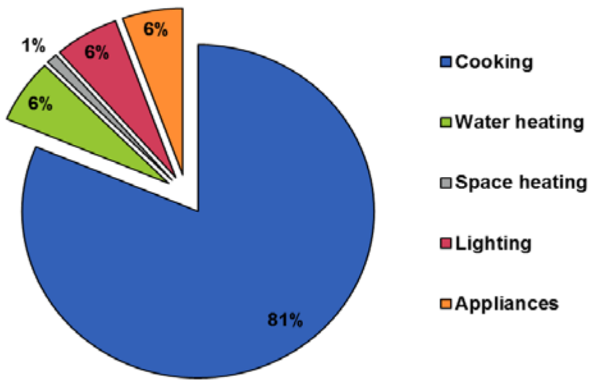

Figure 10 Energy demands per functional use in the Indian residential sector 2010

Figure 10 represents the final use of energy of the Indian residential sector as a result of the research conducted. Total final energy consumption in 2010 was 6401 PJ. Following my own calculations, biomass, accounts for an 81% of the total final energy used in India in 2010.The results for 2009 are an 11% lower than the data extracted from the IEA 2011 Energy Balances which provides an energy consumption of 7,221.3 PJ in the residential sector for that year.

The fuel mix used in the residential sector includes biomass, electricity and LPG. Coal and kerosene are reducing their shares during the last years. Pachauri and Jiang (2008) shown than natural gas is not widely distributed in India. Therefore, LPG is assumed as all the gas fuel consumed in India. In the case of biomass, Venkataraman et al. (2010) assumed a 5-15% of non-renewability for wood harvested in India while other type of biomass like crop waste and dung are accounted for as renewable sources. Following this report, I have set the fraction of non-renewable biomass (NRB) to 10% of the total used as feedstock.

5.1.1 Cooking

Cooking remains as the first use of energy in the Indian residential sector, around a 75% of the final energy used. This fact is explained by the high amount of people relying on traditional biomass for cooking. The rate of shift to modern forms of fuel is very slow at around 0.7% and, accounting for demographic growth, the use of traditional biomass plateaus in the short-term (Venkataraman et al., 2010).

The minimum useful energy required for cooking in rural areas of India was estimated to 2.57 MJue/Cap/day (Ravindranath and J. Ramakrishna, 1997) whereas 2.17 MJue/Cap/day is used in urban centres (TERI, 2006). The final energy demand is bound to the fuel mix used for cooking and the technologies efficiency. Cooking fuel shares were extracted from different reports (UNDP & WHO, 2009; NSS 58th, 2005; NSS 66th Round, 2011) and are shown in appendix 1 to this report.

The energy performance is calculated in relation with the heating value of the fuel and the type of device (Isaac and van Vuuren, 2008). The most common technology is biomass cookstoves which uses to be very rudimentary. The penetration of improved cookstoves (ICS) was estimated as an 8% of households in 2009 (UNDP & WHO, 2009).

Table 8 Pollutant emissions from wood fuelled traditional biomass (g/day)

	BC	CO	CH4	N2O	CO2
g/day	3.4	390.1	28.3	0.5	11,145.5

Table 8 presents daily pollutants emitted from a rural household using traditional cookstoves. It is assumed 5 inhabitants per household. A 15% more energy is used for meeting water heating energy services. Total useful energy use is almost 15 MJ/hh/day and, assuming 17.6 MJ/Kg wood (Bailis et al., 2007), the daily feedstock requirement of a cookstove with an efficiency of 15% equates to roughly 6 Kg of Wood.

5.1.2 Water heating

In 2002, just a 6% of the households in urban areas and 0.4% in rural areas owned a water heater (NSS 58th). This fact is partly explained by the assumption that an 80% of the population did not require hot water because of climate conditions and consumers preference (TERI, 2006). Due to the Indian hot climate, hot water demands ranges from 4 months per year to around 9 months per years in middle climate regions (Maithel et al., 2010).

Also, as a result of low economic development, not all households are equipped with bathroom which can be used as other indicator of the low penetration of water heaters. In rural areas of India the amount of households without a bathroom have dropped from 87% in 1993 to 64% in 2009 whereas this proportion declined from 32 to 22% in urban areas during the same time period (NSSO 65th, 2010).

Northern regions of India have the highest water heating requirements, in rural areas the use of biomass has been estimated as a 15% of the annual amount used for cooking (Maithel et al., 2010) which equate to 0,39 MJue/Cap/day. In the case of urban areas data was subtracted from a value of 4500 MJ/year in 2000 as an aggregated estimation of cooking and water heating (de la Rue du Can et al., 2009b), resulting in 0.42 MJue/Cap/Day or a 16% of the energy required for cooking. Therefore, it is assumed that households relying on stoves for meeting hot water requirements use a 15% of the energy used for cooking.

Electric geyser of 1.5 KW with a capacity of 15 or 25 litres are becoming popular and its stock was estimated around 10 Million units in 2008 (Prayas, 2010) with an annual growth of over 15% up to 2020 (Maithel et al., 2010; de la Rue du Can et al., 2009a). In India, a labelling scheme has been developed for electric storage geysers limiting limits stand-by losses of energy. The losses of a 25 litres capacity storage geyser are of 1.38 KWh/Day/45°C for a 1 start rated device and lower than 0.69 KWh/Day/45°C for the best devices, a five start rated device (BEE, 2012).

Also, the Indian residential sector accounts for the 80% of the overall SWH capacity installed and it is expected to contribute to an 84% of the total installed capacity by 2022 (Maithel et al., 2010). 0.89 Million households are already using solar water heaters (SWH), a 0.4% of the total building stock, with a growth rate of 24.8% during 2004-2008. Households install on average 3m2 of collector area rendering 150 litres per day of hot water and SWH is assumed to satisfy annual domestic needs (Maithel et al., 2010).

Useful energy required for each fuel is estimated as a rough approach to low hot water demands at low economic rungs. van Ruijven et al. (2011) projected water heating energy requirements as a correlation to household incomes leading to maximum values of 8.5 MJue/Cap/day by 2035. However, following my own calculations, this assumption would skyrocket water heating energy consumption. Then, I have followed assumptions by TERI (2006) giving a rate of growth of 13.65% in rural and 8.27% in urban areas for each type of fuel used. This growth is coupled with the growth of households using water heaters as a result of better equipped households. Therefore, useful energy consumption in 2035 will be 1.3 MJ/Cap/Day in rural areas while 4.5 MJ/Cap/Day was equated for urban areas of India. The share of households requiring hot water is expected to be a 72% in rural areas and a 97% in urban areas in 2035.

5.1.3 Lighting

Incandescent Lamps (ICL) remain the most widespread lighting technology. ICL was estimated as a 90% share in the residential sector of India in 2009 (Heer, 2010). The Indian Ministry of Power estimated the penetration of CFL in the same year to be around 5-10% (IMP, 2010), while Fluorescent lamps (FL) are assumed to account for just a 3% of the electric lamps.

ICL lighting points on the residential sector were estimated as 400 million (UNFCCC, 2009) which, including the 10% market share of other electric lamps, averages 2,85 lamps per household with access to electricity. This number of electric lamps varies largely among different household income levels. A previous work from TERI estimated that low income households will be equipped with just one lamp while others may have an average value of 6 lamps per household and it estimates a more extended use of tube light (FL) (TERI, 2006). Another source of information gave a different stock of lighting points in the residential sector. The stock was estimated around 302 for ICL, FL 280 and CFL 68 Million lighting points in 2008 (Praya, 2010).

I have used the lux approach and set the minimum illuminance in households to 150 lux (lum/m2) as an average luminous flux per unit floor area. This value was resolved after reviewing a paper by ESMAP (2010) which indicates that electricity accounted for a third of the total residential electricity in 2007. The average lighting energy consumption in 2011 was then equated to 343 KWh per household in urban areas and 375 KWh per household in rural areas with access to electricity. Rural households use more electricity for lighting as, on average, household size is a 20% higher. In comparison to other countries, average lighting in Austria is 357 KWh and Malta 1172 KWh (ECBS, 2010). The resulting total energy use for lighting in India in 2011 is 62,855 GWh while the World Bank (2008) predicted 57,786 GWh for the same year.

On the other hand, almost a third of Indian households still rely on kerosene lamps for meeting lighting energy services (Indian Census, 2011), a 45% in rural and 7% in urban areas. Following the research by Mills (2003), households using hurricane kerosene lamps, the most widely used in India (TERI, 2006), are estimated to consume 4 litres of kerosene per month. More recently, Rao (2012) assumes households with a monthly consumption below 4 litres to be allocated exclusively to lighting energy services. Therefore, I have assumed 4 litres/month of kerosene consumption for lighting in households without access to electricity (Kerosene, 37.6 MJ/l).

5.1.4 Space heating and cooling

Indian hot climates are responsible for a 15 to 20 times more energy required for cooling than for heating needs (Singh and Garg, 2009). Therefore, few country studies have looked at heating energy needs. ESMAP (2002) conducted a survey about energy patterns in rural areas of India. Heating demands occupied the third position of the ranking but it fell far behind cooking and water heating demands. This report was helpful for understanding energy patterns in rural areas but it did not shed light on a country basis.

Finally, I decided to set heating requirements to 1% of the overall final energy use in 2010. This share of final energy results in 17.8 TWh in 2010 while Prayas (2010) estimated electricity used in 2008 by electric room heaters to 5 TWh. This information was also useful for allocating fuel shares used for space heating slightly different to cooking fuel shares as I consider that poor households leave unmet most of their heating energy needs.

Energy intensity was then equated, after accounting for the technology effect, to an energy intensity of 49 KJ/m2/HDD. Following the same procedure as Isaac and van Vuuren (2008), energy intensity tends towards 100 KJ/m2/HDD in the year 2100.

Nowadays, cooling needs in India are mainly met by fans and air coolers (van Ruijven et al., 2011) but air conditioning market share is expected to growth as more households can afford it. For example, a report from McKinsey (2009) estimated that the 60% of the commercial sector and 4 of each 10 households in urban areas will be air conditioned by 2030. Rates of penetration of space conditioning appliances are presented within the electric appliances section.

Energy used for air conditioning follows the procedure by Isaac and van Vuuren (2008) which equates to an average air conditioning energy consumption of 1315 KWh/year. Energy consumption for fans and air coolers was set at a baseline value of 112 KW/year for fans and 195 KWh/year for air coolers (Prayas, 2010; de la Rue du Can, 2009a).

5.1.5 Electric appliances

In India, the most electricity consuming appliances in 2010 were fans, electric geysers and refrigerators (ESMAP, 2010). Rates of appliances ownership were extracted from national surveys and other research papers (NSS Round 55th; NSS Round 58th; NSS 61st Round; World Bank, 2008; De la Rue du Can, 2009; Prayas, 2010). Projections for the penetration of appliances were correlated to the growth of household income. Due to higher household income in urban areas, the large shares of these appliances are found in urban centres. The results can be reviewed in appendix 1 to this report.

Table 9 . Stock in 2000 and 2010 and yearly energy consumption (units and total)

Type of appliance	Stock 2010 (Mil.) Own estimation / World Bank	KWh/unit in 2010	Consumption 2010 (TWh) (own results)	Stock 2030 (Mil.) Own estimation / World Bank
Air conditioning	5.3 / 4.7	1314	6.0	49.3 / 48
Refrigerator	49.4 / 57	571	28,1	211.2 / 201.4
Washing machine	14.9 / 16.5	239	2.9	69.7 / 99.7
Television	117.1 / 139.6	176	20.6	296,3 / 295.8
Fan	380 / 353.9	112	39,6	965.3 / 1091.7
Air Cooler	28 / 38.5	195	4.9	182,7 / 168.9

Table 9 presents energy consumption per device and in absolute values in 2010. The process for calculating appliances energy use is explained in the appendix 2 to this report and, with the exception of washing machines, fits with the results of Prayas (2010). As well as air conditioning, energy intensity of televisions is expected to growth by the increase of screen size. Refrigerators, fans and air coolers are not expected to suffer any major change and its baseline energy consumption remains constant. On the other hand, operating hours of washing machines follows a downward trend as household size decreases. The estimations of appliances stock in 2010 and in 2030 are compared to a data provided by the World Bank (2008).

Fans are widely spread in India and the projections situates almost 2 fans per household of urban centres by 2020 and keeps growing up to 2.5 fans per household in 2035. During 2025-2030, a 1 fan per household rate will be achieved in rural areas of India. In the case of air cooler, 1 per 4 urban households owns one in 2010 growing to more than a 60% of households in 2030 while in rural areas 40% share of households will use air coolers by 2035.

India is the largest producer and user of ceiling fans and sales market has been projected over 40 Million per year in the period 2012-2020 (IMP, 2012). Fans are the largest end-use of electricity in households with the exception of lighting fixtures. Also, air coolers consume a significant amount of electricity in Indian households. Both cooling devices account for over 80% of the energy consumed by small appliances

(Prayas, 2010). In this report, energy consumed for the use of other small appliances, such as radios and computers, is assumed to keep the same proportion and thus, small appliances are estimated to account for a 20% of the energy used by fans and air coolers during the time period 1992-2035.

Box 2. Energy use in slum areas

The lack of information hampers the development of a dataset for end-uses of energy in slums. Hence, this box summarises the most important habits of slums inhabitants collected from previously reports or assumed in this research.

A large amount of the population living in slums has to cope with energy poverty. A 25% of urban population still relies on biomass cooking fuel (IEA, 2011) which is predominant among poor people living in slums. Also, due to the lack of tap water, water heating energy demands are expected to be very low and met by traditional cookstoves. Therefore, water heating energy demands can be defined similarly to rural areas as around a 15% of cooking energy needs (de la Rue du Can et al., 2009b). Pollution as a result of biomass combustion is responsible for health problems among the slums´ population (USAID, 2004). Please refer to section 5.1.1 in which pollutants emitted from traditional cookstoves where analysed.

Only 1% notified and 7% non-notified slums lack electricity connections in 2009 (NSS 65th, 2010). In slum settlements, stealing electricity has become a normal habitat and thus, electricity is almost universal as free electricity is seen as a right. In other cases, households have to pay higher costs for illegal service than the official market price as they lack legal connections (USAID, 2004). As Indicated by Powergrid, India accounts for the highest electricity transmission and distribution losses (T&D) of the world. T&D in India has been estimated as high as 35% whereas electricity theft represents 20-25% of the generated power (Winther, 2012).

6 Scenarios analysis towards 2035

This chapter show the results of the model developed for assessing energy use and GHGs emission of the Indian residential sector. The baseline scenario depicts the residential sector in the absence of any mitigation measure. The policy mitigation scenario includes on-going initiatives promoted by the Indian government. The aggressive mitigation scenario presents other measures that could enhance the current commitment. This measures are extracted from previous research papers or best-case examples collected from other world regions.

6.1 Baseline scenario

This scenario presents the expected development of energy consumption and GHG emissions of the Indian residential sector as observed in historical data. In absolute terms, energy consumption keeps growing at an average rate of 1.5% during the period 2010-2035. This low rate of growth is explained by the combined effect of the decreasing use of biomass as main cooking fuel and the strong push on the demand for LPG and electricity. Regarding that just 10% of biomass is accounted for a non-renewable source, the growth on GHG emissions is expected to increase at a much faster pace than final energy consumption.

6.1.1 Fuel mix in the Indian residential sector

Indian residential sector is slowly moving away from biomass and kerosene and, especially in urban areas, tends to use LPG as fuel for cooking. In 2030, 75% of the urban population is expected to use LPG as the main fuel for cooking and a 31.5% of households in rural areas. By 2030, the use of biomass is reduced to a 14% share in urban areas while a 65% of households in rural areas keep using it as the main fuel for cooking in the same year and the share is reduced to a 57% in 2035. A 10% of households in urban areas are estimated to use electricity for cooking in 2035.

The other important energy service which can use different fuel mix is water heating. Based on the papers reviewed, 2.4 Million SWHs are installed by 2030, or a 0.8% of the total household stock, being the 89% of the capacity installed in urban areas. The most widely used fuels in urban areas are gas boilers with a 51% share and electric geysers with a 39% share in 2030. In rural areas, a 64% of the population use biomass cookstoves feedstock in 2030 while a 27% is expected to shift to LPG and an 8% to electric devices.

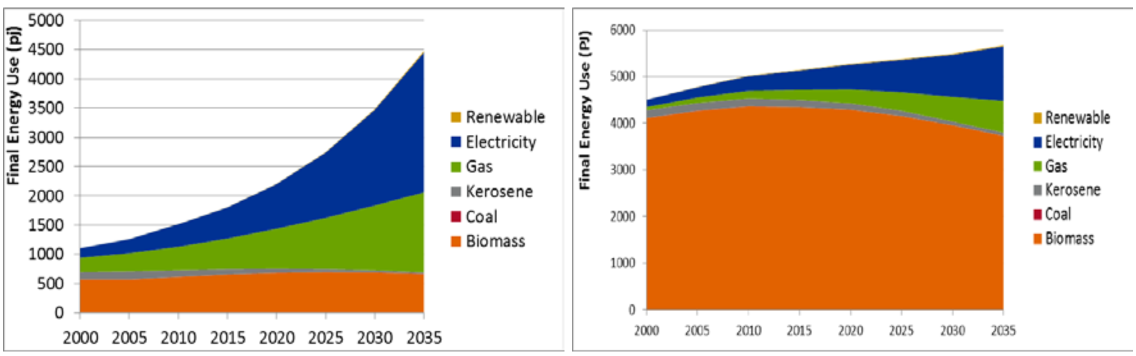

Figure 11 Energy Flows to urban and rural areas of India

Figure 11 present the different distribution of fuel shares in urban and rural areas. Renewable energy sources included in this scenario are a small amount of SWH and even lower share of biogas. Due to the push of electricity demanded for appliances and its use for other energy services, electricity demand experiences a sharp increase in urban areas which in 2035 amounts to over six times the demand in 2010. In rural areas, electricity is expected to increase by a factor of three during the same timeframe. The most meaningful event is the decrease on the use of biomass which is perceived at the end of this decade.

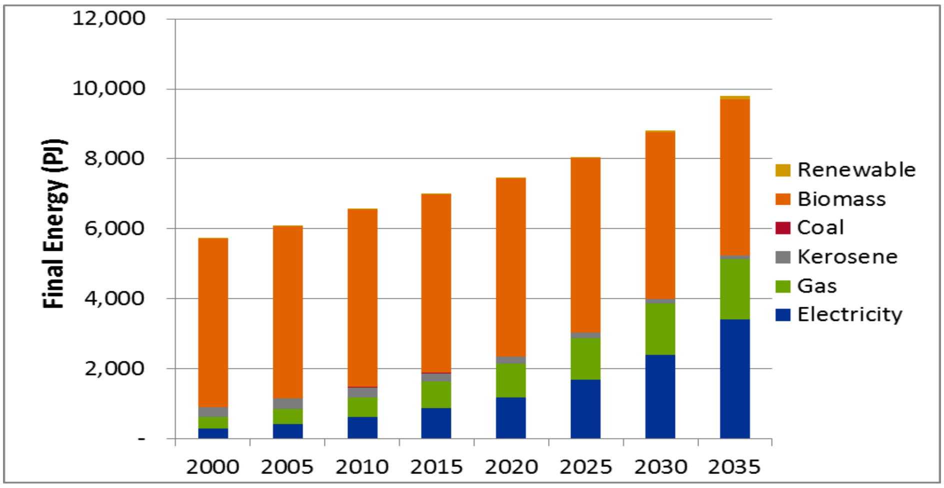

Figure 12 Final energy use in the Indian residential sector

Figure 12 shows the total consumption of final energy use in the Indian residential sector. The demand for biomass is almost equal with a 4% decrease from 2000 to 2035. Coal and kerosene keep decreasing towards insignificant fuel shares in the near future. On the other hand, electricity presents 7% annual growth during 2000-2035. In 2035, electricity consumed by the residential sector alone is close to 7 times as much as the amount consumed in 2000. At an annual growth rate of 5.6%, LPG's demand in 2035 is over 4 times the amount consumed in 2000.

6.1.2 Development of domestic energy services

Energy consumption is driven by an increasing demand of more and of a better quality energy services. The historically low energy consumption of households is changing abruptly. This change is taking place in urban areas while energy consumption is rural areas is stagnate during the next years.

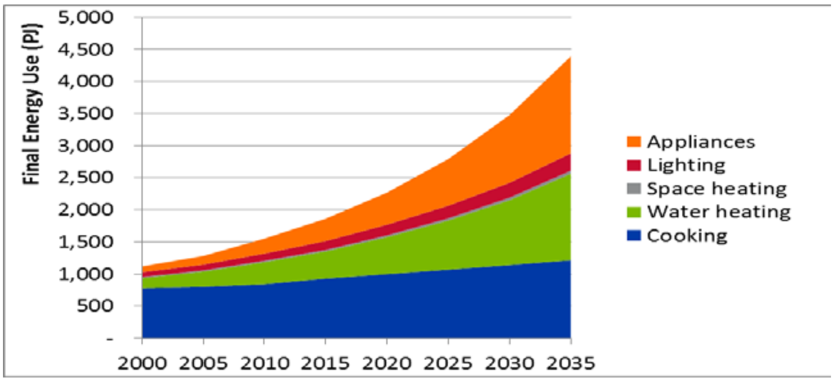

Figure 13 Energy services demand growth in urban areas of India

It is expected a sharp demand increase for modern fuels in urban areas. Figure 13 explains this increase as a result of the affordability of electric appliances. In 2035, the use of appliances requires 407 TWh of electricity per year in urban centres added to the 75 TWh demanded for lighting. Water heating energy demand is also a very important functional use with 1500 PJ of final energy consumption per year in 2035.

In terms of energy intensity of the residential sector, energy consumption of a person living in urban areas is expected to increase, from 4.1 GJ/year in 2010, 57% share of modern forms of fuel on average, to 6.6 GJ, 85% modern fuels, in 2035. A household will consume on average 17.3 GJ in 2010, or 0.43 GJ/m2, in 2010 while in 2035 the same house is expected to use 21 GJ, or 0.5 GJ/m2.

Due to the lack of information about energy use in slum areas it is not possible to accurately predict energy intensities in these settlements. Although electricity is widely used (Box 2), almost half of the slums inhabitants have incomes below the poverty threshold (Box 1). Therefore, energy poverty is an acute problem in slum areas.

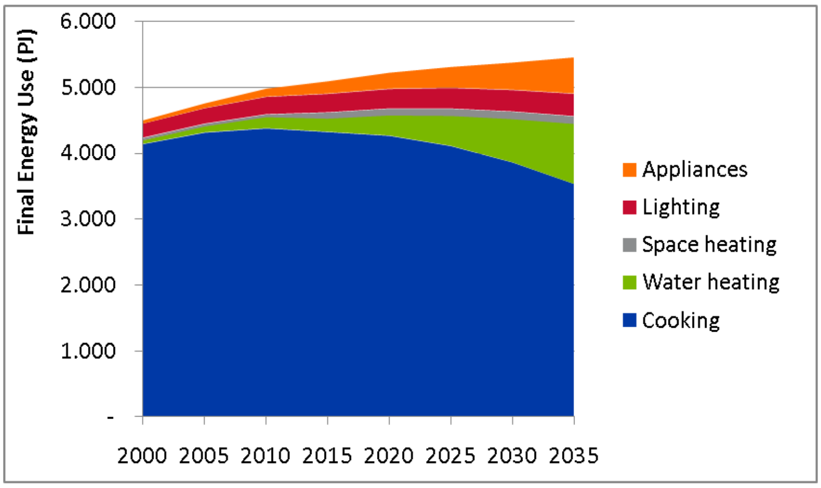

Figure 14 Energy services demand growth in rural areas of India

Figure 14 depicts a different situation in rural areas as the high reliance to biomass and low conversion devices makes this fuel the most consumed final energy use. LPG, a more efficient fuel, is expected to gain a larger share of the fuel mix and it is the main factor explaining the reduction on energy required for cooking. Furthermore, the 147TWh of electricity used for appliances in 2035 is around 4.6 times larger than in 2010. Electricity demands for lighting reaches 94.5 TWh in the same year. Water heating energy demands represents the highest growth on energy services demand which amounts to 911 PJ in 2035 or more than 5.8 times as much as the energy required in 2010.

In rural areas, a person consumes 5.8 GJ are consumed per person in 2010, a 13% of it was modern fuels, while in 2035 it is expected to consume 5.3 GJ/Cap/year, on average a 46% share of modern fuels. A household consumed 29.4 GJ in 2010, or 0.67 GJ/m2. In 2035, the same household is expected to consume 24 GJ of final energy, or 0.53 GJ/m2. On average values for 2035, a person will use just 51 Kg of oil equivalent per year of modern fuels which is halfway below the IEA target for accessing modern energy services (100 Kgoe).

6.1.3 The boom of electric appliances in the domestic environment

Market sales of electricity appliances are ramping up at a tremendous rate. This fact makes the use of electric appliances the main increase on energy demanded by the Indian residential sector. The projected baseline scenario is underpinned by historical data of penetration rate of most important appliances and assumes a relation with households' income as the only factor determining future rates of ownership.

This baseline scenario also accounts for autonomous efficiency gains in the use of domestic devices. Some examples are a 6 points percentage more efficient gas water heaters or 26% more efficient air conditioners in 2030 compared to 2010. The technology effect applied for analysing energy consumption of the different energy scenarios is furthered in the Discussion Chapter.

On the other hand, this scenario assumes same market shares of lighting systems in 2030 as observed in 2010. Therefore, the mitigation scenarios shows the impact of shifting to more efficient lighting bulbs.

Several country analyses have estimated the increase on electricity demand as a bottom-up approach to the penetration of appliances (World Bank, 2008; Letschert et al., 2009; van Ruijven et al., 2011). In this report, the expected increase on appliances ownership fits similarly with the World Bank (2008) estimations. Please refer to table 9 in chapter 5 for more information.

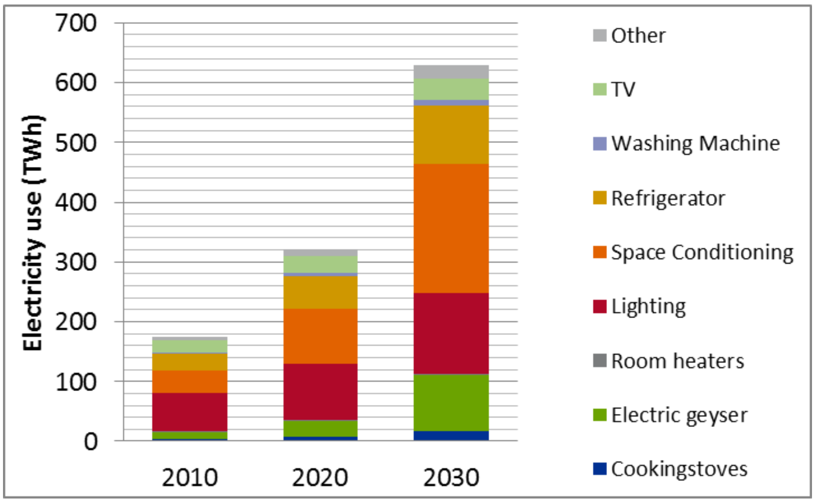

Figure 15 Energy consumption by major appliances in India

Figure 15 presents the modelled development of electricity used for different devices. Lighting left the first position of electricity consumption, decreasing from a 34% share in 2010 to 18% in 2030. The first position is taking over by space conditioning appliances with 21% to 28% in the period 2010-2030. Electric geysers are also important consumers of electricity with over 10% in 2010 and 21% share in 2030. Refrigerators account for a 15% electricity consumption in 2010, 16% in 2020, and 13% in 2030.

6.1.4 GHG emission developments in the baseline scenario

Finally, it is shown GHG emission from the Indian residential sector of the baseline scenario. Only CO2, CH4 and N2O, are included in the analysis. This analysis is marked for the high dependence to biomass which just a 10% was accounted for as a non-renewable source. Also, coal is the predominant fuel for electricity generation and thus, electricity emission factor is very high. I do not address the possibility of lowering this emission factor in the future, although, as seen in several research papers, this possibility can be expectable (Daioglous et al., 2011).

GHG projections are presented in Figure 16. In this figure, CO2 equivalent emissions are sorted by type of energy service rendered. It can be perceived the abrupt increase on GHG emissions from the residential sector which develop at an average annual growth rate of 5.6% as to be over 6 times higher in 2035 than in the year 2000. The major responsible of this increase is the consumption of electricity by appliances.

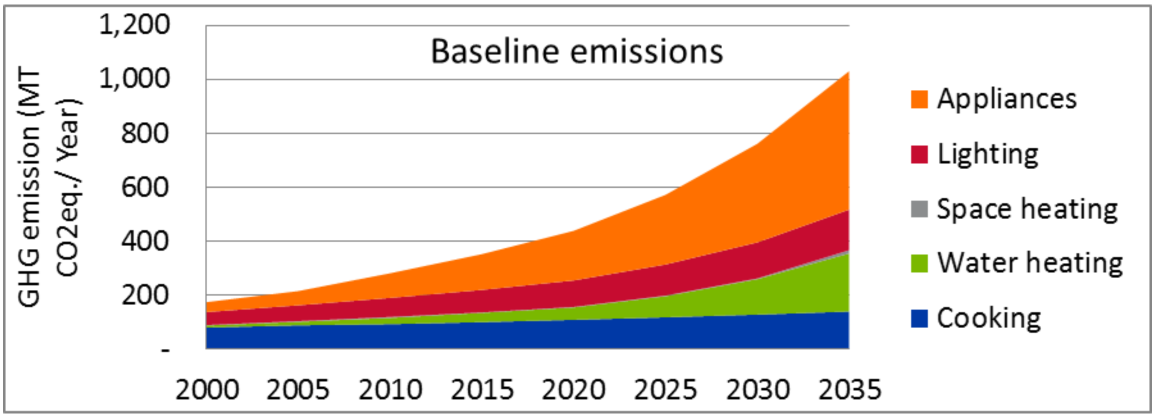

Figure 16 GHG emissions projections for the baseline scenario

From this point of view, CO2 equivalent emissions from cooking are less relevant than other energy services. Nevertheless, the combustion of biomass is also responsible for the emission of other pollutants with detriments effects for both the environment and human health. Traditional cookstoves were shown in the Mitigation Measures chapter as a responsible of a high rate of premature death from indoor pollution with, among others, black carbon. This pollutant was identified as the second most important contributor to climate change after CO2 (Foell et al., 2011). In this baseline scenario, I assume an improved cookstoves penetration rate of 2% in relation with the 8% of households using it in 2010. Therefore, a 12.75% of the biomass cookstoves in 2035 are modernized. Taking into account the efficiency of conversion of each device, almost all final energy use is used from traditional biomass cookstoves.

Table 10 Pollutants emission from biomass combustion in baseline scenario (KT/year)

	2010	2015	2020	2025	2030	2035
BC	166	164	162	157	151	142
CO	18,991	18,667	18,430	17,954	17,178	16,209
CH4	1,359	1,336	1,318	1,284	1,228	1,158
N2O	24	24	24	23	22	21
CO2	564,054	556,388	551,466	539,584	518,774	492,211
Assumes all biomass as wood						

Table 10 presents thousand tonnes of different pollutants emitted per year from the combustion of biomass in cookstoves. The main energy need which is met by cookstove is cooking but also final energy used for water and space heating is represented in Table 10. Around 166 thousand tonnes of BC and 19 million tonnes of CO were released to the atmosphere in 2010. In 2035, the emission of these substances is decreased by a 16% as a result of the penetration of ICS and the shift away to other forms of fuel. Added to the other pollutants emitted, the contribution of traditional cookstoves to global warming is very significant.

6.2 Indian Government Current Policies Scenario

This scenario is built upon Indian government initiatives related with the use of energy and GHG emission mitigation and the expected penetration of low carbon technologies in the built environment. Therefore, this mitigation scenario is a more realistic projection of how the Indian residential sector may look like over the next decades and differs from the baseline scenario which was mainly forecasted to follow the trends observed on historical data. Major mitigation measures are analysed by their potential impact on reducing energy and GHG emissions.

Table 11 Impact of the Government Mitigation Plan Scenario by 2030

Initiative	Energy service	Type of measure	Fuel adopted	energy savings (GJ/hh/Year)	Households affected (Million)	CO2 eq [2] mitigated (MT/Year)
NBMMP	Cooking	Fuel switching	Biogas	29.84 [1]	15.2	2.48
NBCI	Cooking	Energy Efficiency	Biomass	17.05 [1]	96	8.9
JNNSM	Water heating	Fuel switching	Solar	4.35 [1]	19.7	6
Off-grid	Lighting	Fuel switching	Solar	1.8	20	2.8
BLY	Lighting	Energy efficiency	-	0.98	402	96.4
S&LS	Appliances	Energy efficiency	-	0.5	-	49

[1] It assumes a 4.5 occupants/household. Electric geysers substitutes for SWH.
[2] GHG included: CO2, CH4, and N2O. NRB: 10%

Table 11 summarizes the expected outcomes of the different government initiatives. The phase-out of incandescent lamps and the labelling of electric appliances are expected to achieve interesting electricity savings. The replacement of electric geysers by SWH is also very recommendable. The use of improved cookstoves is seen crucial for modernizing cooking energy service. The following sections explain all the initiatives undertaken by the Indian government.

6.2.1 Fuel Switching Measures: Cooking with biogas

The National Biogas and Manure Management Programme (NBMMP) provide subsidies for the purchase of family type biogas digesters. The potential of this fuel switching initiative has been estimated to 12 Million digesters (MNRE, 2012). This scenario assumes the shift from biomass cookstoves to biogas digesters and the fulfilment of the initiative by 2025. The use of family type biogas digesters will double from over 5 million units installed by the same year assumed in the baseline scenario. Assuming that all biogas digesters are substituted for traditional biomass stoves roughly 7,000 tonnes of black carbon and over 0.85 million tonne of CO are not emitted per year in addition to CO2 equivalent emission generated from the combustion of non-renewable biomass (NRB).

6.2.2 Energy Efficiency Measures: Improved Cookstoves

The National Biomass Cookstoves Initiative (NBCI) was launched in 2009 as a series of pilot projects for assessing different types of cookstoves. The goal of this initiative is to increase the current 8% share of households using improved Cookstoves (UNDP & WHO, 2009). It has not been stated penetration targets yet (World Watch Institute, 2012). In order to include this project within this mitigation scenario, I have reviewed the previous initiative targeting biomass stoves, the National Programme on Improved Chulhas (NPIC). It was reported that, as a result of this programme, 35 million cookstoves were distributed during 1985-2002 (Venkataraman et al., 2010). However, this initiative was questionable by the low durability and usage of the new stoves as most families moved back to previous models (US EPA, 2012).

Regarding this precedent, I assume ICS to increase annual sales in 10 point percentages in addition to the 2% of the baseline scenario. This commitment implies over 4 million ICS at the early stage of development. I assume the up-scale of the initiative by keeping the ICS penetration rate at 12% increase and thus, traditional cookstoves are removed from households by 2035.

Table 12 Pollutants emission from biomass combustion Government Plan scenario (KT/year)

	2010	2015	2020	2025	2030	2035
BC	166	142	120	87	44	9
CO	18,991	16,220	13,598	9,822	4,796	593
CH4	1,359	1,158	966	688	316	0.004
N2O	24	21	17	12	6	0.004
CO2	564,054	495,300	438,906	360,207	269,791	215,637
Assumes all biomass as wood						

Table 12 presents the yearly pollutant emission under the implementation of ICS measures and deployment of biogas digesters. The reduction on the emission of this pollutant is very significant especially during the last years when all households are expected to use ICS.

6.2.3 Fuel Switching Measures: Solar Water Heaters

Jawaharlal Nehru National Solar Mission (JNNSM) is the national plan for Solar Energy enacted by the Ministry of New and Renewable Energy (MNRE). This plan provides soft loans and rebates for purchasing solar water heating systems and defines targets of 7 by 2013, 15 by 2017 and 20 million m2 of installed capacity by 2022 (MNRE, 2010). Maithel et al. (2010) forecasts an 84% of SWH capacity to be installed in the residential sector. In this scenario, 5.2 Million domestic SWH are deployed by 2022 or close to a 2% of the total households stock by 2022. This measure supposes a large effort from the 3.8 million m2 of capacity installed assumed by the same year in the baseline scenario.

6.2.4 Fuel Switching Measures: Solar Lighting Systems

The Indian Government currently incurs around USD 4 billion annually on kerosene subsidies. Being USD 2.2 billion for lighting purpose, an 82% of those subsidies are for low-income rural population (IFC, 2012). The use of solar lighting is seen as an economic solution for providing off-grid lighting to rural households whereas the light rendered is 8-10 times brighter than fuel-based lamps (Dish et al., 2010). Already in 2005, the Chaturvedi Report, published by the Indian NSSO, recommended to provide 50 million poor households with solar lanterns, costing 75 US$ each of them.

The total amount of households without access to electricity is estimated in this report as 84 million in 2010, rural areas accounting for a 93% of the total off-grid dwellings. As a result of the commitment of different organizations, it is estimated that 1.1 Million households are already using solar lighting systems (Abdullah, 2012).

This initiative has been now embraced by the JNNSM which aims to install 20 Million Solar Home Systems by 2022 (IFC, 2012). The fulfilment of this commitment will suppose that by 2025 a 40% of the off-grid households in rural areas will be withdrawn from using each of them 48 litres of kerosene per year.

6.2.5 Energy Efficiency Measures: Phase-out of Incandescent Lamps

The “Bachat Lamp Yogna” (BLY) is an ambitious initiative with the objective of replacing around 400 Million of ICL lighting points in the residential sector by 20W CFL models (UNFCCC, 2009). CFL bulbs have a performance of 51 to 56 lm per W or around 4 to 5 times higher than ICLs. I assume that the target will be fulfilled in 2020 and all ICL will be removed from the market, being replaced by CFL. Then, lighting energy requirements will be almost a 25% of the baseline scenario with average energy savings of 273 KWh per household and year.

6.2.6 Energy Efficiency Measures: Standards & Labeling Programme

The Bureau of Energy Efficiency (BEE) established in 2006 a standards and labelling scheme (S&LS) covering major domestic appliances. Since 2010, this energy rating is mandatory for frost-free refrigerators, room air conditioners, distribution transformers, and tubular fluorescent lights (TFLs) while its use is voluntary for, among others, LPG stoves, hot water storage tanks (geysers), colour televisions, washing machines and ceiling fans (CLASP, 2012).

The S&LS implemented in India serve as an information instrument in order to encourage consumers to purchase more efficient products. However, consumer's choice uses to be bound to other characteristics. In the case of refrigerators, it is better explained by the reduction in capital costs than by reduction on operating costs while in the case of air conditioning electricity costs is the most valuated factor. Also, the lack of awareness from the consumer side has been identified as a market barrier which constraints labelling systems to harvest expected results at the early stages of their implementation (Bhattacharya and Croppe, 2010).

The labelling system is assumed to spur the use of, on average, 15 % more efficient technologies than the shown on the business as usual scenario in 2025. For constructing this technology effect, I have assumed that the average energy efficiency of operating systems in 2030 are a 17% improvement for air conditioning, 12% more efficient refrigerators and washing machines and a 10% more efficient TVs and other small appliances.

6.2.7 GHG emissions in Government Plan Scenario

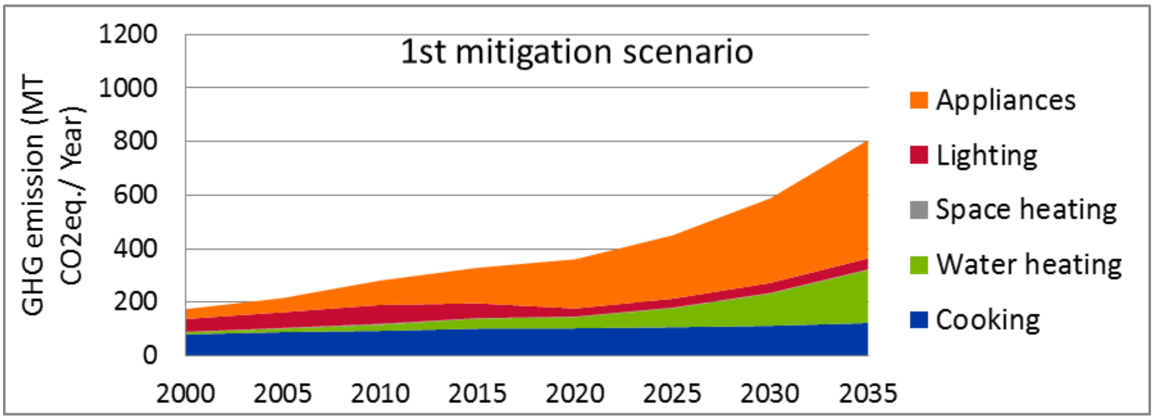

Figure 17 GHG emissions projections for the Government Plan scenario

Figure 17 shows the expected impact of the government initiatives under development which could achieve almost savings of 199 MT CO2eq. per year in 2035. This is an 18.6% decrease of the total emissions from the Indian residential sector in 2035. GHG emission from lighting systems is expected to be sharply reduced by the phase-out of lighting systems. The expected increase in water heating energy demands could be moderated by the use of SWH as well as electricity demand from appliances with the expected result of the implemented labelling system.

6.3 Aggressive target for energy performance

The Indian sector is very diverse and presents a huge scope for applying different mitigation measures. This scenario shows a more aggressive strategy for enabling millions of Indian households to access modern forms of fuel while achieving energy saving and curbing GHG emissions. All measures hereby explained are underpinned by country analysis or global best practices. Therefore, mitigation measures used in this mitigation scenario are also feasible to implement in India.

Table 13 Impact of the Aggressive Mitigation Scenario in 2030

Initiative	Energy service	Type of measure	Fuel adopted	energy savings (GJ/hh/Year)	Households affected (Million)	CO2 eq [2] mitigated (MT/Year)
Building codes	Space conditioning	Insulation	-	0.35	56	5.3
Modern cooking	Cooking	Fuel Switching	LPG	22.4 [1]	55	-14.25
LEDs	Lighting	Energy Efficiency	-	1.1	402	106.2
S&LS	Appliances	Efficiency	-	0.82	-	78.8

[1] It assumes a 4.5 occupants/household. Electric geysers substitutes for SWH. [2] Energy savings with regards to baseline scenario. GHG included: CO2, CH4, and N2O. NRB: 10%

Table 13 represents the expected outcomes of more ambitious initiatives for the reduction of GHG emissions in the Indian residential sector. Building insulation codes can achieve interesting results even though this scenario assumes a low enforcement of the building design regulations. Again, the most meaningful energy savings are achieved by electricity conservation measures. The fuel switching measure introducing LPG cookstoves is not advisable from an environmental point of view and it is better explained by potential co-benefits of shifting away from biomass. Finally, MEPS legislation is now seen as a necessary step for achieving a market transformation towards more energy efficiency appliances (APEC, 2009).

6.3.1 Building Envelop Measures: Soft and Medium Insulation Package

Heating requirements in India are regional and seasonal specific. As this report is a more global overview of the Indian residential sector, cooling requirements gain more importance. The implementation of building insulation measures is expected to lower electricity use for fans, air coolers and air conditioning. This measure could provide a better insulation of new and retrofitted buildings. An annual demolishing rate of 1% is assumed in this scenario, then increasing the rate of new buildings including insulation standards. Also, the retrofitting rate of this scenario was set to a 0.8 % of the existing building stock.

A soft package of measures, which savings of around 15% on heat loads, is implemented in a 30% of new and retrofitted buildings whereas a 15% of new buildings are expected to incorporate the medium package of insulation measures which a reduction of 25% of cooling requirements. These new standards are applied to buildings from 2015 onwards and thus, the number of better insulated households is expected to be a 1.6% in 2015, 6% in 2020, 10.3% in 2025, 14% in 2030 and 17.2% in 2035 of the total building stock. As a result of a more comfortable indoor temperature, the implementation of building envelop measures results in energy savings from space conditioning devices on the range of 0.3% in 2015, 1.1% by 2020, 1.9% in 2025, 2.6% in 2030 and 3.2% in 2035.

6.3.2 Fuel Switching Measures: Substitution of LPG for biomass fuel

Previously in this report, it has been explained the ancillary benefits of replacing biomass by modern fuels. The low implementation of ICS at the early stages of development supposes that in 2020 still 125 million households are using traditional biomass cookstoves. The United Nations Millennium Project encourages halving by 2015 the world population relying on biomass for meeting basic needs (Foell et al., 2011).

A fuel switching measure targeting biomass cookstoves is a slow process requiring a deep analysis of economic and social implications. Nonetheless, this scenario expects a boost of LPG stoves of 40 million more households using in 2030 and substituting it for biomass. The combined implementation of both fuel switching measures to biogas and LPG is expected to eradicate households relying on biomass for cooking in 2035.

This measure is not attractive from a perspective of certificated emissions reduction. With just a 10% NRB, LPG stoves generate more CO2 equivalent emissions as just more methane is generated from a biomass stove in relative terms. Also, regarding the success of the NBCI presented in the first scenario, black carbon emissions are not lowered with the implementation of LPG stoves. On the other hand, this measure could achieve that most Indian households reach the threshold recommended by the IEA of consuming 100 Kg of oil equivalent per year and person (AGEC, 2010).

6.3.3 Energy Efficiency Measures: Promotion of LEDs

Domestic lighting market is undergoing a substitution of halogen lamps and LEDs for inefficient incandescent bulbs. A report by McKinsey (2011) expects a breakthrough of LEDs in the residential sector, achieving a 70% of the market share by 2020. After the fulfilment of the “Bachat Lamp Yogna” initiative, the use of LEDs could be promoted as to achieve a 50% of market penetration by 2030 which would bring about an extra of 10,36 GWh of electricity savings per year. Compare to the baseline scenario, each household is expected to save 301.2 KWh/Year.

6.3.4 Energy Efficiency Measures: Implementation of MEPS

This scenario assumes the implementation of MEPS as a step forward from the current labelling system. MEPS describe a market “push effect” which harvests a more rapid and higher impact of the technology effect as compared to an informative instrument (du Pont, 2004).The assumption is that, since the market is internationalized, MEPS could also be enforced in India in order to match best practices.

I apply best case examples on standards enacted in other countries as provided in chapter 4. The MEPS included boilers, space conditioning devices, refrigerators, washing machines and televisions. Market sales are assumed to meet those requirements and the scheme would be strengthened each 5 years (Zhou et al., 2011). MEPS are implemented in 2016 promoting a 22% better energy performing electric appliances than the baseline average in 2030 and achieve 87. 2 Million Tonnes of CO2 equivalent reduction in 2030. Boilers are on average a 12% more efficient which brings about 12.3 MT CO2e./year.

6.3.5 GHG emissions in the Aggressive Mitigation Scenario

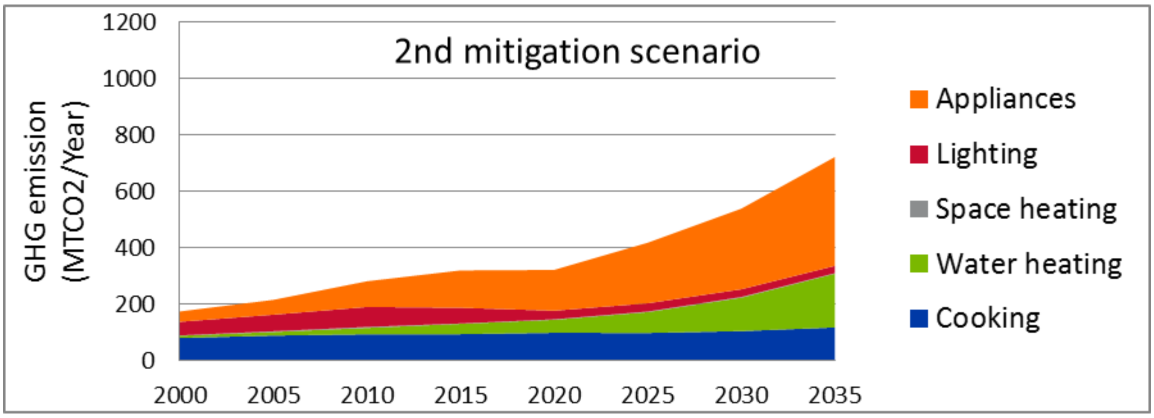

Figure 18 GHG emissions projections for the Aggressive Mitigation Scenario

Figure 18 depicts the total GHG emissions from the Indian residential sector considering the impact of all ongoing government initiatives and the new mitigation measures analysed in this scenario. Compared to the baseline scenario, this mitigation scenario curbs emissions by 280 million tonnes CO2e/year. The new measures included in this scenario achieve 86 MT CO2eq/year more than the governmental plan in 2035.

MEPS legislation is expected to provide a technology effect which, during the first years of its implementation, restrains the electricity demanded for its use in appliances. The promotion of LEDs shrinks GHG emission from lighting energy services as to make them relatively insignificant. In 2035, lighting accounts for just over 3% of the total GHG emissions of the Indian residential sector. Building insulation measures achieves moderate results and the fuel switching measure to LPG has a moderate backfire effect on GHG emissions mitigation.

7 Discussion

This chapter serves as to summarize the results of the analysis as well as to discuss main hurdles encountered during the development of the report. Also, some of the assumptions applied in modelling the Indian residential sector are stressed under alternative conditions or effects.

7.1 Summary of the results

As a result of this scenario analysis, different mitigation measures have been posed for reducing GHG emissions from the Indian residential sector. These measures are expected to moderate to some extent the unavoidable sharp increase of GHG emissions. Historically, the Indian population has relied on biomass and the demand for modern energy services was scant. Currently, pushed by economic growth, new energy services are demanded as well as more convenient forms of fuel.

Biomass consumption is responsible of more than 500 MT CO2e/ year in 2015. However, a 90% of the biomass used is accounted for as renewable, then constraining the potential GHG emission reductions of fuel switching measures to non-renewable sources. Nevertheless, it must not be forgotten the detriment effects to human health of indoor pollution. Different technologies can be deployed in order to enable more convenient ways of cooking. However, those technologies can incur in an economic burden that should also be taken into account (See table 6 as illustrative example of the cost of modern convenient form of fuels and water heating technologies). Initiatives for the widespread use of improved cookstoves could serve as improving the quality of living of millions of Indian households in the near future.

In this report, it is shown that the joint implementation of biogas digesters and LPG stoves could bring about the phase-out of biomass-based cookstoves by 2035. While the biogas initiative has been already embraced by the Indian Government, to achieve more than 40 million households can access LPG stoves by 2030 is a very demanding task. Nevertheless, there are some previous initiatives which impressive results. In Indonesian 50 million households were able to shift cooking-fuel from kerosene to LPG in approximately four years (Foell et al., 2011).

In India, an Initiative of TERI and Humboldt-Universität zu Berlin targets groups of poor families in Indian slums in order to distribute LPG stoves that will be shared by groups of 30 participating households. Each family contributes within their economic possibilities to buy a LPG connection and necessary accessories. This type of initiatives could result in an affordable way to encourage poor households to move away from biomass-based cookstoves (Werthmann, 2012).

The demand for gas fuels is growing substantially. Following my estimations, 9.2 million tonnes of LPG were consumed by the residential sector in 2005. Other research paper indicates that the LPG amounts to 12 Million tonnes in 2007-2008 and an 86%, or 10.3 Million tonnes, flowed to the residential sector (MSSRF, 2010). I project in the Government Policy Scenario that 21.6 Million tonnes of LPG is demanded by the residential sector alone in 2020. The promotion of LPG fuelled stoves presented in the aggressive mitigation scenario brings up LPG demands by a 25% in the same year. Due to the current constraints in the supply of this fuel, India faces an important challenge as regards of improving the LPG availability and distribution systems (MSSRF, 2010).

Other pressing challenge is to curb to some extent the increase on electricity demand which is projected in the policy scenario to be by 2035 over 4.5 times the electricity consumed in 2010. India is characterized by high distribution and transmission electricity losses as well as often blackouts (Alagh, 2011). To improve the electric grid and to enact new products design standards is a pressing need for ensuring the economic and environmental sustainability of the power sector.

The phase-out of ICL is expected to harvest the most important energy savings. It is recommended to continue this initiative promoting the use of LEDs, especially in the mid-term when this technology is expected to achieve marketable prices. In areas without access to electricity, combustion lamps could be replaced by solar lighting systems. The combined effect of all measures targeting lighting energy services could bring about 105 MT CO2e/year emission reductions.

Furthermore, building insulation measures can also reduce the sharp increase in energy consumed for cooling households. Building envelop measures are normally related with the reduction on heating needs but in the hot climate of India important energy savings can be achieved through a more comfortable temperature within well insulated buildings. Building envelop measures is estimated to reduce 5.3 MT CO2 per year with just a 17% of the household stock complying with building insulation standards by 2030. It must bear in mind that 75% of the Indian building stock in that year is still to be constructed and that, following the calculations of this research, more than 150 million households, a 70% increase, must be constructed from now until 2030.

7.1.1 GHG indicators in the residential sector of developing countries

Due to the low efficiency of burning biomass, the increase on energy consumption is deemed moderate as the push for electricity and LPG is undermined by the reduction in the use of traditional fuels. Therefore, the analysis of GHG intensity turns into a more accurate analysis of the expected development of the Indian residential sector.

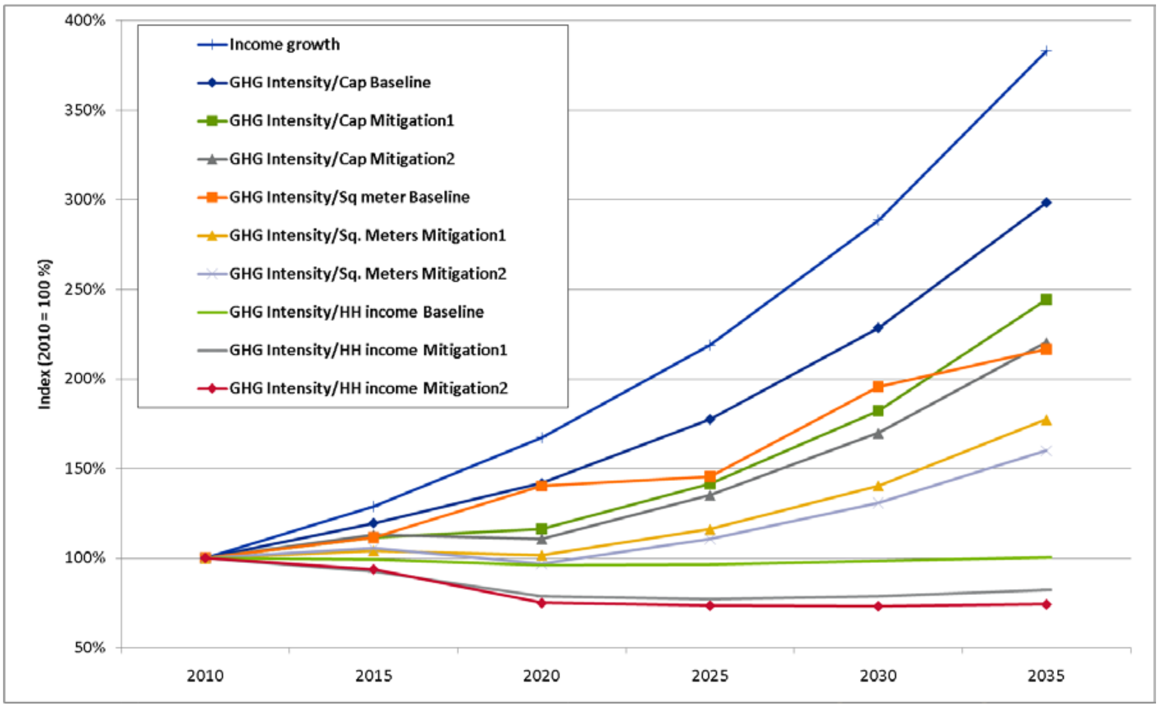

Figure 19 Evolution of GHG projections under main driving factors (2010 = 100)

This section explains how GHG intensity of different variables is expected to change in each analysed scenario. The volume of activity of the residential sector can be explained by population and floor space constructed. Also, the economic development has been shown as an important driver for energy consumption. Therefore, these three factors are used as patterns for analysing the expected energy intensity development in households of India.

Figure 19 shows the development rates of GHG intensity against population, floor space and household expenditures. Figure 19 was constructed as an index rate taking 2010 as baseline value. GHG per capita is expected to be more than three times higher in 2035. The most ambitious scenario can moderate the increase by a 25% with the highest decrease before 2020 when the mitigation measures analysed expects to have the highest impact. GHG intensity of floor space fluctuates largely in the baseline scenario as a result of high consumption of electricity for lighting. The phase-out of incandescent lamps is the main responsible for the reduction in energy intensity of buildings floor space in both mitigation scenarios.

The most important result of Figure 19 is the close relation that economic growth keeps with GHG emissions rate and, consequently, with energy consumption. While the baseline scenario is very well explained by economic growth, mitigation measures are expected to achieve a decoupling effect, mainly as a result of energy efficiency. This outcome of the analysis highlights how important mitigation measures are for reducing GHG intensity of the economy.

7.1.2 Role of energy efficiency legislation

Policymakers could take into account a wide range of initiatives to shape the development path for energy consumption. Setting new building codes can increase buildings insulation and thus, reduce the amount of energy needed for space cooling. Also, the implementation of a labelling and standards scheme has been used as a strategy for the phase-out of obsolete technologies and to inform consumers about the benefits of purchasing more energy efficient appliances.

India has already implemented a labelling system aiming to influence consumer's choice of more energy efficiency technologies. As a result of this legislation, it has been forecasted that 47 MT CO2 can be reduced per year. However, a more strict commitment to energy efficient technologies could double this amount up to almost 100 MT CO2/year emissions reduction by the year 2030.

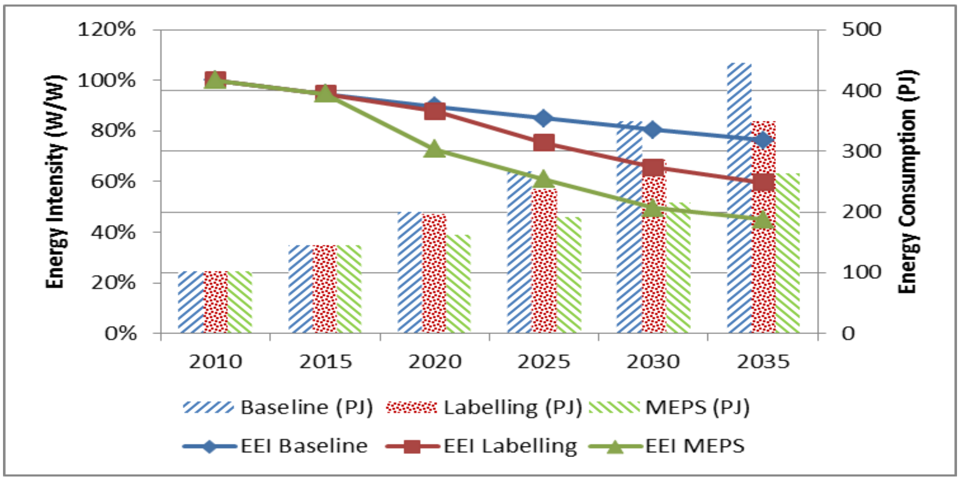

Figure 20 Expected technology effect for the different scenarios constructed

Figure 20 represents the importance of a rapid development of new legislation on MEPS. I use the examples applied for construction the scenario analysis of refrigerators energy use. I choose this appliance because it is an important consumer of electricity in households and their capital cost is the more valuated factor for its purchase (Bhattacharya and Croppe, 2010). The lifetime of this appliance is 15 years which means that total energy savings can be significant at the end of its useful life.

Figure 20 is constructed from different development paths including a baseline scenario which includes autonomous efficiency gains. A second path estimates the impact of a labelling system which, in line with du Pont (2004), has a moderate impact on consumers' choice at the early stage of its implementation. I have assumed that new sales have an average efficiency of 1 KWh/l in 2025.

Finally in the aggressive mitigation scenario, MEPS are implemented in 2016 banning refrigerators consuming more than 1 KWh/l (same target as the first mitigation scenario). As shown in figure 20, the result of implementing MEPS is expected to harvest energy savings at the early stage of its development, as it push the market of more efficient technologies by obligating product manufacturers to commit to design standards. When developing MEPS it has to be considered the premium cost of more efficient technologies as to create a cost-effective market transformation which does not suppose an economic burden for consumers.

7.2 Sensitivity analysis

The modelling of the residential sector requires the use of a fair amount of assumptions which increases the uncertainty of the predictions. This section analyse how sensitive the model developed is to changes in input parameters and tries to explain what if some factors are different from the input data applied to the modelling.

Economic factors are expected to develop in line with a GDP growth of 6.6%, as estimated by the IEO (2009). However, it is difficult to predict the average growth of the Indian economy over 20 years. Maithel et al. (2009) used three economic scenarios based on a GDP growth during 2010-2020 of, 5.5 for a pessimistic, 8.5% for an optimistic, and 7% for a realistic scenario. Similarly, I analyse the impact in the purchase of electric appliances of 5% and 8% economic growth rates.

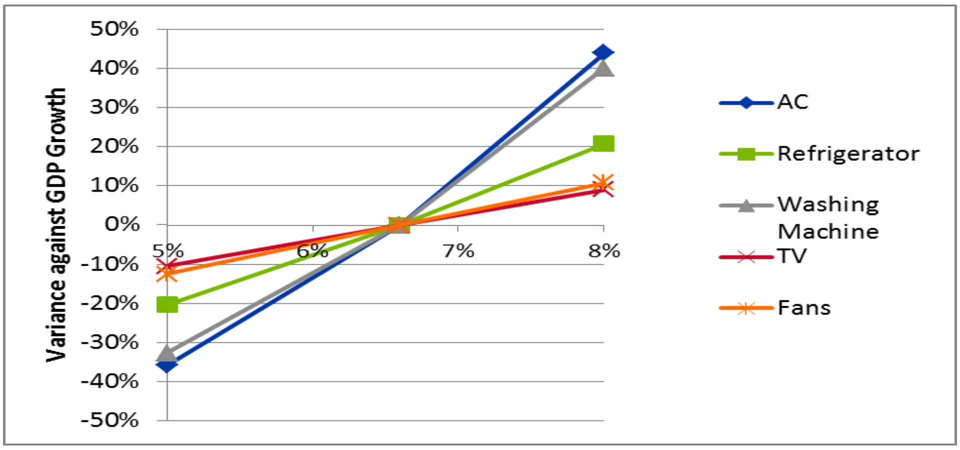

Figure 21 Sensibility Analysis of appliances ownership for economic growth fluctuations

Figure 21 shows that air conditioning and washing machines are more sensible to economic fluctuations. Air conditioning is an expensive appliance with high price elasticity as cooling energy services can also be met with fans and air coolers. Washing machines is not considered a basic need for a high amount of people as clothes washing is still carried out in a traditional way by a high share of the Indian population. Refrigerators ownership also differs in the two economic scenarios as refrigerators market is still far from being saturated. TV and fans are less sensible to exogenous factors due to the low price of fans and the high consumers' choice of televisions.

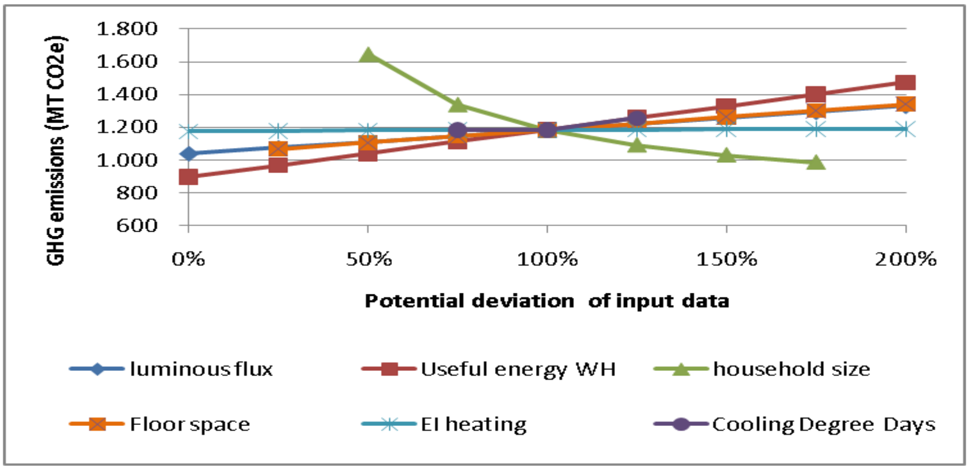

Figure 22 Impact to total GHG emissions of different input data to the model

Besides economic growth, other variables can influence final GHG emissions. Figure 22 shows how GHG emissions could vary with changes in other input data used in the modelling. GHG emissions for the baseline scenario have been used for illustrating this sensitivity analysis.

The variable which can affect by a higher degree final GHG emissions is household size. It is an expected result as household size defines the increase in the building stock. For instance, rates of ownership of appliances are directly related to the number of households and thus, increase the appliances stock and energy consumption.

The variability of luminous flux per unit of area (lux) responds to both more light intensity required and more operation hours. This factor shows a very similar performance to floor space per capita. Floor space can influence lighting energy intensity and also space heating requirements. Due to the hot climate of India, most of the energy consumed in relation to living area is explained by the use of lighting systems. Heating energy intensity was stressed by a factor of two but, as expected, the change in final GHG emissions is insignificant.

Useful energy for water heating shows also an important impact in the energy used. It is very difficult to come out with a precise value about this energy services as energy requirements can vary largely in relation to the technology rendering hot water, e.g. cookstoves or electric geysers.

Finally, cooling degree days (CDD) is also included to show how energy required in buildings could develop in the context of climate change. Also, it explains how energy used during hot year varies in relation to other with mild temperatures. It can be observed that at lower temperatures energy consumed may not differ significantly from the calculated baseline. On the other hand, it is expected highest energy requirements during hot year.

8 Conclusions

The objective of this research paper was to analyse different paths for GHG emitted as a result of energy used in the built environment. The research questions stated for achieving this objective are hereby answered:

- How can the built environment be modelled?

The wide variety of energy services and the variety of the fuel mix used makes the modelling of the built environment a very demanding task. An effective way to succeed in this endeavour is to conduct a bottom-up approach identifying energy services, main fuels demanded and main conversion technologies used within the targeted building sector. Understanding the performance of energy services is a required step for disaggregating total energy use into functional uses that can be more easily analysed. Identifying forms of fuel used for each functional provides information about the type and quantity of pollutants emitted and the type of technologies used within buildings. Finally, an analysis of the technologies helps to understand the amount of input energy required for rendering an output energy service.

- What variables have the biggest impact on GHG emissions from buildings in developing countries?

Variables playing a main role on GHG from the use-phase of buildings can differ in relation to the type of buildings. Among the, demographic and socio-economic factors are the main drivers for energy consumption. Other factors such as climate conditions, building physics and consumers' behaviour are secondary drivers which an important influence in final energy uses.

Energy demands from the residential sector are explained by demographic factors such as population growth and urbanization rate. Population is important for understanding the total volume of activity in the building sector as people benefits for the energy services and thus, they are the main responsible of energy consumption and trends in GHG emissions.

Urbanization rates results to be a fundamental indicator of the expected increase on energy demands. Enormous differences were observed in the development of energy consumption in rural and urban areas of India. In the appendix 1, It is shown the correlation of household income to appliances ownership. It shows that even at similar levels of household's income, households in urban centres present higher ownership rates. This characteristic could be related to social behaviour and lower availability of appliances in rural areas.

Therefore, other important factors are measured in monetary units. It has been shown that energy demands and GHG emissions are closely coupled with household expenditure. The use of economic factors involves uncertainty as a wide range of aspects such as the price elasticity of fuels and technologies and population density in the case of floor space could also affect the projected scenarios. It is recommended to use an economic model integrating micro and macroeconomic variables and to underpin projections with the help of other sources of information. The simplified approach used in this report considers that the compiled historical data is directly correlated to economic growth but in fact, many other factors determine consumers' behaviour.

Household size and floor area are two demographic and economic depended variables. Household size is an important factor of the modelling as it defines trends in housing stock. Floor area is widely used as a measure of energy intensity in the building sector and can be used for defining minimum energy performance of buildings. This variable is related to space heating energy demands and it can also explain changes in energy used for lighting.

Climate conditions are important as it dictates energy required for heating and cooling purpose. Building physic factors are also closely related to heating/cooling requirements as they determine how efficiently buildings are insulated from external temperatures.

- How can CO2 emissions be reduced by the use of different mitigation actions?

The building sector offers a wide variety of mitigation measures that falls into three main categories. These categories aim at reducing energy demands, the use of more quality fuels and the deployment of energy efficient and low carbon technologies. Some initiatives such as the phase-out of ICL are always advisable. In the case of other measures, it is the role of governments to choose which of them should occupy the first positions of their political agenda. However, it is recommended to implement as many different measures as possible and achieve better results from their synergies.

The most important technologies used in the residential sector of the analysed country explain energy demands and GHG emissions. The analysis of their energy performance provides information about how the residential sector could align with world best practices. Whether the government should focus on fuel switching measures to more convenient fuels or on enacting new energy efficiency regulation for improving the way energy is used in the built environment is a required step forward. Countries in which the population suffers from energy poverty are urged to deploy measures for pushing poor households closer to average living standards of the region.

The high building construction rates urge to regulate the design standards of buildings as to ensure a lock in effect of energy savings. The implementation of building insulation codes are normally enforced in a regional level as its impact is closely related to local climate conditions. In the case of countries with an expected high rate of growth of the building sector, such as the case of India, the government should not overlook this kind of measures as they can bring about important energy savings.

Fuel switching measures for reducing the use of biomass do not show important environmental benefits. This is explained by the lack of information about the impact of other pollutants emitted from biomass-based cookstoves. For instance, in the case of

India, treating 20% of the biomass combusted as non-renewable sources or given more importance to the global warming potential of, for instance, CO and black carbon, could include GHG emission reductions within the large array of benefits of this type of measures. Therefore, more environmental benefits from abolishing energy poverty could be added to the well-known social co-benefits.

Especially in rural areas, fuel switching measures to non-renewable sources can be hampered by difficult accessibility and the economic burden incurred to poor households. In this case, decentralized systems based on renewable sources of energy are highly recommendable.

To regulate the energy performance of domestic appliances has been already undertaking but most developed countries and it is increasingly implemented in developing countries. The purchase of some appliances with large operating costs is more influences by informative tools such as labelling schemes. Once that the labelling scheme is implemented, all countries are recommended to go a step forward and develop MEPS in order to ban low efficient technologies. Standards for energy performance of domestic appliances are expected to push the market towards more efficient products as soon as early stages of their implementation.

- How can mitigation scenarios be constructed in relation to the variables and mitigation actions studied?

This research question can be seen as to wrap up the main outcomes of this report. First of all historical data and other variables influencing the modelling are used for projecting a baseline scenario. In general, economic and demographic factors are main responsible for the expected increase on energy demands and GHG emissions in developing countries.

In countries departing from low levels of energy use in buildings, energy and GHG intensity per capita may not be the best indicator as mitigation measures may just moderate their increase. The same logic can be applied for intensities per unit of floor space. Therefore, to assess the potential of these measures to reduce the energy and GHG intensity of the economy provides a good indicator for assessing mitigation measures targeting the built environment of developing countries.

In the case of developing countries with a current high use of traditional biomass and coal, energy intensity indicators are not so meaningful for identifying the performance of mitigation measures. The replacement of low efficient conversion technologies offset to some degree the growth in energy consumption. Therefore, to directly look at GHG emissions can provide a more meaningful perspective to the impact of mitigation measures.

The mitigation scenarios used in this report explore different possibilities for reducing GHG emissions. The value of this type of model is that, by not seeking an accurate result, they can offer a broad variety of possibilities for curbing GHG emissions in the built environment. It is recommended to firstly identify those mitigation measures with a larger potential and, in consequence, undertake a more precise analysis of the selected initiatives.

8.1 Further research opportunities

The built environment of developing countries is still highly unknown by the research community. The high demographic and economic growth of India has attracted more attention and it was possible to find more information about its residential sector. One of the highest barriers encountered in my research was to find disaggregated data about flows of energy to functional uses in dwellings. It is recommendable to make a deeper research on how each functional use of energy is consumed among income levels within household. Among the poorest households, as in slum settlements, information is scant about both the use of energy and ownership of domestic appliances.

The international community should lead the efforts into a better understanding of how polluting substances such as black carbon are contributing to global climate change. This type of research could reveal further environmental benefits of fuel switching measures to modern forms of fuel in order to achieve further economic benefits from carbon markets.

Energy labelling should be seen as a first step into energy efficiency legislation but it is recommended to enact more strict design standards in order to ban inefficient products. More research is needed for understanding the real impact that information instruments have into consumers´ choice and how capacities should be built in order to implement agencies for the good monitoring, compliance and enforcement of the legislation.

Even in developed countries, the service sector has not been explored in depth and more information should be compiled about how energy is used in its different sub-sectors.

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Appendix 1 Household Income and Appliances Ownership in India

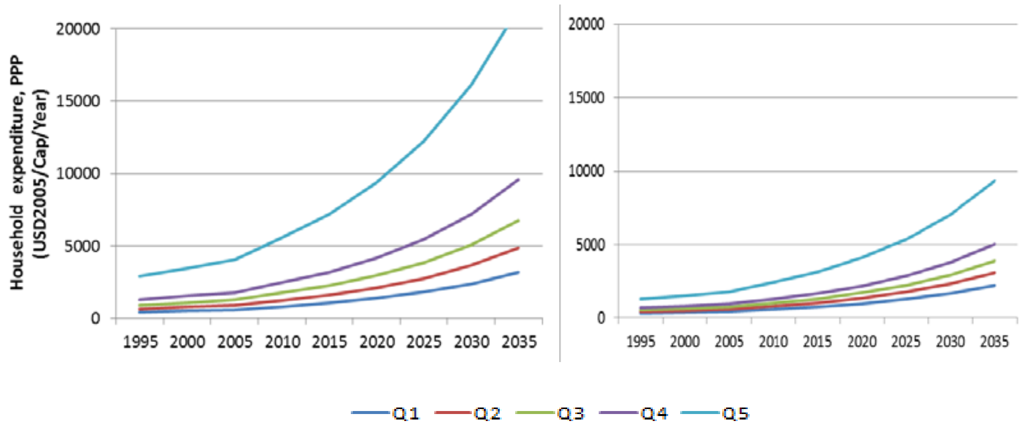

Figure 23 Households Income Projections per Quintile in Urban and Rural Areas

This graph represents the expected development of household income of the different economic quintiles constructed from national surveys and the PovCalNet database of the World Bank. Based on my results, the gap between the rich-poor and urban-rural areas will keep increasing. The GINI coefficient has remained almost constant in rural areas and it has increased in urban areas during the last decades (SCUPC, 2011). I did not expect a change on the inequalities during the modelled time period.

The below presented graphical representations are the result of a correlation to household expenditure of data points of appliances ownership that were collectesd from different reports and national surveys (NSS 55th; NSS 58th; NSS 66th; Prayas, 2010; Letschert, 2009). The data points were collected for the following years: 1992, 1995, 1999, 2002, 2005 and 2009. These figures put accent in how technologies are expected to develop along economic growth and the weight of urbanizations rate.

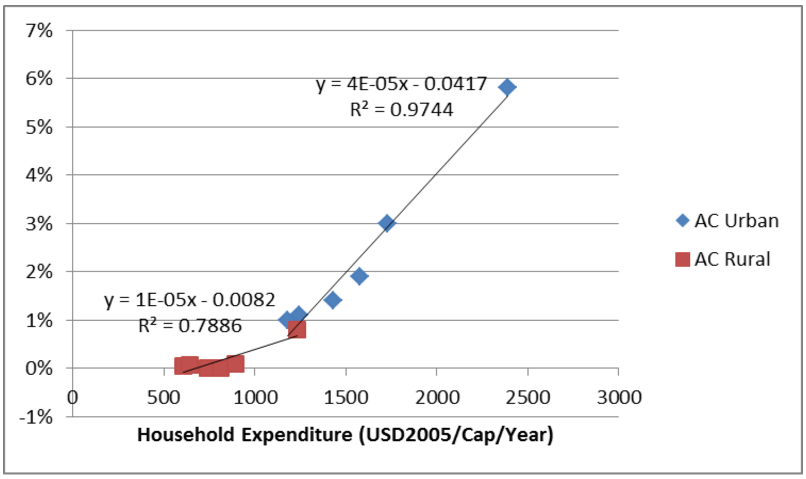

Figure 24 Air Conditioning Ownership Rate

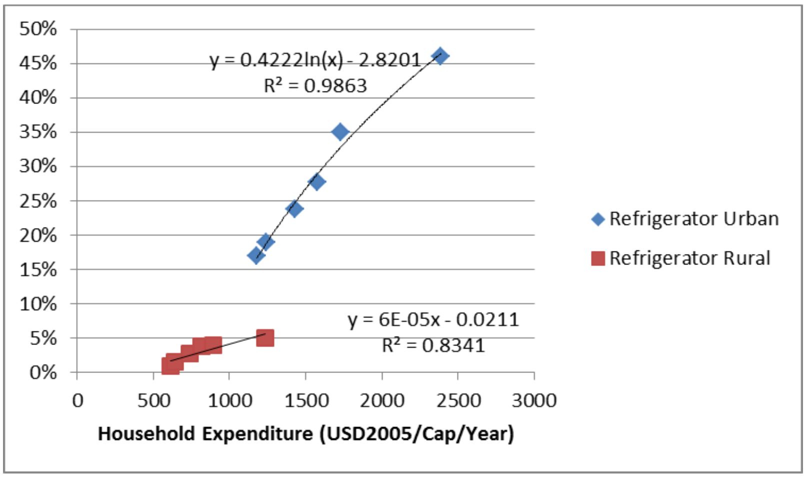

Figure 25 Refrigerators Ownership Rate

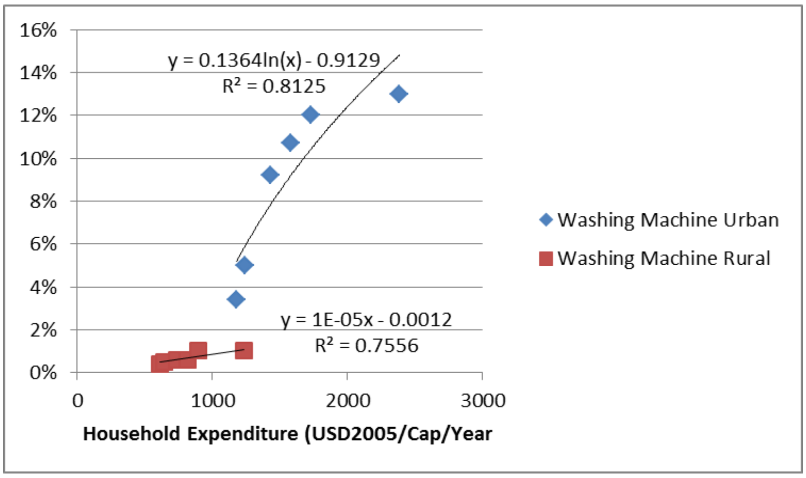

Figure 26 Washing Machine Ownership Rates

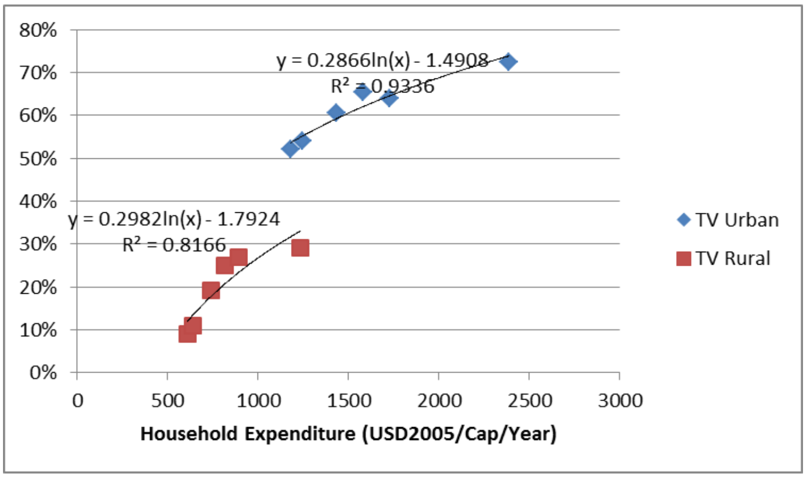

Figure 27 Television Ownership Rate

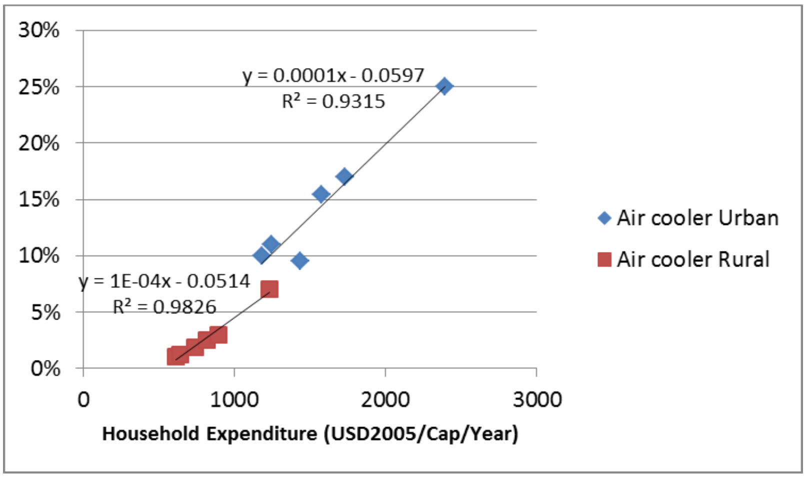

Figure 28 Air coolers ownership rates

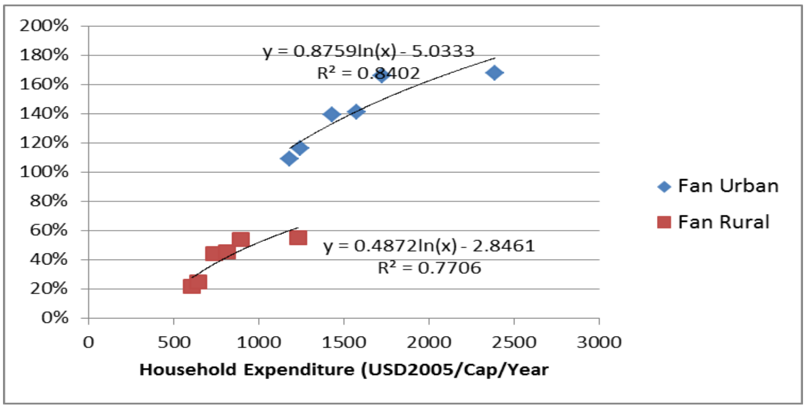

Figure 29 Fans ownership rates

Appendix 2. Model details

This section can be seen as a guideline for the use of the model developed. It has been slightly modified in order to serve as a sectoral approach to the residential sector of developing countries. Some new functionalities were added in order to lowering input data requirements.

The template is composed of six different sheets:

1. Input Data: This sheet includes most of the compiled data.
2. Assumptions: it is a review of the assumptions used in the modelling
3. End-use Energy: it shows the calculation of the baseline energy consumed for each functional use.
4. Mitigation actions: It disposes the different measures to define two mitigation scenarios
5. Technologies: More calculations required to set the results of the mitigation measures

6. Energy and GHG emissions: It presents the final results for the baseline and the two mitigation scenarios.

2.1 Compilation of input data

This section shows the data required for making a country analysis of the residential sector

- **Sheet Input data:**

1. Demographic factors:

   1.1. Population and Population density are extracted from: http://esa.un.org/unpd/wpp/unpp/panel_population.htm

   1.2. Urbanization rate is extracted from the World Development Indicators database (WDI)

2. Economic factors:

   2.1. Household expenditure: It is downloaded from the WDI: "*Household final consumption expenditure, PPP (constant 2005 international $)*"

   2.2. Urban and rural household expenditure: It requires RateUrbanIncome & RateRuralIncome provided in the assumptions sheet

3. Number of households: Data extracted from national surveys.
   India case example: Households in 2011 and 2001, extracted from: http://censusindia.gov.in/

4. Access to electricity: It is extracted from WDI

- **Sheet Assumptions:**

1. Rate urban and rural hh expenditure: Average income differences between rural and urban population. It is extracted from national surveys.

2. Compound average growth: it estimates annual GDP growth rate to 2035. It was extracted from the IEO (2009)

3. Fuel shares for cooking: Cooking fuel shares is extracted from the UNDP & WHO (2009). Water heating fuel shares is set equal to cooking by default. Space heating fuel shares is set equal to water heating shares by default. Fuel shares are provided for three years. These years can also be modified.

4. Shares of fuels included in Gas group of fuels: Shares of natural gas and LPG/DME (UNDP & WHO, 2009)

5. Space heating share of final energy use in 2010

6. Which share of the biomass is form renewable sources?

7. Heating and Cooling Degree Days: It was extracted from Baumert and Selman (2003)

8. Is there a significant share of the population relying on solid fuels? If the respond is no, mitigation actions related to cooking would be hidden from the mitigation actions sheet.
9. Shares of households relying on solid fuels: it is extracted from UNDP & WHO (2009)
10. Useful energy required for cooking in urban and rural areas: For further information, read section 3.1 of the report.
11. Lighting hours: For further information, read section 3.3 of the report.
12. Current shares of electric lamps: For further information, read section 4.3.2 of the report.
13. Building insulation packages: It can be modified the expected reduction on heating and cooling requirements of each of the three packages of measures.

2.2 Calculation process

- **Input data sheet:**

1. Rural and urban population is calculated from total population and urbanization rates
2. Average hh expenditure: "*Household final consumption expenditure, PPP (constant 2005 international $)"* is divided by total population

3. Rate urban/rural income: E.G.: Indian urban population almost doubles the income of rural population (NSSO survey 66th). Rate income Urban was stated as 1,55 and rural 0,8. "Average household expenditure in 2011" is set alongside and fluctuates as rate urban and rural income is modified. "Average household expenditure in 2011" should not differ largely from average household expenditure in 2011 calculated in the input data sheet. These values are used for calculating urban and rural household expenditure (PPP. $US2005)

4. Floor space: For further information read Daioglou (2010).

   4.1. Average floor space:
   FSav=(-2,964*LN(PD)+60,577)*(1+(0,125*hhYrural)/35000)*EXP(-1,641*EXP(-(0,125/1000)* hhYrural))

   4.2. Urban floor space:
   FSurb=(0,28925*UrbR+0,72705)*FSav

   4.3. Rural floor space:
   =(FSav-(UrbR*FSurb))/(1,1- UrbR))

   Where PD is population density; hhYrural is the average household expenditure in rural areas; UrbR is the urbanization rate

5. Household size: urban and rural number of households divided by urban and rural population for the values extracted from national surveys. The same trend, Average

Annual Growth Rate (AAGR), between the two data points calculated is expected for the remaining historical data. Its correlation to floor space was calculated for projecting values up to 2035.

6. Urban and rural households: Besides the two values from national surveys, the remaining values are calculated from rural and urban household size and population data.

7. Electrification rate: Future access to electricity is calculated as a time-dependent trend function.

- **Assumptions sheet:**

1. New buildings: growth of the residential building stock each 5 years (2015, 2020, 2025, 2035)

2. Average illuminance efficiency: For further information, read section in chapter 4

3. Climate based maximum saturation: For further information, read section in chapter 4

4. Baseline energy consumption of washing machines, refrigerators and TV: Based on the indicators explained on chapter 4, it is calculated a baseline energy consumption.

- **End-Use Energy**
  This sheet disaggregates the different functional uses of energy in households. Useful energy is calculated for urban and rural areas. Final energy use is calculated with regards to type of fuels and technologies efficiency.

1. Cooking: it is calculated from useful energy used for cooking, fuel shares and technologies

2. Water heating: In order to express water heating energy demands, van Ruijven et al. (2011) for used a correlation to household expenditure per rural:

$$UE_{p,q\ EC(t)}\ [MJ/Cap/day] = 8,5 * (1- exp^{-(0,1/1000)Y\ p,q\ (t)})$$

3. Space Heating: Space heating energy intensity as extracted from total final energy use

4. Lighting: it is calculated from lux (lumen/m2) provided in assumptions sheet and the floor area of the household (hh size * floor space per capita)

5. Appliances:

   - Air conditioning (Leschert, 2010)

     $$CMBS = 1.00 - 0.949 * e^{-0.00187*CDD}$$

     UEC [kWh/hh] = CMBS * CDD*(0.865*ln(Income) -6,04

   - Refrigerators: It has to be provided an average value for the volume of freezer and refrigerator. (Siderius et al., 2012):

Total adjusted volume = Declared Volume Fresh + 2,15 * Declared Volume Frozen.
The total adjusted volume is multiplied by the energy intensity of the average labelling system (e.g., Label G = 1.5 KWh/l)

- Washing Machine: Energy is required for Kg of capacity and cycle; capacity is set to 6 Kg by default; Cycles per year is calculated by person; Household size determines the number of cycles per year.

- Television: A higher screen demands more energy (IEA, 2010d; EU Directive 2010/30/EU):
  Screen Area (dm2) = (Screen size (dm)^2) * 0,427
  EEI = P(On mode Power)/ Pref;
  Pref (W)= 20W + (4,3224(W/dm2)*Screen-Area(dm2))

- Other appliances such as fans and air coolers are assumed to have an standard energy consumption.

2.3 How does the model work?

- **Energy end-use sheet:**

Once that the input data has been provided the end-use energy sheet process the information as it has been explained throughout the report. Still, further details have to be explained.

1. Fuel shares of each functional use: Fuel shares are provided by three different years (they can be modified as to match with the year when the data is collected). Fuel shares will develop throughout the time in relation to an AAGR formula. Future projections are also established with the AAGR approach but the data is calibrated each 5 years (in 2015, 2020, 2025, 2030 and 2035)

2. Space heating: once that the share of final energy used for heating is provided, the heating energy intensity is calculated by discounting the technology effect. It develops as explained in chapter 3.

- **Mitigation actions sheet:**

1. Building insulation: Heating and cooling requirements is extracted from final energy used for heating and air conditioning (after accounting the technology effect). Retrofiring rates for the two mitigation scenarios can be modified. The share of new buildings and retrofitted buildings in which each of the packages is used can be modified. Also, the year of implementation of the insulation measures.

2. Cooking stoves: It can be applied fuel switching measures to a target and an adopted fuel. Improved cook stoves for solid fuels is set as share of traditional cookstoves in 2020.

3. Water and space heating measures: Fuel switching measures can be applied following the same procedure followed for cooking. An energy labelling system is presented as

to select which label is the new MEPS. Also the year of implementation of the MEP can be modified from 2013 to 2025

Table 14 labelling . Water and space heating devices. Seasonal Energy Efficiency Requirement (SEER)

	A	B	C	D	E
Electricity	97%	95%	93%	89%	85%
Gas	96%	89%	82%	75%	68%
Kerosene	87%	80%	73%	66%	59%
Coal	75%	60%	55%	40%	25%
Biomass	55%	45%	35%	25%	15%

After it is set the year of implementation, the MEP would be reviewed each 5 years as to make it a 4% stricter. Labelling A is the most efficient that the MEPS can become. All new boilers (in new houses) would have the efficiency established by the MEPS and the replacement of old boilers is accounted for as regards of the technology´s lifespan.

The calculations of the MEPS are processed via excel macros and gives the average energy efficiency of boilers (on the sheet technologies). Average efficiency could be lower than the MEPS as there are old appliances that have not been replaced yet.

4. Lighting: the shares of IL, FL, CFL and LEDs can be modified for the year 2020 and 2030

5. Appliances: a labelling system is presented and the MEPS procedure above explained is applied

Table 15 Labelling system large appliances

		A	B	C	D	E	F	G
Air conditionir	**SEER (W/W)**	610%	529%	459%	398%	345%	300%	260%
Refrigerators	**EEI (Eb/Ea)**	25%	35%	45%	55%	70%	85%	100%
Washing mac	**EEI (Eb/Ea)**	46%	52%	59%	68%	77%	87%	100%
TV	**EEI (Eb/Ea)**	30%	40%	50%	65%	80%	100%	120%
Others	**EEI (Eb/Ea)**	25%	31%	40%	50%	63%	79%	100%

2.4 Outputs of the model

The Sheet Energy & GHG emission of the model provides information for each functional use and type of fuel used. Also, it is provided GHG intensities per capita, floor space (m2) and economic units (hh expenditure USD2005).

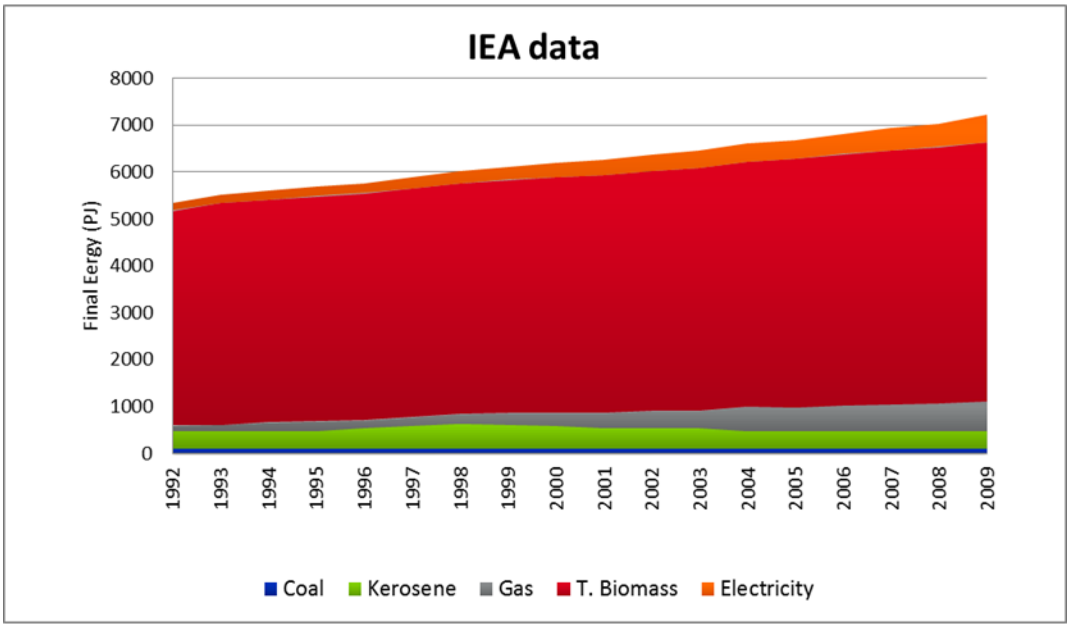

Figure 30 IEA 2011 Energy Balances Indian Residential Sector (1992-2009)

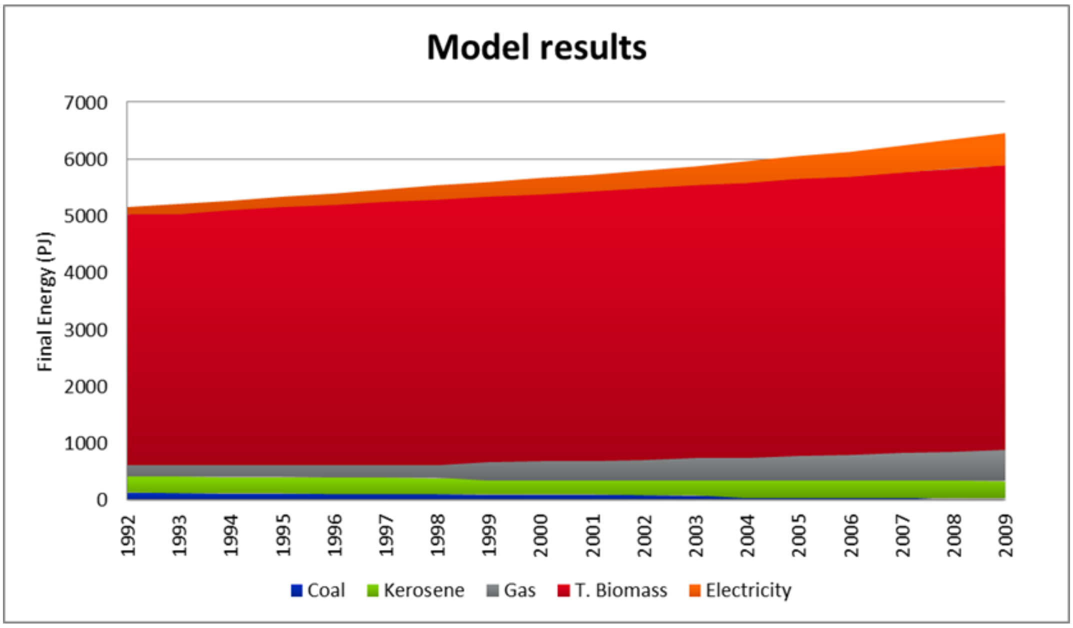

Figure 31 Model results Indian Residential Sector (1992-2009)

Appendix 3. Fuel Shares of the Indian Residential sector

		Cooking					Water Heating					Space Heating				
	Year	1992	2006	AAGR (1992-2006)	2011	AAGR (2006-2011)	1992	2006	AAGR (1992-2006)	2011	AAGR (2006-2011)	1992	2006	AAGR (1992-2006)	2011	AAGR (2006-2011)
Renewable	Urban	0.5%	0.6%	1.01	0.7%	1.03	0.0%	0.2%	1.2	0.3%	1.133	0%	0%	1.00	0.0%	1.00
	Rural	0.1%	0.9%	1.17	1.3%	1.08	0.0%	0.0%	1.1	0.1%	1.129	0%	0%	1.00	0.0%	1.00
Electricity	Urban	0.3%	1.8%	1.137	2.6%	1.07	4.0%	9.7%	1.1	14.3%	1.080	4.0%	20%	1.12	39.5%	1.15
	Rural	0.0%	0.2%	1.37	0.3%	1.05	0.3%	1.5%	1.1	2.3%	1.085	0.3%	15%	1.32	10.0%	0.92
Gas	Urban	39.5%	57.6%	1.03	63.1%	1.02	31.3%	46.0%	1.0	52.3%	1.026	28%	44%	1.03	35.5%	0.96
	Rural	2.4%	8.7%	1.10	11.7%	1.06	2.9%	8.8%	1.1	11.7%	1.059	3%	7.7%	1.07	18.3%	1.19
Kerosene	Urban	15.0%	12.8%	0.99	9.0%	0.93	22.1%	12.2%	1.0	6.4%	0.879	23%	12.20%	0.96	12.0%	1.00
	Rural	1.3%	1.5%	1.01	1.3%	0.97	0.7%	4.0%	1.1	0.9%	0.734	1%	4%	1.13	0.9%	0.73
Coal	Urban	0.3%	0.2%	0.97	0.2%	0.94	0.4%	0.7%	1.0	0.5%	0.935	0%	2%	1.16	0.5%	0.74
	Rural	0.1%	0.2%	1.02	0.1%	0.92	0.4%	0.6%	1.0	0.6%	0.986	1%	1%	0.99	0.6%	0.99
Biomass	Urban	44.4%	27.0%	0.97	24.5%	0.98	42.2%	31.3%	1.0	26.2%	0.965	45%	22%	0.95	12.5%	0.90
	Rural	96.0%	88.5%	0.99	85.3%	0.99266	95.7%	85.1%	1.0	84.6%	0.999	95%	73%	0.98	70.3%	0.99
Total	Urban	100.0000%	100.0000%		100.000%		100.000%	100.000%		100.000%		100.00%	100.00%		100.00%	
	Rural	100.0000%	100.0000%		100.00%		100.000%	100.000%		100.000%		100.00%	100.00%		100.00%	

Appendix 4. Emission Factors

Table 16 Emission factors Tonne GHG/TJ

Fuel	CO2	CH4	N20
Wood	112	0,03	0,004
Charcoal	112	0,03	0,004
Biomass	112	0,03	0,004
Coal	94,6	0,001	0,0015
Kerosene	71,90	0,003	0,00006
LPG	63,10	0,001	0,00015
NG	56,15	0,001	0,0001
Biogas	54,6	0,001	0,0001
Electricity	264,28	0,004	0,01

This information was extracted from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2 Energy