Manual for

Benefits of Action to Reduce Household Air Pollution (BAR-HAP) Tool

Version 2

July 2021

World Health Organization

Disclaimer

About

Further information about the Benefits of Action to Reduce Household Air Pollution (BAR-HAP) tool are available on the WHO Household Air Pollution website, including the license information, download link for the Excel tool, feedback information and acknowledgements.

Acknowledgements

The Benefits of Action to Reduce Household Air Pollution (BAR-HAP) Tool was developed by Dr. Marc Jeuland and Dr. Ipsita Das at Duke University, Durham, USA, for the World Health Organization (WHO), with support from Yutong Xue (user interface and coding) and Jiahui Zong (database construction). Tool development was coordinated by Dr. Jessica Lewis, WHO Headquarters Office, Geneva, with support from Kendra Williams (WHO Consultant).

Suggested Citation

Benefits of Action to Reduce Household Air Pollution (BAR-HAP) Tool. Version 2. Geneva, World Health Organization, 2021.

Contents

Disclaimer 2

About 2

Acknowledgements 2

Suggested Citation 2

Introduction 4

BAR-HAP Overview 5

Fuel and technology transitions in BAR-HAP 5

Policy interventions in BAR-HAP 7

BAR-HAP Outputs 8

Default data in BAR-HAP 8

Instructions for Use of BAR-HAP 9

Brief Introduction on use of Microsoft Excel™ Software 9

Basic structure of the BAR-HAP Tool 10

How to Use BAR-HAP 13

Key model parameters 27

Hidden sheets 29

Modification of the tool by advanced users 30

Example Scenarios 31

Example Scenario 1 34

Equations for cost-benefit calculations for Transition 1: Traditional biomass stoves to improved cookstoves (natural draft) with stove subsidy policy intervention 34

Example Scenario 2 46

Equations for cost-benefit calculations for Transition 2: Traditional biomass stoves to LPG stoves using fuel subsidy policy intervention 46

Appendix: Default parameter values 55

References 60

Introduction

Household air pollution (HAP) from the combustion of dirty fuels in inefficient devices is a significant risk to health. WHO estimates that HAP exposure from cooking is responsible for millions of deaths each year[1]. Despite increasing awareness of these risks, around 2.6 billion people continue to rely on polluting fuels and technologies for their daily cooking needs[2]. Dirty cooking systems release high concentrations of pollutants including particulate matter and carbon monoxide, leading to serious cardiovascular and respiratory illness among other health impacts.

In recognition of the adverse health, environmental and climate impacts of inefficient cooking, Sustainable Development Goal 7, Target 7.1 calls for universal access to affordable, reliable and modern energy services. Progress towards this goal is tracked with Indicator 7.1.2, the proportion of the population with primary reliance on clean fuels and technologies, where clean is defined by the WHO *Guidelines for indoor air pollution: household fuel combustion*[3].

This 'benefits of action to reduce household air pollution' (BAR-HAP) tool has been developed to assist stakeholders in the cooking energy sector calculate the national-level costs and benefits of transitioning to various cleaner cooking options. BAR-HAP allows users to **select a country, examine the baseline fuel use situation, select one or multiple transition(s)** to cleaner cooking fuels or technologies, as well as **policy interventions** to apply to the transition scenario(s). Importantly, the tool incorporates evidence on the effectiveness of different interventions and on the demand for improved cooking solutions, for prediction of impacts from different actions. While different health economic analyses could be relevant (such as, cost-effectiveness analysis where the benefits are quantity of life or quality of life, and unit of measurement is life years gained; or cost-utility analysis where the benefits are quantity and quality of life, and unit of measurement is health years),[4] this tool uses cost-benefit analysis following WHO advice on health economic analysis and evaluation.[5] It is important to note that there is no dedicated standard framework or approach for health economic analysis for environmental health interventions, including those for HAP. Still, the multifaceted nature of economic benefits from HAP interventions suggest the need for holistic cost-benefit measures, rather than cost-effectiveness measures that account only for diseases reduction benefits.

[1] WHO 2021. Exposure to household air pollution. Accessible from https://www.who.int/data/gho/data/themes/air-pollution

[2] IEA, IRENA, UNSD, World Bank, WHO 2021. Tracking SDG7 The Energy Progress Report 2021. Accessible from https://trackingsdg7.esmap.org/downloads

[3] WHO 2014. Guidelines for indoor air pollution: household fuel combustion. Accessible from https://www.who.int/publications/i/item/9789241548885

[4] NIH. 2016. Health Economics Information Resources: A Self-Study Course: Module 4. Accessible from: https://www.nlm.nih.gov/nichsr/edu/healthecon/04_he_06.html

[5] Lauer, J.A., Morton, A., Culyer, A.J. and Chalkidou, K., 2020. What Counts in Economic Evaluations in Health? Benefit-cost Analysis Compared to Other Forms of Economic Evaluations.

BAR-HAP Overview

Fuel and technology transitions in BAR-HAP

In summary, the user selects (1) transition(s) from currently used cooking fuels or technologies to cleaner fuels or technologies, and (2) policy interventions that are applied to the transition(s). The majority of included transitions represent a movement from a more polluting cooking system to one that is cleaner for health and the environment (Figure 1). The main exception to this is a transition from LPG to electric cooking, both of which are considered clean for health. BAR-HAP allows users to model transitions to fuels and technologies that WHO considers to be clean for health (i.e. those that achieve substantial reductions in air pollution levels), as well as transitional fuel and technology combinations (i.e. those that provide some health benefit but are not considered clean for health).

Thus, the transitions include movements to **clean fuel and technology combinations** (biogas, LPG, ethanol, and electric), which are defined based on the WHO Guidelines and are focused on the health benefits of HAP reduction. The transitions also include **transitional fuel and technology combinations** (improved biomass stove with chimney, improved natural draft biomass stove, improved forced draft biomass stove, and improved forced draft biomass stove with pellets), which are those that provide some benefits but do not reach WHO Guidelines levels. The selection of transitional options included in the tool was based on the improved and clean stoves currently available in the global market and the feasibility of implementation of strategies to promote them.

The term **improved cookstove (ICS)** is used in the tool and in this manual to describe both clean and transitional fuel and technology combinations.

Sixteen technology transition scenarios are currently included in the BAR-HAP tool. The technology/fuel transitions are classified into four major types (Figure 1)[6], from:

(a) Traditional biomass or traditional charcoal to so-called transitional fuels and technologies ("cleaner" fuels/devices);
(b) Traditional biomass or traditional charcoal to clean fuels and technologies;
(c) Kerosene to clean fuels and technologies; and
(d) One clean fuel/technology to another (specifically LPG to electric).[7]

[6] Das, I., Lewis, J. J., Ludolph, R., Bertram, M., Adair-Rohani, H., & Jeuland, M. (2021). The benefits of action to reduce household air pollution (BAR-HAP) model: A new decision support tool. *Plos one*, *16*(1), e0245729.
[7] This transition was included because several countries are interested in decreasing their reliance on imported gas, given their ability to generate electricity locally.

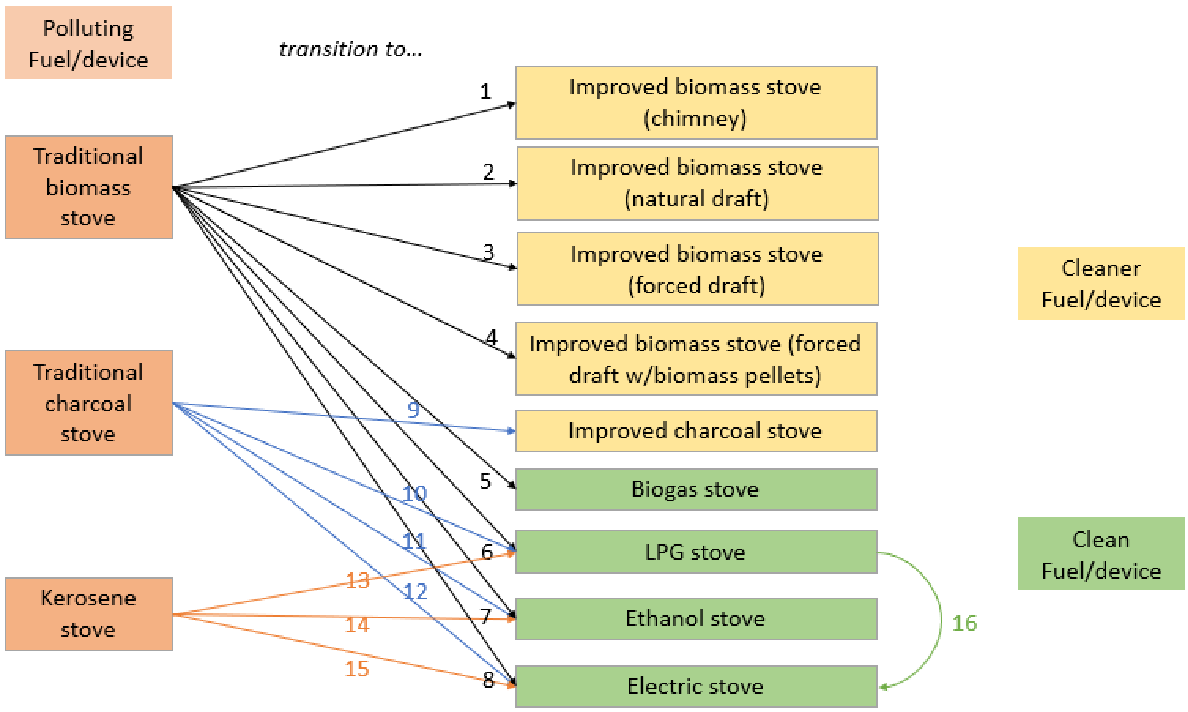


Figure 1. The sixteen technology/fuel transition scenarios included in BAR-HAP. All but the last of these involves moving from one technology and fuel combination to a new combination that is cleaner for health. BAR-HAP permits consideration of multiple transitions targeting different population subgroups at a single time. Eight transitions are from traditional biomass stoves to cleaner options; four are from traditional charcoal stoves to cleaner options; three are from kerosene stoves to cleaner options; and one transition is a "clean to clean" transition that is of policy interest in some locations (LPG to electric).

Eight of the transitions concern a move from traditional biomass or charcoal stoves to transitional (4) and clean (4) technologies:

1. Traditional biomass stove to improved biomass stove (chimney)
2. Traditional biomass stove to improved biomass stove (natural draft)
3. Traditional biomass stove to improved biomass stove (forced draft)
4. Traditional biomass stove to improved biomass stove (forced draft with biomass pellets)
5. Traditional biomass stove to biogas stove
6. Traditional biomass stove to LPG stove
7. Traditional biomass stove to ethanol stove
8. Traditional biomass stove to electric (induction or coil) stove

Four additional scenarios concern a move from traditional charcoal stoves to transitional (1) and clean (3) technologies:

9. Traditional charcoal stove to improved charcoal stove
10. Traditional charcoal stove to LPG stove
11. Traditional charcoal stove to ethanol stove
12. Traditional charcoal stove to electric stove

Three transitions consider a move from kerosene to clean technologies:

13. Kerosene stove to LPG stove

14. Kerosene stove to ethanol stove
15. Kerosene stove to electric stove

Finally, one transition considers the switch from one clean technology (LPG) to another (electric):

16. LPG stove to electric stove

Policy interventions in BAR-HAP

For each of the sixteen transitions, the user can select from the following five **policy interventions** (Figure 2)[8]:

1. Subsidy for stoves only;
2. Subsidy for fuel (where fuel subsidy is only possible for biomass pellets, LPG, electricity and ethanol), alone or in concert with stove subsidy;
3. Stove financing that would allow adopting households to spread payments for new technology over time, alone or in concert with stove subsidy;
4. Behavior Change Communication (BCC), alone or in concert with stove subsidy; and
5. Technology ban.

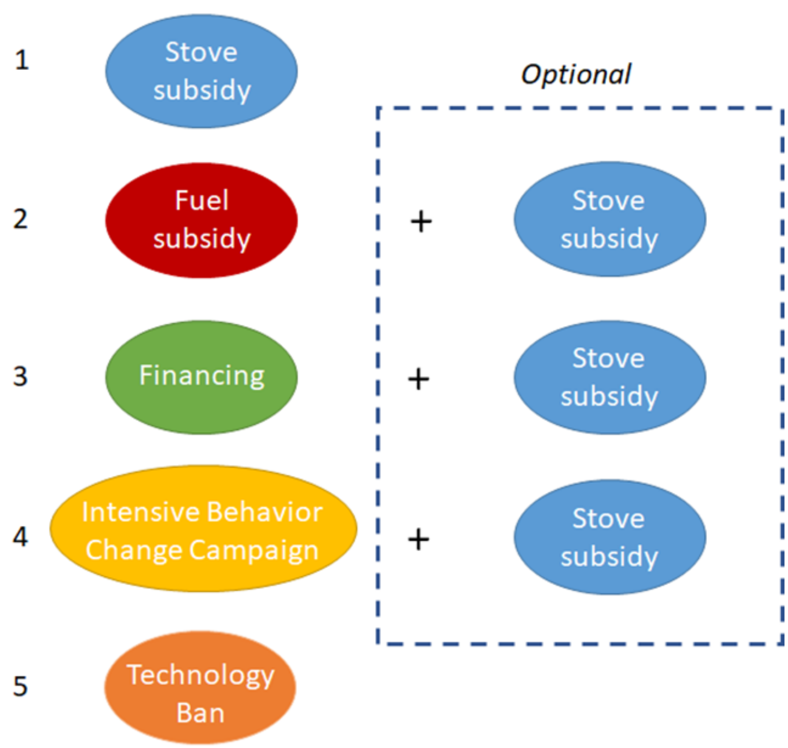


Figure 2. Five policy interventions that can be applied to all fuel/technology transition scenarios. Stove subsidy can range from 0 to 100% of stove cost. Fuel subsidy can range from 0 to 100% of fuel costs.

[8] Das, I., Lewis, J. J., Ludolph, R., Bertram, M., Adair-Rohani, H., & Jeuland, M. (2021). The benefits of action to reduce household air pollution (BAR-HAP) model: A new decision support tool. *Plos one*, *16*(1), e0245729.

BAR-HAP Outputs

After running a scenario in BAR-HAP, the following costs and benefits are produced[9].

Costs	
1. Government subsidy costs (i) Stove subsidy cost (ii) Fuel subsidy (iii) Program costs	2. Private costs (i) Stove cost (ii) Fuel cost, pecuniary and non-pecuniary, e.g., collection time cost (iii) Maintenance cost (iv) Learning costs
Benefits	
1. Private health benefits (i) Morbidity reductions of chronic obstructive pulmonary disease (COPD) (ii) Mortality reductions of COPD (iii) Morbidity reductions of acute lower respiratory infections (ALRI) (iv) Mortality reductions of ALRI (v) Morbidity reductions of ischemic heart disease (IHD) (vi) Mortality reductions of IHD (vii) Morbidity reductions of lung cancer (LC) (viii) Mortality reductions of LC (ix) Morbidity reductions of stroke (x) Mortality reductions of stroke	2. Social health benefits (incorporating HAP contribution to ambient air pollution (AAP)) (i) Morbidity reductions of COPD, ALRI, IHD, LC and stroke – using social discount rate and accounting for health spillovers (ii) Mortality reductions of COPD, ALRI, IHD, LC and stroke – using social discount rate and accounting for health spillovers
3. Time savings	4. Basic (Kyoto-protocol gases) and full (with additional pollutants) climate benefits
5. Other environmental benefits (sustainability of biomass harvesting)	

Default data in BAR-HAP

This tool has a user-friendly format and is pre-filled with default demographic data and epidemiological data for all low- and middle-income countries. The human resource, equipment and capacity building costs are based on a previous tool developed by the WHO for interventions to address non-communicable disease burden, the WHO Non-Communicable Disease Costing Tool[10], and have not been modified owing to lack of data on how these requirements would diverge in the context of interventions to address HAP.

For 134 low- and middle-income countries (LMICs), there are country-specific data on total population, household size, number of children under five per household, fuel use, incidence, prevalence and mortality of the five HAP-related health conditions under consideration in this tool, and life expectancy remaining by disease. On stove costs and lifespan, and stove-fuel

[9] Detailed equations for each of these costs and benefits in the first two policy interventions (subsidy for stove & subsidy for stove and fuel) developed in this Tool are given in the Example Scenarios 1 and 2.

[10] WHO Non-Communicable Diseases (NCDs) Costing Tool is available here: https://www.who.int/ncds/management/c_NCDs_costing_estimation_tool_user_manual.pdf?ua=1

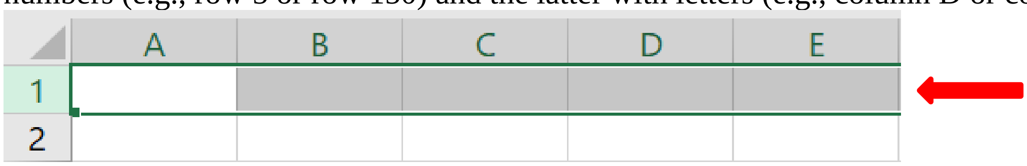
thermal efficiency, we have used country-specific data wherever available; where country-level data are unavailable, we have used WHO-classified region estimates, and used global estimates where regional data are unavailable.

The BAR-HAP Tool can be used without any additional country-specific data/information; however, the user has the option to amend the country-specific data/information (e.g., costs of stoves, fuels, commodities and human resources), as appropriate and necessary. Finally, BAR-HAP allows users to specify whether interventions to promote clean cooking transitions should include planning (years 1 and 2) and scale up phase (years 3-5, with the speed of scale up at user discretion), or already fully scaled up (starting from year 1).

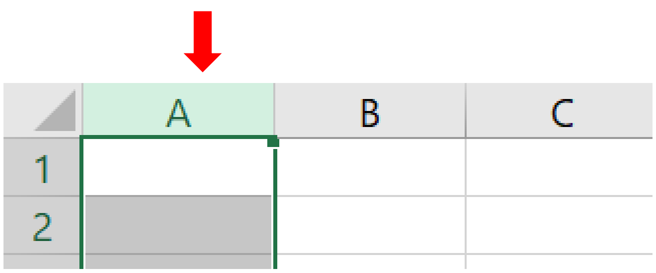
Instructions for Use of BAR-HAP

Brief Introduction on use of Microsoft Excel™ Software

1. Each Microsoft Excel™ spreadsheet has rows and columns. The former is labelled with numbers (e.g., row 5 or row 150) and the latter with letters (e.g., column D or column G).



Above: Example of a row in Excel (Row 1)



Above: Example of a column in Excel (Column A)

2. A cell is where a row intersects with a column. It is referred to by its column letter followed by the row number. A1 is the first cell in the top left corner of a worksheet.
3. There can be multiple worksheets in an Excel workbook. Every worksheet has a name, found on the worksheet tab at the bottom of the screen.
4. The worksheet whose name is bolded in green in the row of tabs at the bottom of the screen is the active worksheet.
5. In Excel, one typically navigates between different worksheets by clicking on the worksheet tabs at the bottom of the screen. (Note that workbooks with many tabs require you to scroll through the tabs by pressing on the arrows in the bottom toolbar). However, BAR-HAP includes a built-in user interface with buttons and associated macros (or short programs) that are essential for the full functioning and updating of model results. Therefore, users should generally navigate between tabs using the buttons in each worksheet, rather than the tabs at the bottom. The tabs at the bottom can be used by

advanced users to explore the tool more completely, or to skip steps that are not essential, once users are sufficiently familiar with how the BAR-HAP Tool works.

6. One can create a shortcut to the BAR-HAP Tool software on a Windows desktop. On double clicking the created tool icon on the desktop, the tool application software gets activated. The tool is meant to run with Microsoft Excel version 2003 or later. Visual Basic for Excel (typically installed automatically with the default package for Excel) must also be installed on the computer.
7. The first time the program is launched, users may get a warning message that the file contains macros that may be harmful to one’s computer with an option to disable these macros. Rest assured, the macros are perfectly safe and should be kept active. **Important: If macros are disabled, the tool will not work properly.**
8. The BAR-HAP Tool is a single Excel file (*.xlsm). The “m” at the end indicates that it contains macros, and these must be enabled for the tool to function properly (for example to have the transition selections and parameter reset buttons work).
9. **Important**: The Excel file is also designed to function as a “master” file. It may be desirable to create copies of the Tool before using it (either by creating copies on your computer desktop, or by opening the Excel file and saving it under a new name before you start using it). This way, the original BAR-HAP Tool can be kept as a master file for future use, in case something goes wrong.

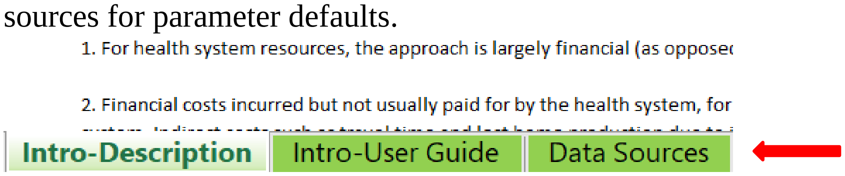
Basic structure of the BAR-HAP Tool

The Tool consists of 22 active worksheets (tabs colored in various shades of green) in a single Microsoft Excel™ file (it also contains a number of additional sheets with tabs having other colors, as well as hidden sheets). Navigation between worksheets can be performed either a) by clicking on the corresponding name of the worksheet at the bottom of the worksheet, or b) via the user interface. **Important**: As noted above, it is best for users to navigate through the buttons in each worksheet when doing a policy analysis, to ensure that macro codes run and that results are updated appropriately.

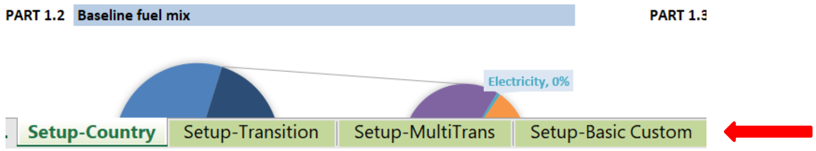
The user interface cannot be used to access the tabs not colored in green. Therefore, advanced users who would like to study elements in those sheets must navigate to them via the tabs at the bottom of the screen.

Specifically, this Tool comprises the following worksheets:

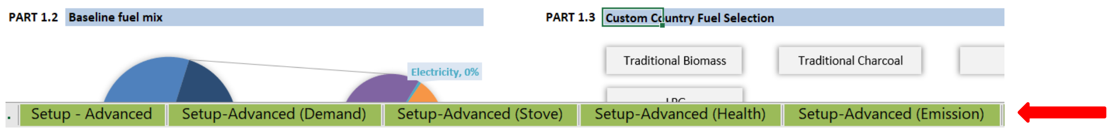
1. **Intro-Description**, **Intro-User Guide,** and **Data Sources** (indicated with **bright green** tab coloring – see screenshot below): Contains BAR-HAP Tool generalities, and data sources for parameter defaults.



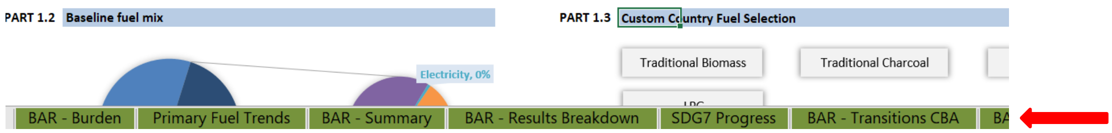
2. **Setup-Country; Setup-Transition, Setup-MultiTrans, Setup-Basic Custom** (indicated with **light green** tab coloring – see screenshot below): The only worksheets where the user must make selections, if happy to use country-specific default data. One advances to basic results from the **Setup-Basic Custom** tab.



3. **Setup-Advanced; Setup-Advanced (Finance); Setup-Advanced (Stove); Setup-Advanced (Health); Setup-Advanced (Emission)** (indicated with **dark green** tab coloring – see screenshot below): In these worksheets, the user can review and change advanced parameters, if needed.

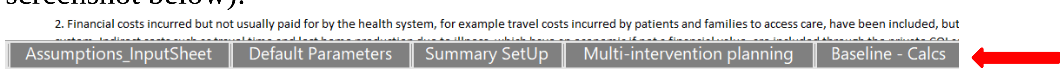


4. **Output tabs** (indicated with **darker green** tab coloring – see screenshot below):



   a. **BAR-Burden**: This worksheet shows the private and social health burdens, environmental burdens and time burdens in the current or baseline situation – in the absence of any cooking transition(s). *Credits are due to Brian Hutchinson and Rachel Nugent at RTI International for their work motivating inclusion of this tab.*
   b. **Primary Fuel Trends**: The graphs in this worksheet provide the baseline fuel breakdown for the selected country, from 2010-2020.
   c. **BAR - Summary**: This worksheet contains the total cost estimates (i.e., governmental cost, private cost) and total social net benefits (including intervention private and social health benefits, intervention time savings, and intervention environmental benefits) for implementing the transition scenarios.
   d. **BAR - Results Breakdown; BAR – Transitions CBA; BAR – Public Cost; G-Time; G-Morb; G-Climate;** and **G-Other**: These tabs contain additional graphical results that are accessed through the **BAR - Summary** tab.

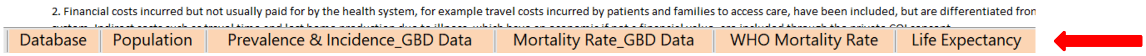
5. Default assumptions and calculations sheets (indicated with **grey** tab coloring – see screenshot below):



   a. **Assumptions_InputSheet**; **Default Parameters; and SummarySetUp**: These sheets store and contain economic and demographic parameters; baseline cooking parameters (e.g. traditional stove cost, fuel usage, fuel cost, learning and maintenance costs); stove and fuel parameters; health benefits calculations (for each of the five health outcomes linked with household air pollution: chronic obstructive pulmonary disease, acute lower respiratory infection, ischemic heart disease, lung cancer and stroke); and environmental and climate benefits calculations.
   b. **Multi-intervention planning:** This tab manages parameters invoked when partial transitions or multiple overlapping transitions are considered, based on information entered in the **Setup-MultiTrans** sheet. It should not be modified.
   c. **Baseline – Calcs**; **Summary results**; **Transition-Summary** and **Inter-Graph**: These sheets store intermediate calculations that are used to generate tool outputs and graphs. They should only be modified with care but advanced users. For

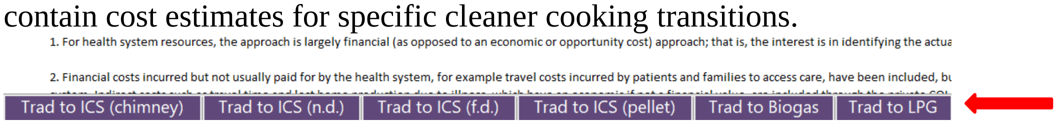
example, **Baseline – Calcs** was largely developed by Brian Hutchinson and Rachel Nugent at RTI International, using BAR-HAP version 1.

6. Database sheets (indicated with **peach** tab coloring – see screenshot below):

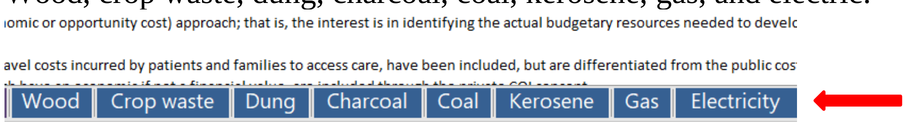


   a. Database: General country-specific parameters
   b. Population: Population trends in each country
   c. Prevalence & Incidence_GBD Data: Prevalence and incidence rates for the diseases included in BAR-HAP: ALRI, COPD, IHD, lung cancer, and stroke, from the global Burden of Disease project.
   d. Mortality Rate_GBD Data: Mortality rates for the diseases included in BAR-HAP: ALRI, COPD, IHD, lung cancer, and stroke, from the global Burden of Disease project.
   e. WHO Mortality Rate: Mortality rates for the diseases included in BAR-HAP: ALRI, COPD, IHD, lung cancer, and stroke, from the WHO.
   f. Life Expectancy: Average normal life expectancy remaining among those dying from the diseases included in BAR-HAP: ALRI, COPD, IHD, lung cancer, and stroke, from the global Burden of Disease project.
   g. VSL and income: Relationships between income and health valuation parameters, used to derive the value of a statistical life and cost of illness for each country.
   h. Stove: Data on stove options and costs in each country or region.

7. Transition-specific calculations sheets (indicated with **purple** tab coloring – see screenshot below): **Trad to ICS (chimney) to LPG to Electric**: These 16 worksheets contain cost estimates for specific cleaner cooking transitions.



8. Baseline fuel use data sheets (indicated with **blue** tab coloring – see screenshot below): Sheets that store data on the primary fuel use trends from 2000-2020 in the countries: Wood, crop waste, dung, charcoal, coal, kerosene, gas, and electric.



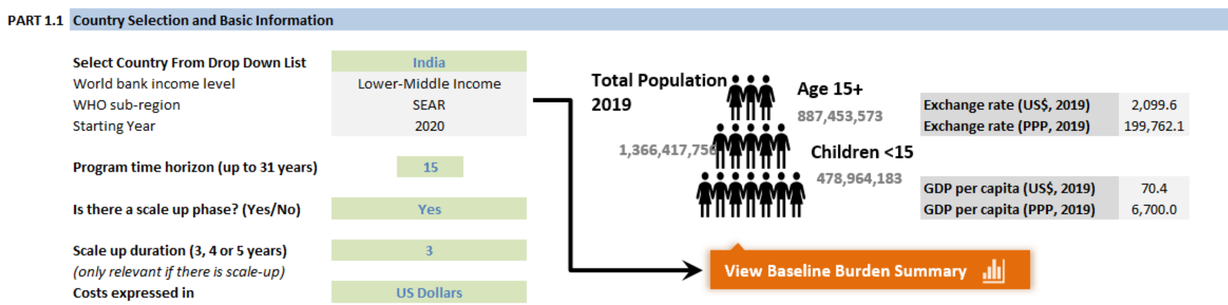
9. Various hidden sheets:
   a. ICS Demand: This sheet provides reference information on how demand for stoves is calculated (the calculations themselves are in the Default Parameters sheet).
   b. Other Hidden worksheets: Contain calculations and assumptions for some of the included parameters, as well as the full database for various parameters.

By default, BAR-HAP runs in *protected mode*. This protected mode is the safest way to use the tool without irreversibly altering its functionality (e.g., by changing equations and model references). Specifically, protected mode indicates that many cells and sheets are locked to users. Only experienced users or those very comfortable with Excel should run the model in unprotected mode. Instructions for modification of the tool by advanced users is provided below in the section “Modification of the tool by advanced users”.

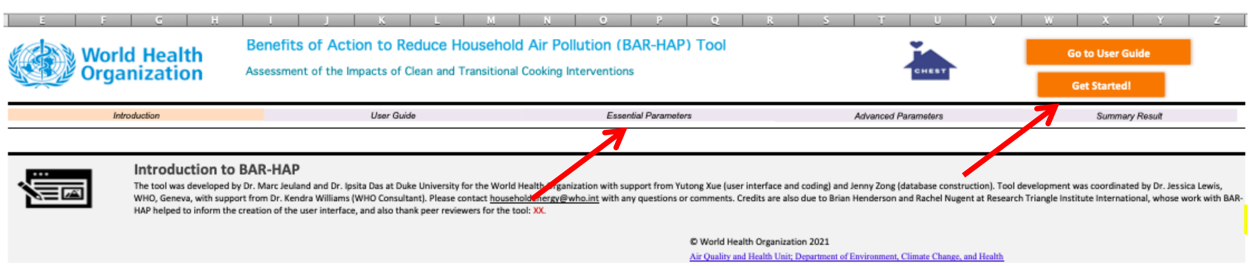
How to Use BAR-HAP

The following steps illustrate how to use BAR-HAP to run a clean cooking transition scenario.

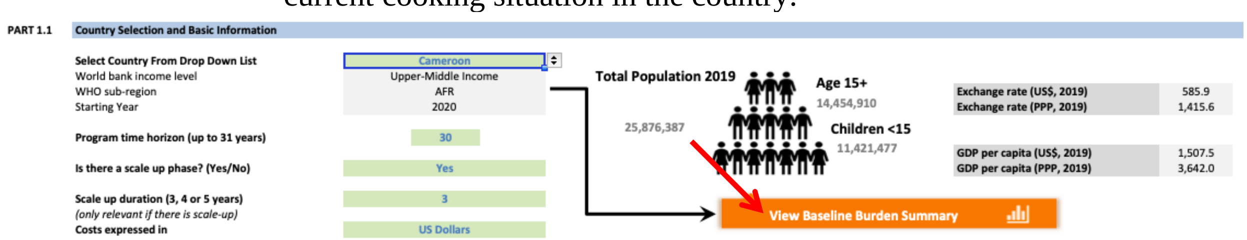
1. Save a copy titled “BAR-HAP Tool.xlsm” on your desktop or in a preferred drive on your computer. Keep the original stored in a backup folder in case you ever want to go back to it.
2. Open the BAR-HAP Tool (Excel file) from your desktop.
3. Read the **Intro-Description** and **Intro-User Guide** worksheets.



4. Click on the **“Get Started!”** button or on the **“Essential Parameters”** link in the worksheet, to proceed to **SetUp-Country**:



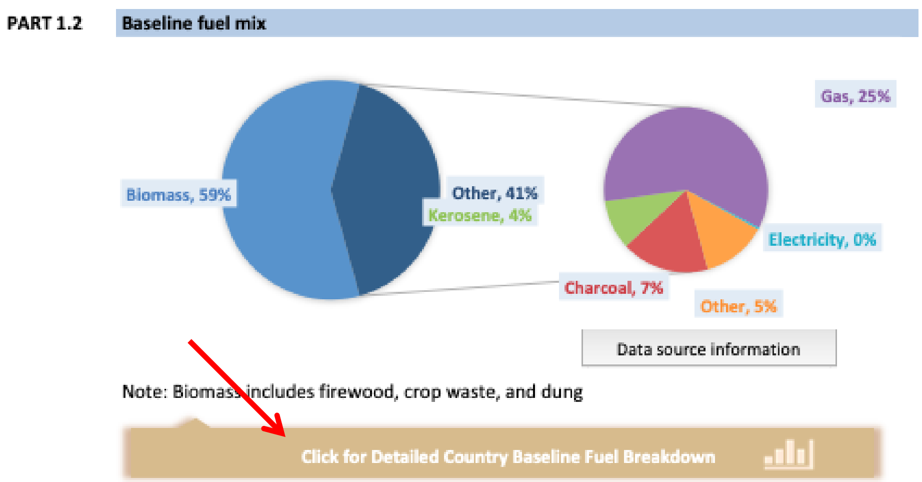
   a. In Part 1.1 of the worksheet, select your country of choice from the drop-down menu (cells JKL19). Default demographic, epidemiological, stove- and fuel-related and economic data for this country will be automatically populated[11].
      i. Click “View Baseline Burden Summary” to view the worksheet “BAR-Burden”, which shows the health, environmental and time burdens of the current cooking situation in the country.

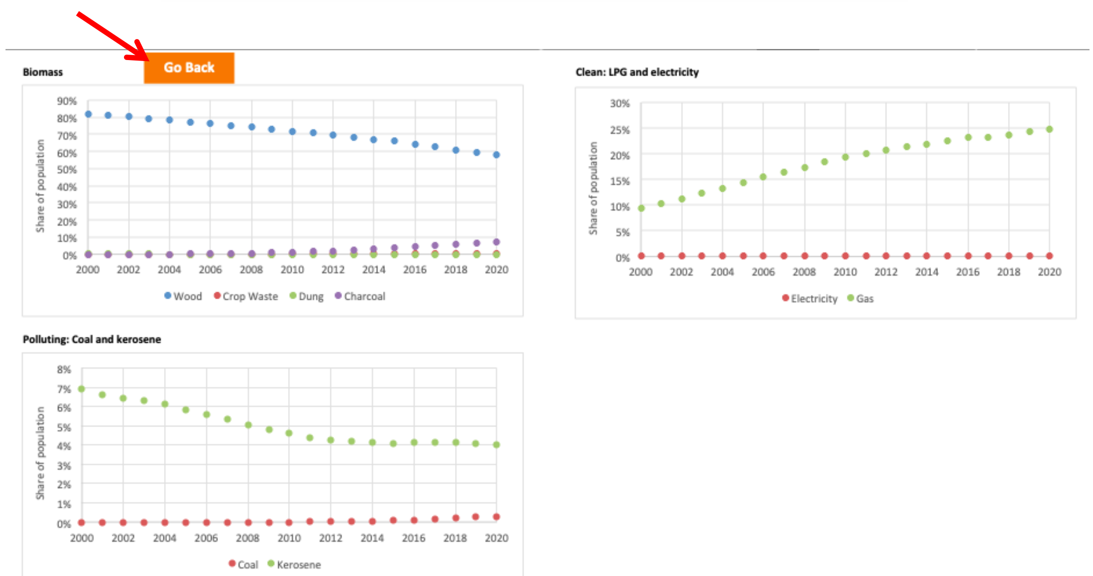


         1. To return to the **Setup-Country** tab, click the “Go Back” button.

[11] Note: This version of the BAR-HAP Tool includes default data for 134 LMICs.

b. Part 1.2 of the Setup-Country worksheet shows the baseline fuel mix (i.e., the mix of cooking fuels in the absence of any cleaner/clean cooking transition). Click the "Click for Detailed Country Baseline Fuel Breakdown" button to view the worksheet "Primary Fuel Trends", where the user can see the biomass, clean and transitional fuels' trend over 20 years (2000-2020). To return to the Setup-Country tab, click "Go Back".

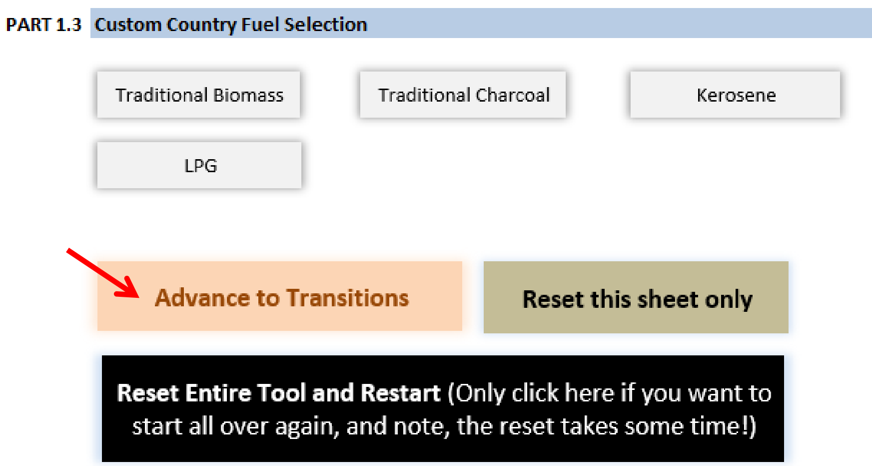


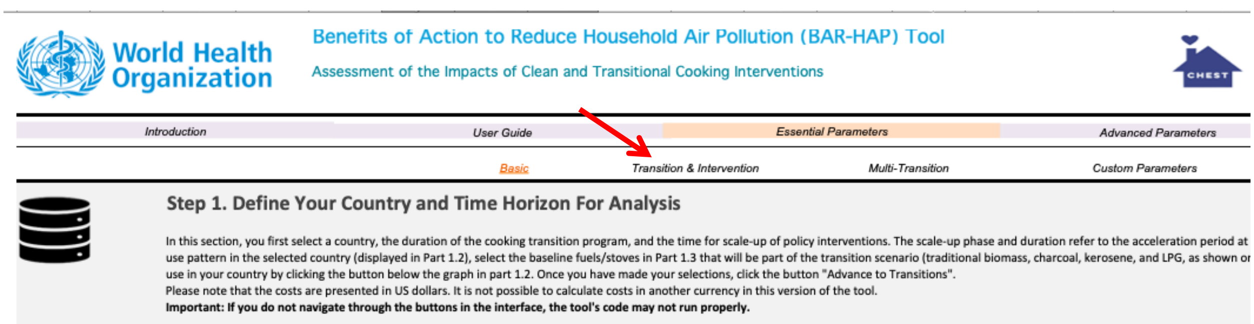


i. Click "Data source information", beneath the figure 'Baseline fuel mix', to view the "Data Sources" worksheet tab, which lists all the parameters used in the BAR-HAP Tool and their sources. To go back to the Setup-Country tab from the "Data Sources" worksheet, one must click on the "Essential Parameters" menu item at the top of the worksheet.

c. In Part 1.3, the user must select at least one fuel that people in the selected country currently use (please read "Tips" in cells YZ 33-45). The selected fuel(s) is the baseline option which users will transition away from, and this should be informed by the fuel mix shown in part 1.2. More than one fuel selection is possible: the analysis will consider transitions away from all fuels selected here.

   i. After selecting the fuel(s), click the **"Advance to Transitions"** button (or alternatively, click the **"Transition & Intervention"** link in the user interface. This is the only way to properly specify the transitions to be targeted with policies. Do not simply click the tabs at the bottom to navigate between tabs.

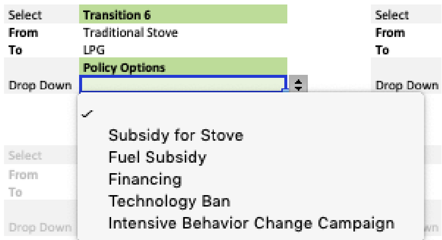




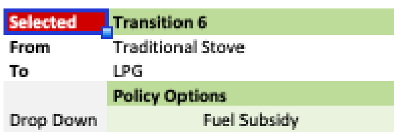
5. In the worksheet tab titled **Setup-Transition** (which the user is taken to after clicking "Advance to Transitions" in Part 1.3. of the "**SetUp-Country**" worksheet tab), the user can see the full set of relevant cooking transitions based on the fuel(s) selection made earlier. Note that only baseline fuels selected in Part 1.3 will show up (all others will be greyed out).

   a. For each cooking transition of interest, the user must select a policy option from the drop down menu. The user can select only 1 policy intervention per transition. However, if the user would like to combine a stove subsidy with a fuel subsidy, BCC, or financing, in this worksheet the user should choose the other intervention of interest (NOT the stove subsidy). The stove subsidy will be added later (step XX) by setting the stove subsidy to the desired percent of stove costs in columns VW in the worksheet tab "Setup-Basic Custom".

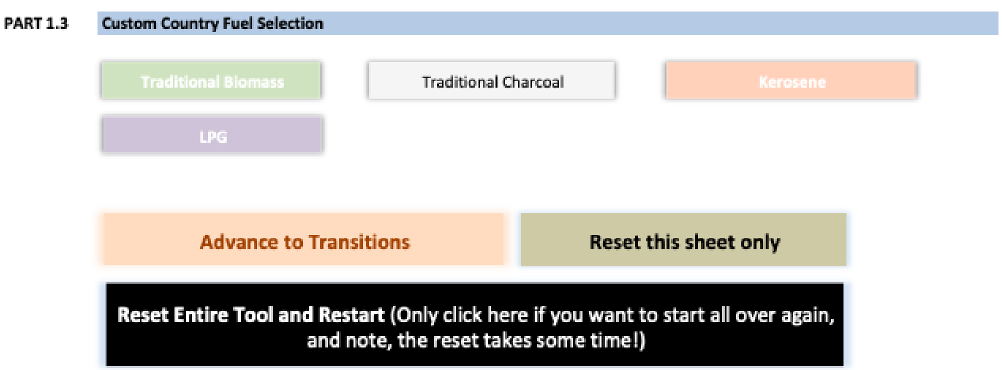
i. Note that fuel subsidies are not allowed when considering transitions that only involve biomass or charcoal fuel (it is allowed for processed biomass (pellet) fuel, however).

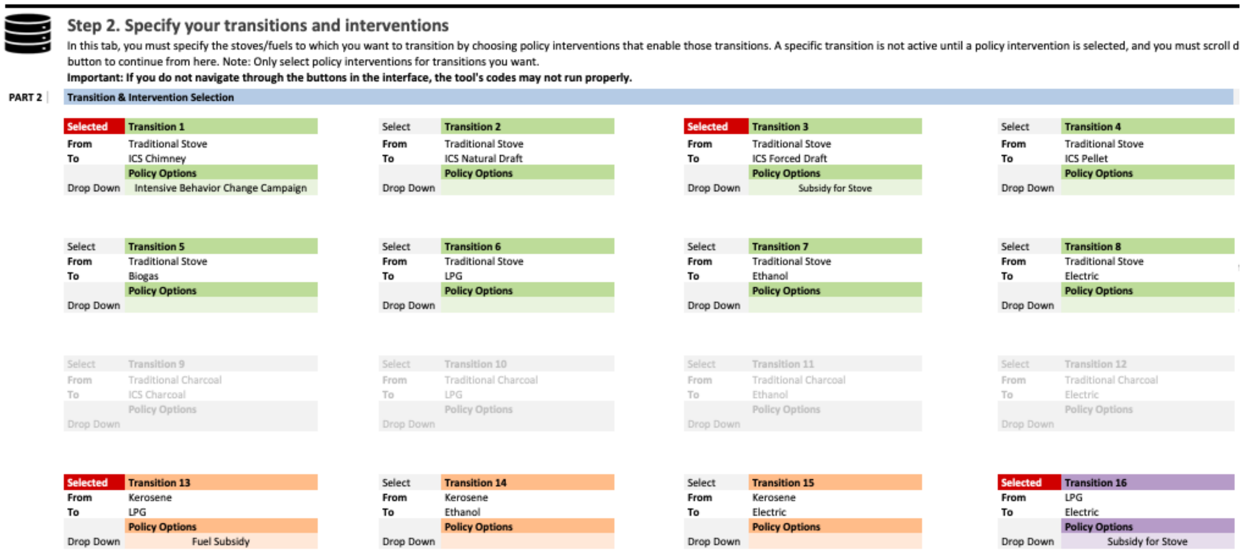


b. Once the user has selected a policy option, the upper left cell in the transition box will turn red and indicate "Selected". For further details, please read the "Tips" in cells YZ 12-35 and YZ 36-42.

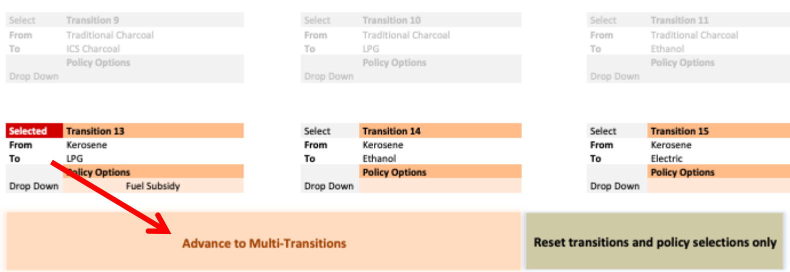


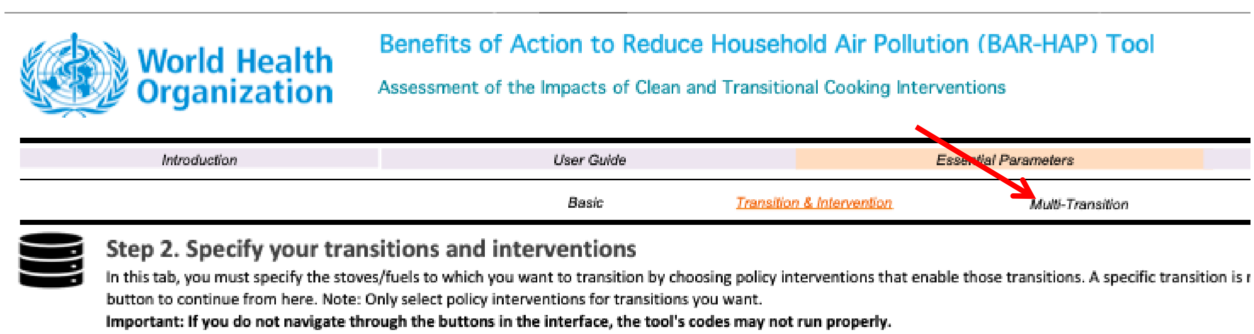
c. It is possible to include multiple transitions, i.e. specifying that certain segments of the population who all use the same baseline fuel will transition to different fuels/technologies. For example, the user can select "traditional to ICS (chimney)", "traditional to ICS (biomass-forced draft)", "Kerosene to LPG" and "LPG to electric" as part of a single analysis. In this example, the user would have had to have clicked on the "Traditional Biomass", "Kerosene" and "LPG" buttons in Part 1.3 of the "Setup-Country" tab.





d. Next, the user **must click** "Advance to Multi-Transitions", or use the link in the user interface. These are the only ways to properly specify the transitions to be targeted with policies; do not simply click on the tabs at the bottom to navigate between sheets.





e. To reset the entire tool and start again, please read the instructions in cells T-Z 44-47.

6. In the worksheet tab titled **Setup-MultiTrans** (which the user is taken to on clicking "Advance to Multi-Transitions" in the "SetUp-Transition" worksheet tab), the user can see the full set of relevant cooking transitions based on the fuel(s) selected earlier. This worksheet allows the user to specify what percent of the population will make each of the transitions that were selected in the "Transition & Intervention" section.
   a. This worksheet is divided into sections based on the starting fuel used in the population. The user must identify the percentage of the population currently

using each starting fuel that will switch to different cleaner fuels, and this process must be done for each starting fuel type.

   i. Please read detailed instructions in row 13.
   ii. For example, suppose the user would like half the traditional biomass stove users to transition to natural draft improved cookstoves, and the other half to LPG.

      1. In the "Setup-MultiTrans" sheet, in the 'Traditional biomass users' section, under 'Proportion', in the row for 'Natural draft ICS' enter 50% and in the row for 'LPG' enter 50%. The Total will show as 100%, which means that 100% of the traditional biomass stove users in the selected country will transition to these cleaner options.

From	Traditional biomass Users	Proportion
To	Chimney ICS	0%
	Natural draft ICS	50%
	Forced draft ICS	0%
	Pellet ICS	0%
	Biogas	0%
	LPG	50%
	Ethanol	0%
	Electric	0%
Total		100%
Check	This Portfolio Is Ok	

      2. If you see an error message 'Please adjust proportion', please check that the sum of proportions under a given stove category is 100% or less (since it is not possible for more than 100% of people to transition away from a given fuel).

From	Traditional biomass Users	Proportion
To	Chimney ICS	0%
	Natural draft ICS	100%
	Forced draft ICS	0%
	Pellet ICS	0%
	Biogas	0%
	LPG	100%
	Ethanol	0%
	Electric	0%
Total		200%
Check		ERROR: Please Adjust Proportion!

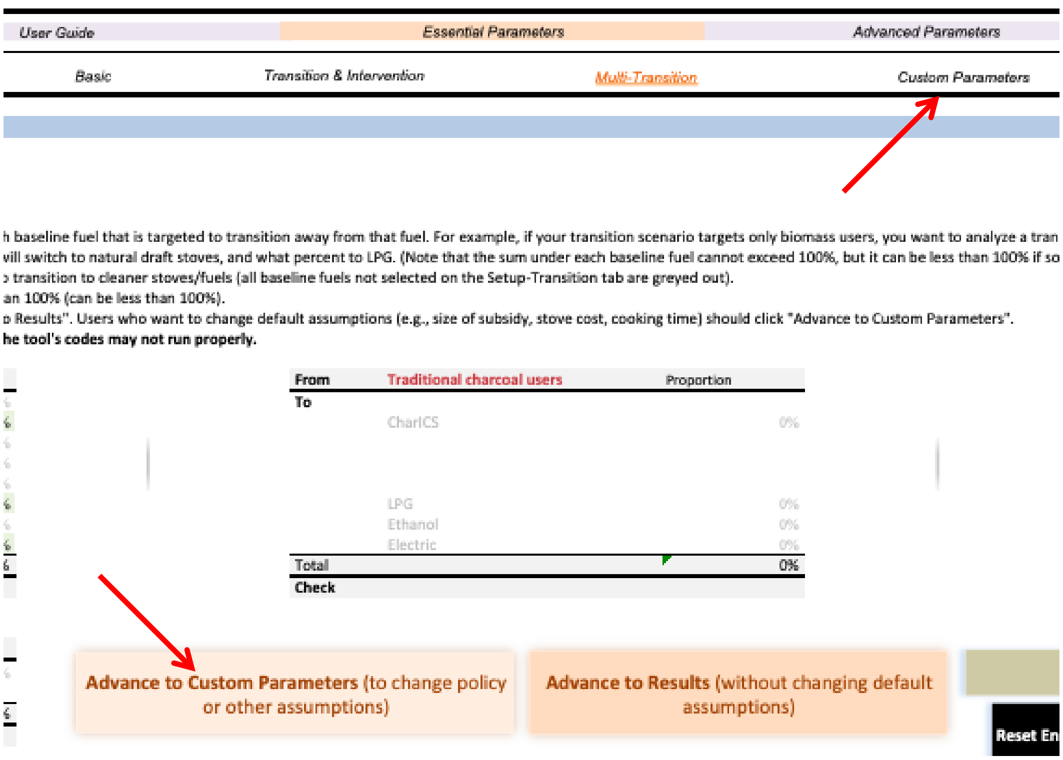
b. The user can consider clean cooking transitions that aim to *reach less than 100% of the target population* using a specific fuel type.

   i. For example, suppose the user expects that only 70% of the households currently using traditional biomass stoves will transition to cleaner options, and 30% will continue using traditional stoves. In this example, of the 70% of users who will transition to clean options: one-third will be targeted with natural draft biomass stoves (i.e., 23.3%), one third with LPG (23.3%), and one third with electricity (23.3%).

      1. In the "Setup-MultiTrans" sheet, in the 'Traditional biomass users' section, under 'Proportion', in the row for 'Natural draft ICS' enter 23.3%, in the row for 'LPG' enter 23.3% and in the row for 'Electric' enter 23.3%. The Total will show as 70%, which means that only 70% of the traditional biomass stove users in the selected country will transition to these cleaner options.
      2. If you get an error message 'Please adjust proportion', please check that the sum of proportions under a given stove category is 100%.

From	Traditional biomass Users	Proportion
To	Chimney ICS	0%
	Natural draft ICS	23%
	Forced draft ICS	0%
	Pellet ICS	0%
	Biogas	0%
	LPG	23%
	Ethanol	0%
	Electric	23%
Total		70%
Check		

c. To view (and change) the default values of the parameters included in the calculations, the user may navigate by clicking the “Advance to Custom Parameters” button or selecting the “Custom Parameters” link in the user interface. This will then proceed in succession through the Setup-Basic Custom; Setup-Advanced; Setup-Advanced (Finance); Setup-Advanced (Stove); Setup-Advanced (Health); Setup-Advanced (Emission) tabs (as users “Click to Confirm” after each step). The values from these tabs feed into each of the individual transition sheets as appropriate. Do not simply navigate across tabs at the bottom.



d. Users who want to use all default parameter assumptions as built into the Tool for the selected country may directly click the "Advance to Results" button from the **Setup-MultiTrans** tab. However, if the user wants to change assumptions, click "Advance to Custom Parameters".

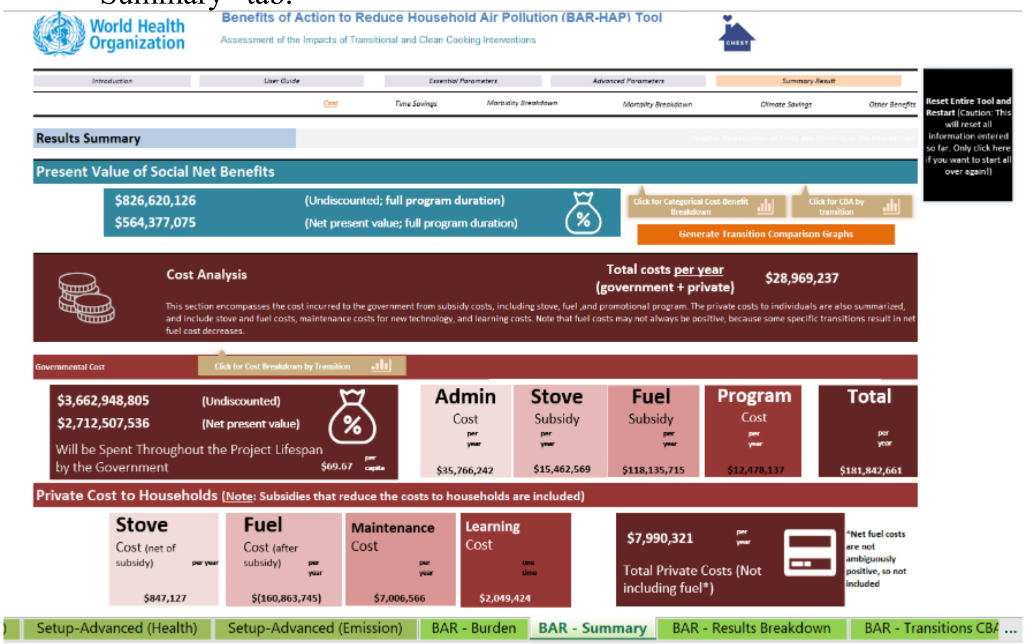
7. If a user decides to use the default parameter assumptions and clicks on “Advance to Results”, they are taken to the **BAR-Summary** worksheet, which displays the main results. This worksheet contains the total cost estimates (i.e., governmental cost, private cost) and total social net benefits (including intervention private and social health

benefits, intervention time savings, and intervention environmental benefits) that would be expected to occur from implementing the transition scenarios.

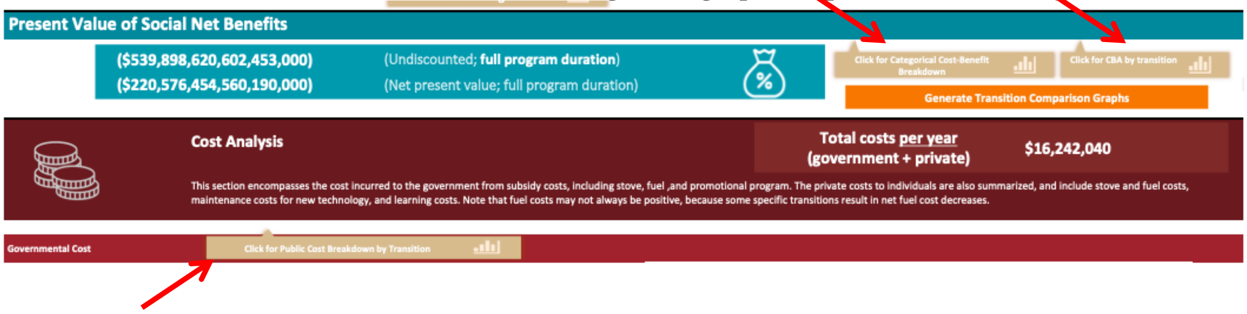
a. The sheet is organized to show the total present value of net benefits first, followed by cost items (government and private), and then finally benefits (health, time, and environmental).

b. All monetary values, unless labeled "undiscounted" are based on present values discounted over the full period. Thus, costs and benefits per year correspond to the net present value of the time stream of costs and benefits divided by the number of program years.

   a. Please see the screenshots below, for an example of results in the “BAR-Summary” tab.



c. There are three buttons that navigate to graphical presentation of key results:

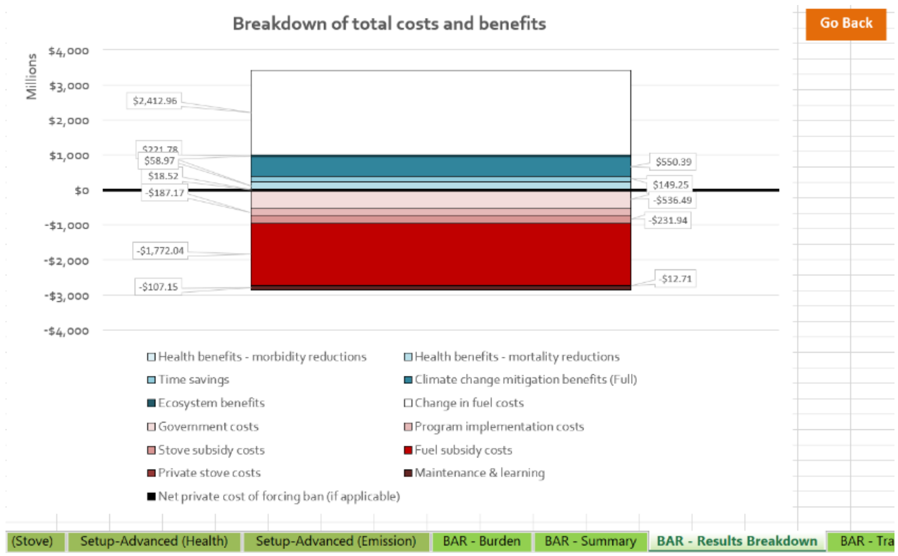


a. "Click for Categorical Cost-Benefit Breakdown" displays a disaggregated breakdown of the costs and benefits by category. Categories included in this display are:

   i. Benefits: 1) Health – morbidity reductions; 2) health – mortality reductions; 3) Time savings; 4) Climate mitigate benefits; 5) Ecosystem benefits;

   ii. Costs: 1) Government admin costs; 2) Program implementation cost; 3) Stove subsidy cost; 4) Fuel subsidy cost; 5) Private stove costs; 6) Maintenance and learning; 7) Cost of forced change (for ban intervention only); and

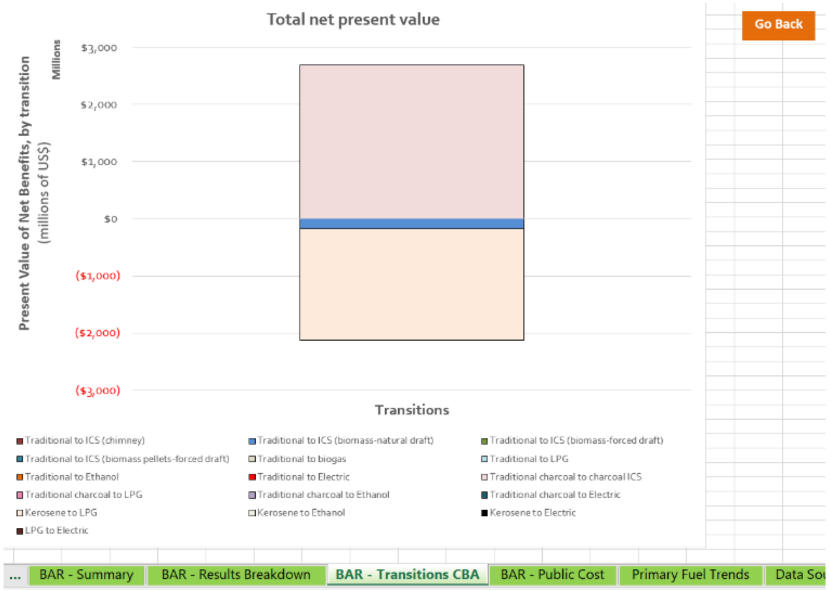
      1. Please see the screenshot below for an example of results available by clicking the "Categorical Cost-Benefit Breakdown" button.



   iii. Ambiguous refers to values that may be net cost or benefit, such as a change in fuel costs.

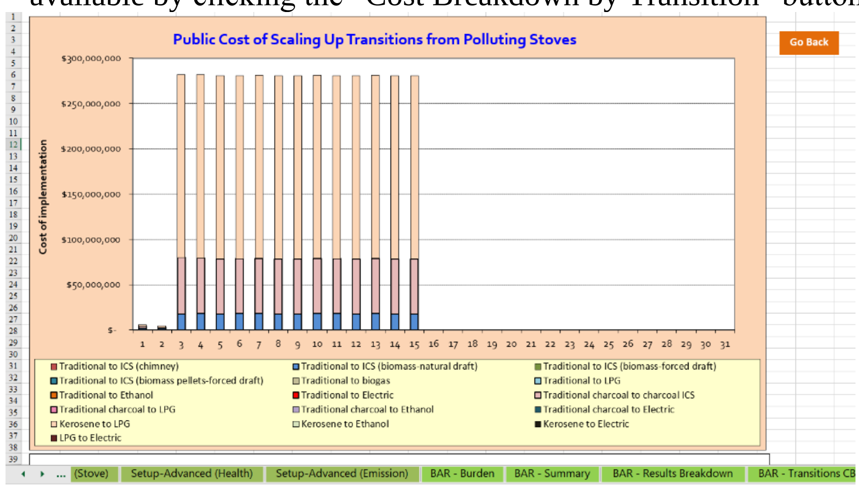
b. "Click for CBA by transition" displays a transition-specific disaggregation of the total net benefits, and is most useful when exploring multiple transitions with different policies.

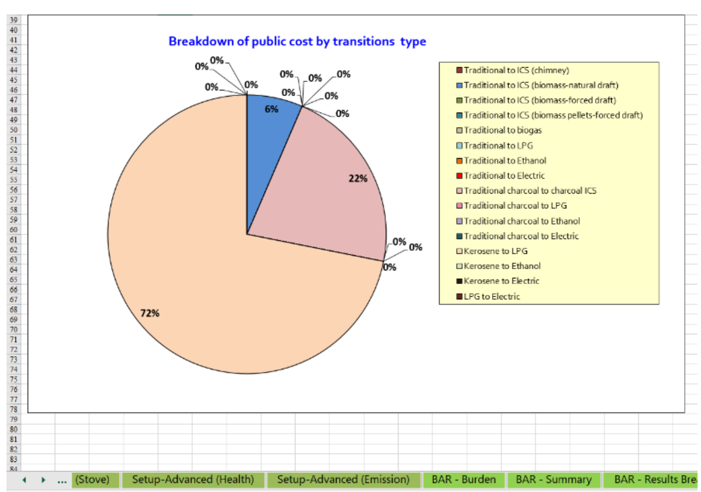
   i. Please see the screenshot below, for an example of results available by clicking the "CBA by transition" button.



c. "Click for Public Cost Breakdown by Transition" shows the public cost of the intervention over time (bar chart), and also across different transitions (pie chart).

i. Please see the screenshots below, for an example of results available by clicking the "Cost Breakdown by Transition" button.

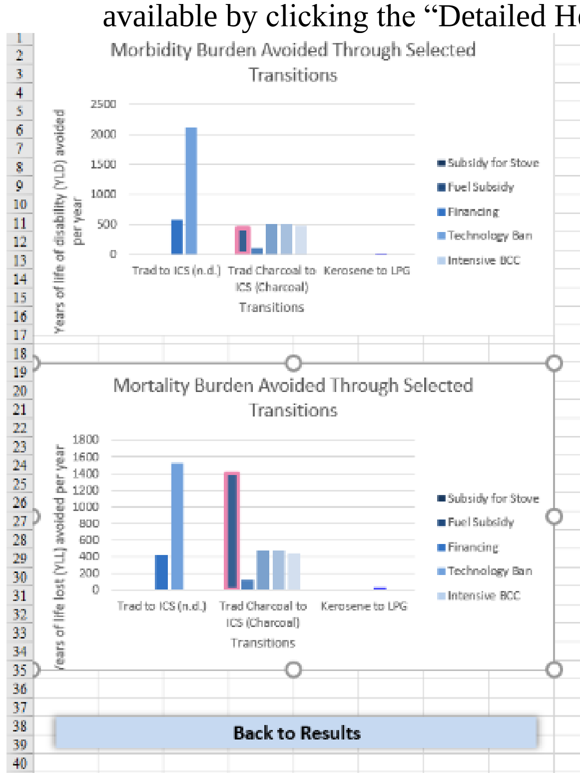




d. In addition, there is an orange "Generate Transitions Comparison Graphs" button on this page. Click on the "Generate Transition Comparison Graphs" to create the graphs that compare the benefits that other policy options would produce, relative to the selected one. To view these comparisons (in each case, the user-selected policy intervention highlighted in pink outline), click on the tan graph display buttons that appear in the sections for each type of benefit:

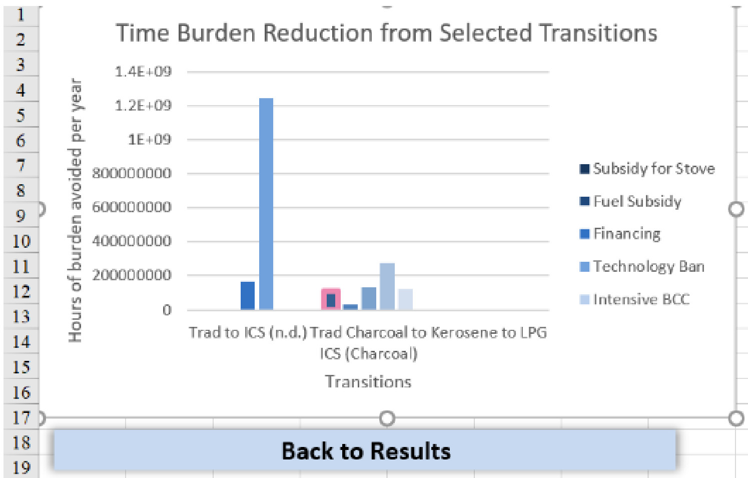
   a. Health benefits: click on "Click for Detailed Health Breakdown" under the "Private and Social Health Benefits" section. This will take the user to the "G-Morb" worksheet tab.

      i. Please see the screenshot below, for an example of results available by clicking the "Detailed Health Breakdown" button.

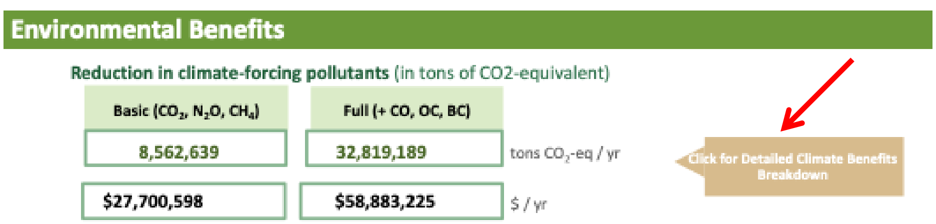


   b. Time savings: click on "Click for Detailed Time Saving Breakdown" under the "Time Savings" section. This will take the user to the "G-Time" worksheet tab.

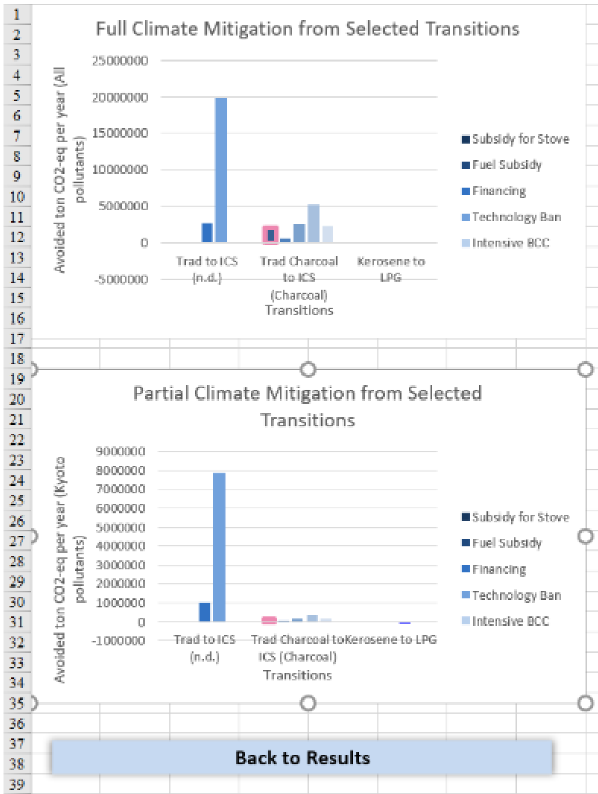
i. Please see the screenshot below, for an example of results available by clicking the "Detailed Time Saving Breakdown" button.



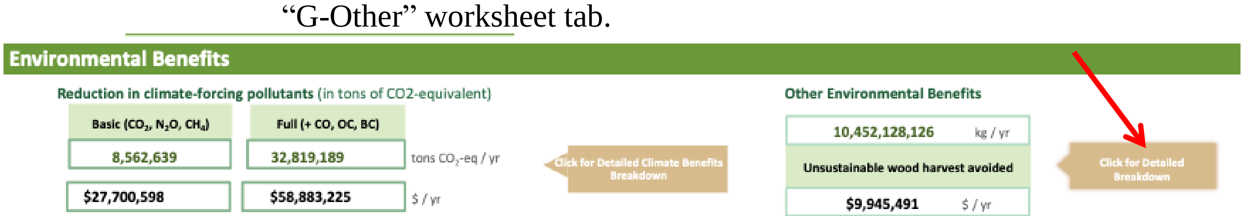
c. Climate mitigation benefits: click on "Click for Detailed Climate Benefits Breakdown" under the "Environmental Benefits" section. This will take the user to the "G-Climate" worksheet tab.



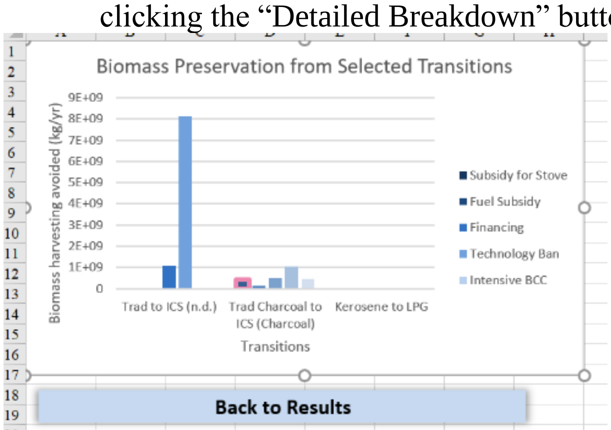
i. Please see the screenshot below, for an example of results available by clicking the "Detailed Climate Benefits Breakdown" button.



d. Other environmental benefits: click on “Click for Detailed Breakdown” under the “Environmental Benefits” section. This will take the user to the “G-Other” worksheet tab.

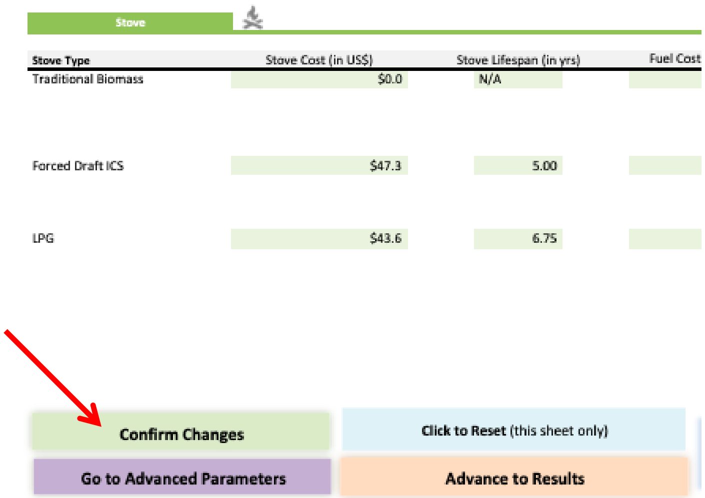


i. Please see the screenshot below, for an example of results on clicking the “Detailed Breakdown” button.



8. If a user wants to change parameter default values, on clicking on “Advance to Custom Parameters” from the “Multi-Transition” worksheet, they are taken to the **Setup-Basic Custom** worksheet.
   a. Please read the note in rows 12-13.

b. Here the user will see various finance, stove, fuel and other parameters relevant to the selected country, selected cooking transitions and policy interventions.
c. To change these parameter values, enter the value in the green-colored cell(s) next to each parameter. This can be done even when the Tool is running in fully protected mode (see details on how to unprotect the tool further below). This protected mode is the safest way to use the tool without irreversibly altering its functionality (e.g., by changing equations and model references).
d. Next, click "Confirm Changes" so that the calculations use the new values entered and not the default values for the specific parameter(s).



e. After having made the changes to certain parameter(s), if the user wishes to reset back to the default values built into the Tool for a particular sheet, please click "Click to Reset (this sheet only)".
f. On completing either task (in points d. or e. above), the user must click on "Advance to Results", or, to change additional parameters, click on "Go to Advanced Parameters." Do not simply navigate using the tabs at the bottom.

9. Experienced users who are comfortable with BAR-HAP or who are confident in alternative data sources may want to also make modifications in the advanced parameter tabs: **Setup-Advanced; Setup-Advanced (Finance); Setup-Advanced (Stove); Setup-Advanced (Health); Setup-Advanced (Emission).**
    a. In each of these worksheets, the user can change any of the parameter values by entering the value in the green-colored cell(s) next to each parameter.
    b. Then "click to confirm" to confirm the changes.
    c. Upon clicking "Click to Confirm" the worksheet will automatically open the next Setup-Advanced tab.
    d. If the user would prefer to revert to the default values, click "Click to Reset", and then proceed to the next step by clicking "Click to Confirm".
10. In a selected country, or across countries, users may reconfigure the model to see the impact of different parameter choices, in particular:
    a. Implementation of different policy interventions.
    b. Altered effects of selected clean cooking scenarios.
11. **General reminder**: Please note that if the user does not navigate through the buttons or links in the worksheets, the tool's codes may not run properly.

Key model parameters

Several variables which have a significant impact on the results are described below (and marked with **red bolded** font). Users are suggested to pay particular attention to these variables if they wish to make any modifications to default values.

1. In **Setup-Basic Custom**, the user can select the percentage of stove subsidy (in the 'Stove' section) or fuel subsidy (in the 'Fuel' section) (which is always in combination with the stove subsidy) for each stove and corresponding fuel type. In addition, two parameters are included to reflect the fact that subsidies are often imperfect instruments for transferring economic benefits across parties. Specifically:
    a. Stove subsidy leakage: This parameter would reflect issues such as subsidy capture by producers, who might increase overall prices and therefore only partially pass savings on to consumers. Alternatively, some subsidies may be captured by households who already own clean stoves, who would then turn around and resell those same stoves at higher prices, or use them to increase their cooking capacity, without improving health and other outcomes. This parameter is in the **Setup-Advanced** worksheet tab.
    b. Fuel subsidy leakage: Fuel subsidies would be even harder to target to those using less clean fuels; this parameter reflects the fact that consumers already using such options would benefit without generating additional health and environmental benefits. As with stove subsidies, fuel distributors might also capture some of the subsidy, such that price discounts would only be a fraction of the subsidy amount. This parameter is in the **Setup-Advanced** worksheet tab.
2. **Setup-Advanced** contains other cooking-related parameters. Several of these variables have a significant impact on the analyses.
    a. The **Use rate (% of cooking done on ICS)** variable represents the fraction of time that an improved stove is actually used in a household. After receiving or purchasing an ICS, many households do not actually use ICS for all cooking tasks, fully replacing their traditional cooking device. This can be due to shortages in fuel, cost of the cleaner fuel, shortages in fuel or power, taste preferences, or other reasons. Thus, this variable reduces the benefits from cleaner cooking transitions to reflect realistic ICS stove usage. The default value (48%) means that households use an ICS only 48% of the time – this estimate is taken from a recent review[12].
    b. Section 'Country' contains other parameters including total population, household size, number of children under five years per household, unskilled wage rate, and value of a statistical life.
3. The **Setup-Basic Custom** and **Setup-Advanced** tabs contain data on stove, fuel and interventions. These worksheets contain several variables that are not policy intervention specific (maintenance cost, learning cost, and program cost), but two variables are specific to the financing and behavior change campaign policy interventions, respectively:

---

[12] Jeuland, M., Tan Soo, J.-S., & Shindell, D. (2018). The need for policies to reduce the costs of cleaner cooking in low income settings: Implications from systematic analysis of costs and benefits. Supplementary Material. Energy Policy, 121(June), 275–285. https://doi.org/10.1016/J.ENPOL.2018.06.031

a. The **Stove financing cost** variable (cell J21 in **Setup-Basic Custom**) is used for the *financing policy intervention*. This variable represents the additional cost of financing stoves, due to administration of the financing intervention (e.g., multiple visits to collect payments) and the opportunity cost of funds whose collection is deferred in time (which is related to interest rates). Due to lack of evidence on the importance of different financing parameters in driving this cost and ICS adoption, the user does not specify parameters such as the frequency and number of payments. Instead, this financing cost represents the additional costs of spreading payments over time, according to local financing models.

b. The **Intensive behavior change campaign** variable (cell J19 in **Setup-Basic Custom**) is used in the *behavior change campaign policy intervention*. It represents the cost per target household of behavior change communication efforts.

4. **Setup-Advanced (Finance)** specifies the stove demand curves. The assumed functional forms are linear, and three parameters are possible to specify:
    a. The maximum price that anyone would pay for a stove;
    b. The maximum coverage rate that can be achieved; and
    c. The price at which coverage would reach that maximum.
    Specifying the parameters in a way that makes sense is not trivial and should be done by more experienced users only.

5. **Setup-Advanced (Stove)** contains information on stove efficiencies and fuel energy content. This information is used for developing estimates of time savings and changes in fuel costs and emissions from the different stove options, which is used in turn for calculating health, time, and climate impacts.

6. **Setup-Advanced (Health)** has data on HAP-related disease parameters.
    a. The **Health Spillovers** parameter (Cell P24) is an important variable to consider. This variable represents "social health benefits" and is used to account for the fact that some household air pollution exits the home environment and becomes ambient air pollution. Thus, reductions in household air pollution will lead to a reduction in ambient air pollution, and to the burden of disease from ambient air pollution. The health spillovers variable is the percent of the HAP-related burden of disease (BOD) (morbidity and mortality) that is estimated to be saved due to reduced AAP. For example, the default value of 13%[13] for Nepal means that the transition will produce health benefits from reduced AAP which are equal to an additional 13% of the health benefits from HAP reduction.
    b. **Exposure adjustment factors** – these variables are used to account for the fact that household members do not spend the entire 24-hour period near the cookstove, and thus actual personal exposure to air pollution is lower than the kitchen area concentration. These variables are calculated using information on kitchen and personal exposures from a recent systematic review and meta-analysis.[14] Fifteen studies in total calculated both personal exposure and kitchen concentrations before and after transitional/clean technologies were used. This

[13] Karagulian, F., Belis, C. A., Dora, C. F. C., Prüss-Ustün, A. M., Bonjour, S., Adair-Rohani, H., & Amann, M. (2015). Contributions to cities' ambient particulate matter (PM): A systematic review of local source contributions at global level. *Atmospheric Environment*, *120*, 475–483. https://doi.org/10.1016/j.atmosenv.2015.08.087

[14] Pope D, Johnson M, Fleeman N, Jagoe K, Ludolph R, Adair-Rohani H., Lewis J. 2021. Impact of household stove and fuel technologies on particulate and carbon monoxide concentration and exposures, a systematic review and analysis. Environmental Research Letters, *accepted.*

variable is applied to calculating effective $PM_{2.5}$ emissions of a cleaner stove with respect to a polluting or baseline stove. The effective $PM_{2.5}$ emissions of each stove thus calculated are used to then calculate relative risks of each of the five health conditions (COPD, ALRI, IHD, LC and stroke). In turn, the relative risk of each health condition, under a given stove technology, is used to calculate the population attributable fraction (PAF) of each health condition under a given stove technology. The PAFs are finally used to calculate morbidity and mortality reductions from a given cooking transition.

i. The **exposure adjustment factor – traditional stove** is used for biomass-using technologies (traditional stoves using firewood and charcoal). This is the fraction of personal PM2.5 exposure relative to kitchen PM2.5 concentration in each study 'before' the transitional/clean technology was used. This fraction is averaged across the 15 studies to get a biomass-using technology exposure adjustment of 0.51 (in other words, personal exposure to PM from traditional stoves is 51% of kitchen concentrations on average).

ii. The **exposure adjustment factor – ICS** variable is used for all transitional and clean cooking technologies as well as kerosene. The variable is the fraction of personal PM2.5 exposure relative to kitchen PM2.5 concentration in each study 'after' the transitional/clean technology was used and then average this fraction across the 15 studies, to get transitional/clean technology exposure adjustment of 0.71 (in other words, personal exposure to PM2.5 from ICS is 71% of kitchen concentrations). This suggests that individuals may avoid spending time around traditional stoves (perhaps because they produce more smoke) more than ICS.

7. **Setup-Advanced (Emission)** contains data on stove emissions, which is used to calculate health and climate impacts.

Hidden sheets

There is a hidden worksheet that stores the default parameter values. It is called "Default Parameters" and has cells that are modifiable (rows 175-326), except where there are pre-set calculations and/or they are linked to other worksheets, namely, "Relative disease risks", "ICS[15] demand" and "Demand assumptions". Only advanced users should modify elements of the "Default Parameters" hidden sheet (see instructions for advanced users further below).

There are several other hidden sheets, containing information on relative disease risks, ICS demand and climate global warming potential. It should not be necessary to modify information on these sheets when doing an analysis.

[15] Here, ICS refers to all transitional (improved biomass stoves and improved charcoal stoves) and clean stoves.

Time Frame of analyses

The BAR-HAP Tool allows users to determine a time frame ranging from 1 to 30 years over which interventions would be implemented. The default time horizon is 15 years. Users can modify this time horizon in Cell K24 in the “Setup-Country” tab. The implications for analysis are explained in the equations in example scenarios (pgs. 29-48).

Modification of the tool by advanced users

Advanced users may want to change the structure of the tool, but this should be done carefully. If there is a need to make such changes, the user should go to the sheet in question, click on the Review menu in Excel, and click “Unprotect Sheet”. The password for unprotecting every sheet is cleancooktool.

Example Scenarios

This manual includes detailed equations used to calculate the benefits and costs for two example transition scenarios, presented below. The first scenario is a transition for all households currently using traditional biomass stoves to shift to use of ICS (natural draft). The second scenario is for all households currently using traditional biomass stoves to shift to LPG stoves.

As discussed earlier and shown in Figure 2, five different policy instruments (i.e., stove subsidy, fuel subsidy, financing, intensive behavior change campaign, technology ban) can be added to the transition scenarios. The first example scenario includes very detailed cost-benefit equations for the first policy instrument (stove subsidy), and the second example scenario uses the second policy instrument (fuel subsidy) followed by a brief description of equations that differ for the other policy instruments is included at the end of the second example scenario.

Although a high level of detail is only provided for these two transitions, and for two of the policy instruments, the formulae can be modified for other stove transitions by replacing the stove type notation used in the example with the notation for the stove of interest as explained in the paragraph on Table 2 below.

Table 1 below contains an overview of the notation used for all different stove types in the formulae below and in BAR-HAP. These stove names (e.g., *ICS_chim*) are often used as part of another variable name to make other parameters stove-specific.

Table 2 below contains variable definitions and units for the example transition from traditional biomass stoves to ICS (natural draft). The parameters and descriptions in Table 2 are similar for transitions to other cleaner stoves, but the parameter name would need to be modified for different stoves (for example, the parameter *ICS_ndqty* would change for each of the stove types with "*ICS_nd*" in the parameter name replaced by another stove type – for LPG, the *ICS_ndqty* parameter would become *ICS_lpgqty*). There are also certain parameters that are stove specific.

Table 1. Stove type notations

Notation	Description
ICS_biogas	Biogas stove
ICS_char	Improved charcoal stove
ICS_chim	Improved chimney stove
ICS_elec	Electric stove
ICS_ethanol	Ethanol stove
ICS_fd	Improved biomass stove (forced draft)
ICS_kero	Kerosene stove
ICS_lpg	LPG stove
ICS_nd	Improved biomass stove (natural draft)
ICS_pellet	Improved biomass stove (forced draft with pellets)

Table 2. Parameter definition and units for Transition 1: Traditional biomass stoves to ICS (natural draft)[16]

Parameter	**Description**	**Unit**
Popn	Total country population	People
hhsize	Number of persons per household	persons/hh
perc_sfu	% of households using solid fuels	%
ICS_ndqty	Proportion of improved cookstoves natural draft (ICS n.d.) with the stove subsidy	Fraction
ICS_ndqty_fin	Proportion of improved cookstoves natural draft (ICS n.d.) with the financing option	Fraction
ICS_ndqty_bcc	Proportion of improved cookstoves natural draft (ICS n.d.) with the intensive behavior change campaign	Fraction
ICS_ndlspan	Lifespan of ICS n.d.	Years
ICS_ndcost	Cost of ICS n.d.	US$/stove
ndstove_subsidy	Subsidy % for transitional or clean stove type ICS (n.d.)	%
ndfuelsub_inc	Fuel subsidy included	0 or 1
ndICSban_inc	ICS technology ban included	0 or 1
ndICSbcc_inc	Intensive behavior change campaign (BCC) included	0 or 1
ndICSfin_inc	Stove financing included	0 or 1
ndICSsub_inc	Stove subsidy included	0 or 1
pctndICS	Proportion of population shifting to new stove intervention	%
*usagerate_ics_*	Usage rate of the ICS	%
stovesubleak	Subsidy leakage – stove subsidies	%
stove_subsidy_int	Binary variable for whether stove subsidy intervention is implemented	0 or 1
cost_prg_default	Stove promotion program cost	US$/hh
bcccost_default	Intensive behavior change campaign cost	US$/hh
fincost_default	Financing cost	% of stove cost
fineffect_default	Effectiveness of financing	(% increase in demand)
bcceffect_default	Effectiveness of BCC	(% increase in demand)
*wtpwood_*	Private WTP for technology (from demand curve)	US$/hh
fuelcost_ndICS	Fuel cost of ICS (n.d.)	US$/yr
fuelcost_tradstove	Baseline fuel cost of traditional stove	US$/yr
fuel_subsidy_int	Binary variable for whether fuel subsidy intervention is implemented	0 or 1
ICS_bioqty_fuelsub	Relative adoption of ICS (n.d.) with subsidy	%
ICS_bioqty_nofuelsub	Relative adoption of ICS (n.d.) with no subsidy	%
learning_hours	Hours spent learning use of ICS	hours
$fuelusage\_ndICS$	Fuel usage in improved (biomass) stove	kg
$fuelusage\_tradstove$	Fuel usage in traditional biomass stove	kg
cost_wood	Cost of wood	US$
buywood_	Percent buying wood	%
firewoodcolltime	Firewood collection time	Hrs/day
*svaluetime_cooking_*	Shadow value of time spent cooking (fraction of market wage)	Fraction
wagerate	Unskilled market wage	US$/hr
*fueleff_tradstove_*	Fuel efficiency of traditional wood stove	MJ useful energy/MJ heat
*fueleff_ndICS_*	Fuel efficiency of ICS	MJ useful energy/MJ heat
*energyconv_wood_*	Energy conversion of wood	MJ/kg fuel
timecook_biotrad	Time spent cooking on traditional stove	hr/day

[16] Parameters are the same for the other transitions, except for stove-specific parameters that depend on the transition and follow the notation format given in Table 1.

timecook_ndICS	Time spent cooking on ICS (natural draft stove)	hr/day
*fueluse_trad_*	Fuel spent cooking on traditional wood stove	kg/hr
cost_biotrad	Traditional stove cost	US$
maintenencecost_ICS	Cost of ICS maintenance	US$/yr
maintenencecost_tradstove	Cost of traditional stove maintenance	US$/yr
timeff_ndICS	Time efficiency of ICS (n.d.) relative to traditional biomass stove	Unitless ratio
χ_0	Percent use of baseline stove	%
IR_k	Incidence/prevalence of disease *k*	cases/100
MR_k	Mortality rate due to disease *k*	deaths/10000
COI_k	Cost-of-illness of disease *k*	US$/case
LE_k	Life expectancy remaining	years
firstyrlag_ k	Percentage of health benefits from HAP improvements observed in the first year	%
secondyrlag_ k	Percentage of health benefits from HAP improvements observed in the second year	%
thirdtofifthyrlag_ k	Percentage of health benefits from HAP improvements observed in years three to five	%
vsl	Value of statistical life	US$
π	Health spillover parameter i.e. proportion of ambient air pollution due to HAP	None
pubCOI_ k	Cost of illness of health outcome that is public	%
ε_i	Exposure adjustment parameter for stove *i*	None
c^{CO2}	Cost of carbon emissions	US$/ton
nr_biomassfuel	% of biomass harvesting that is non-renewable	%
δ_s	Discount rate (social)	None
δ_p	Discount rate (private)	

Example Scenario 1

Equations for cost-benefit calculations for Transition 1: Traditional biomass stoves to improved cookstoves (natural draft) with stove subsidy policy intervention [17]

The equations below apply to other cooking transitions as well, but the specific stove notations would need to be substituted with the appropriate notation from Table 1, i.e., replacing *ICS_nd* which represents ICS (natural draft) with the stove notation for the appropriate cooking device.

For all equations below, "partial implementation" refers to the scaling phase of an intervention. As previously explained, the intervention is assumed to be only partially implemented in this period, and covers a somewhat limited population (that is directly increasing in proportion to the year of scaling). In the following years, the intervention is assumed to apply to the entire population, represented by the "full implementation" calculations below. All interventions are can be implemented over a 15 to 30 year (user-specified) period.

POLICY INTERVENTION 1: SUBSIDY FOR STOVE

COSTS

1. **Government subsidy costs**

Three main costs borne by the government in implementing a policy intervention are considered here. These are (a) cost related to providing a stove subsidy, (b) cost related to provision of fuel subsidy, and (c) cost of rolling out the program itself. We assume no subsidies for biomass fuel as they are freely available, therefore fuel subsidies are zero in this transition.

Before providing detailed equations of each of these three costs, below are some unit costs that are factored in relevant calculations.

$$Partial\ implementation\_stove = (\frac{1}{scaleup}) * ((Popn/hhsize) * perc\_sfu * ICS\_ndqty/ICS\_ndlspan)$$

$$Full\ implementation\_stove = ((Popn/hhsize) * perc\_sfu * ICS\_ndqty/ICS\_ndlspan)$$

$$Stove\ subsidy\ unit\ cost = ICS\_ndcost * ndstove\_subsidy * (1 + stovesubleak)$$

$$Fuel\ subsidy\ unit\ cost = 0$$

$$Inflation = \frac{1 + Inflation\ rate}{Year\ of\ expansion}$$

a. Stove subsidy cost (households)

If applicable, for scaling up in years 1-2: $Stove\ subsidy\ cost = 0$

And in year 3-5 of scale-up:

[17] In line with the NCDs Costing Tool approach developed by the WHO, we allow up to 5 years for scaling up all transitions in the BAR-HAP tool. The scale-up assumption may be changed in the Setup-Country tab.

$Stove\ subsidy\ cost$
$$= (Partial\ implementation_{stove} * Stove\ subsidy\ unit\ cost * inflation) * ndICSsub_{inc} * pctndICS$$

For full implementation:

$Stove\ subsidy\ cost$
$$= (Full\ implementation_{stove} * Stove\ subsidy\ unit\ cost * inflation) * ndICSsub_{inc} * pctndICS$$

b. Fuel subsidy cost (households)

Since fuel subsidy unit cost is 0, there are no fuel subsidy costs in this policy intervention.

c. Program cost (households)

As we expect governments to spend initial years planning the program implementation, *if applicable, for scaling up in years 1-2*: $Program\ cost = 0$

And in year 3-5 of scale-up:

$Program\ cost = Partial\ implementation\_stove * cost\_prg * inflation * ndICSsub_{inc} * pctndICS$

For full implementation: $Program\ cost = Full\ implementation\_stove * cost\_prg * inflation * ndICSsub_{inc} * pctndICS$

2. **Private costs**

a. Stove cost (households)

Stove cost to households is the difference between the subsidized cost of the new stove, in this transition, ICS-natural draft $\left(ICS_{ndcost} * \left(1 - ndstove_{subsidy}\right)\right)$ and that of the baseline stove ($cost\_biotrad$). The cost of a traditional biomass stove is assumed to be zero as these stoves are made by households themselves. It is important to note that if the stove lifetime is less than 15 years (the assumed period of implementation of all transitions in the current version of the BAR-HAP Tool), then multiple stoves would be needed, which in turn will increase stove costs.

$Stove_{private} unit\ cost = \left(ICS_{ndcost} * \left(1 - ndstove_{subsidy}\right)\right) - cost\_biotrad$

As we expect governments to spend initial years planning the program implementation, *if applicable, for scaling up in years 1-2*: $Stove\ cost\ (households) = 0$

And in year 3-5 of scale-up:

$Stove\ cost\ (households) = Partial\ implementation * Stove_{private} unit\ cost * inflation * ndICSsub_{inc} * pctndICS$

For full implementation: $Stove\ cost\ (households) = Full\ implementation * Stove_{private} unit\ cost * inflation * ndICSsub_{inc} * pctndICS$

b. Fuel saving cost

Fuel saving cost is calculated as the difference between the cost of the fuel used in the new stove ($fuelcost_{ndICS}$) and the cost of the fuel used in the baseline stove ($fuelcost_{tradstove}$). In both costs, we include cost of purchasing wood, if households purchase wood instead of collecting it

($cost\_wood * buywood\_$) and multiply by fuel usage in respective stoves. Also included is the monetized fuel collection time ($firewoodcolltime\_ * svaluetime\_cooking\_ * wagerate\_ * (1 - buywood\_)$). In fuel cost of the new cost, we also include fuel usage in the new stove as a fraction of fuel usage in the traditional stove ($fuelusage\_ndICS/fuelusage\_tradstove$).

The equations for the fuel saving cost[18] are given below:

$$Partial\ implementation_{fuelsaving} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * \left(fuelcost_{ndICS} - fuelcost_{tradstove}\right) * usagerate\_ics\_$$

$$Full\ implementation\_fuelsaving = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * \left(fuelcost_{ndICS} - fuelcost_{tradstove}\right) * usagerate\_ics\_$$

where, $fuelcost\ ndICS = fuelusage\_ndICS * cost\_wood * buywood\_ + 365 * (firewoodcolltime\_ * fuelusage\_ndICS/fuelusage\_tradstove) * svaluetime\_cooking\_ * wagerate\_ * (1 - buywood\_)$

and $fuelcost_{tradstove} = fuelusage_{tradstove} * cost_{wood} * buywood\_ + 365 * firewoodcolltime\_ * svaluetime\_cooking\_ * wagerate\_ * (1 - buywood\_)$

$$Fuelusage\_ndICS = fuelusage_{tradstove} * \left(\frac{fueleff_{tradstove\_} * energyconv_{wood\_}}{fueleff_{ndICS\_} * energyconv_{wood\_}}\right)$$

$$Fuelusage_{tradstove} = 365 * timecook_{biotrad} * fueluse_{trad\_}$$

$$Fuel\ saving\ unit\ cost = 0$$

As we expect governments to spend initial years planning the program implementation, *if applicable, for scaling up in <u>years 1-2</u>*: $Fuel\ saving\ cost = 0$

And in <u>year 3-5 of scale-up</u>:

$$Fuel\ saving\ cost = Partial\ implementation_{fuelsaving} * inflation * ndICSsub_{inc} * pctndICS$$

For <u>full implementation</u>:

$$Fuel\ saving\ cost = Full\ implementation_{fuelsaving} * inflation * ndICSsub_{inc} * pctndICS$$

c. <u>Maintenance cost (households)</u>

Net operation and maintenance cost (*O&M)* are the difference between the maintenance cost of clean cooking option ($Maintenence\ cost_{ICS}$) and that of a baseline stove ($Maintenence\ cost_{tradstove}$). The cost of maintenance for a traditional biomass stove is assumed to be zero as these stoves are easily replaced and typically much cheaper compared to their clean cooking counterparts. On the other hand, while it has been well-documented that

[18] Please note that we have assumed the usage rate for all transitional and clean stoves to be 48% (based on eight field studies that reported transitional or clean stove usage). This usage rate has been included in calculations because studies show that households do not typically use the new cleaner stove all the time i.e. households continue to "stack" stoves (and use multiple stoves). The usage rate of ICS in our formulae, therefore, captures this partial use. Depending on country-specific usage rates, BAR-HAP Tool users can change this rate in the 'Default Parameters' tab (hidden) under the relevant ICS or clean stove in Row 225.

regular maintenance is essential for continuing clean energy usage, very few studies collected data on maintenance cost.

$$Full\ implementation\_maintenence \ = ((Popn/hhsize) * perc\_sfu * ICS\_ndqty$$

$$Maintenence\ unit\ cost = Maintenence\ cost_{ICS} - \ Maintenence\ cost_{tradstove}$$

If applicable, for scaling up in *years 1-2*: $Maintenence\ cost = 0$

And in *year 3-5 of scale-up*:

$$Maintenence\ cost = Partial\ implementation\_stove * Maintenence\ unit\ cost * inflation * ndICSsub_{inc} * pctndICS$$

For *full implementation*:

$$Maintenece\ cost = \ Full\ implementation_{maintence} * Maintenence\ unit\ cost * \ inflation * ndICSsub_{inc} * pctndICS$$

d. Learning cost (hours)

We expect there to be costs for learning how to use a new technology. Since the empirical literature is limited on learning cost for different transitional and clean stoves, we include the same learning cost for all transitional and clean stoves. Net learning cost is the difference between the learning cost of a clean cooking option ($learning\ hours * svaluetime\_cooking * wagerate\_$) and that of a baseline stove (which is zero, since households are accustomed to using their existing stoves).

$$Partial\ implementation\_learning \ = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * learning\ hours$$

$$Full\ implementation\_learning = ((Popn/hhsize) * perc\_sfu * ICS\_ndqty/ICS\_ndlspan) \ * learning\ hours$$

$$Learning\ unit\ cost = svaluetime\_cooking * wagerate\_$$

If applicable, for scaling up in *years 1-2*: We assume no learning costs.

And in *year 3-5 of scale-up*:

$$Learning\ cost = Partial\ implementation\_learning * Learning\ unit\ cost * inflation * ndICSsub_{inc} * pctndICS$$

For *full implementation*: We assume no learning costs year 6 onwards, as we expect households to have learnt how to use the new stove technology.

BENEFITS

1. Time Savings

Under time savings, we only consider time spent cooking (fuel collection time savings is captured in the fuel saving cost). It is calculated as the difference between time spent cooking on the baseline or old stove technology ($timecook_{biotrad}$) and the time spent cooking on the new stove technology ($Timecook_{ndICS}$). This difference is then monetized by multiplying with the shadow value of time ($svaluetime\_cooking\_$) and existing wage rate ($wagerate\_$).

$$Partial\ implementation\_{time\ savings} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * usagerate_{ndICS\_} * (timecook_{biotrad} - timecook_{ndICS}) * 365$$

Where, $Timecook_{ndICS} = efftime_{ndICS} * \ timecook_{biotrad}$

$$Full\ implementation\_{time\ savings} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * ICS\_ndqty\right) * usagerate_{ndICS} * (timecook_{biotrad} - timecook_{ndICS}) * 365$$

$$Time\ savings\ unit\ cost = svaluetime\_cooking\_ * wagerate\_$$

If applicable, for scaling up in <u>years 1-2</u>: $Time\ savings = 0$

And in <u>year 3-5 of scale-up</u>:

$$Time\ savings = Partial\ implementation\_timesavings * Time\ savings\ unit\ cost * inflation * ndICSsub_{inc} * pctndICS$$

For <u>full implementation</u>:

$$Time\ savings = Full\ implementation\_timesavings * Time\ savings\ unit\ cost * inflation * ndICSsub_{inc} * pctndICS$$

2. Private Health Benefits

As described in the supplementary materials to Jeuland et al. (2018), we use the exposure-response functions derived by Burnett et al (2014) for various respiratory-related diseases as they relate to concentrations of $PM_{2.5}$ (μg/m^3 in 24 hours). To calculate the level of $PM_{2.5}$ exposure following the transitional or clean cooking intervention ($PM_{2.5}$), we use data on emissions from different transitional or clean cooking stove options ($PM_{2.5,i}$) and scale the reductions from the baseline stove ($PM_{2.5,0}$) using the rate of the transitional or clean cooking option usage and also a pollution exposure adjustment parameter ε_i, which is meant to account for the behavioral response that may reduce exposure reductions due to cleaner cooking increasing individuals' contact time with harmful smoke[19]:

$$\mathrm{PM}_{2.5} = \chi_i \cdot \varepsilon_i \cdot \mathrm{PM}_{2.5,i} + (1 - \chi_i) \cdot \varepsilon_0 \cdot \mathrm{PM}_{2.5,0}$$

[19] Explained above under the exposure adjustment factor variable

Using this new concentration $PM_{2.5}$, we use the Burnett relationship to calculate the relative risk (*RR*) of mortality (or morbidity) for specific diseases for each stove-fuel combination.[20] Because there are multiple causes for each disease, we must also assign the portion of risk attributable to stoves' emissions using the population attributable fraction (*PAF*). Calculation of the PAF for stove i (PAF_i) requires the fraction of population exposed to HAP and we use the proportion of solid fuel users (*sfu*)[21] in the population as a proxy for this indicator:

$$PAF_i = \frac{perc\_sfu * (RR_k - 1)}{perc\_sfu * (RR_k - 1) + 1}$$

Next, to quantify the reduction in mortality from a specific disease k (in the above relationship the following diseases are included: acute lower respiratory illness (ALRI), chronic obstructive pulmonary disease (COPD), ischemic heart disease (IHD), lung cancer (LC) and stroke) given the use of stove i, the change in the PAF is multiplied by the mortality rate of the disease MR_k. For morbidity improvements, we multiply the change in the PAF by the incidence rate (for ALRI) or prevalence rate (for other diseases) (IR_k).

$Morb_{k\_priv} = hhsize \cdot (PAF_0 - PAF_i) \cdot IR_k$[22] and

$$Mort_{k\_priv} = hhsize \cdot (PAF_0 - PAF_i) \cdot MR_k$$

For valuing these benefits of reduced morbidity and mortality, we must account for the fact that the health improvements from HAP reductions are staggered in time by discounting those that occur in the future. To do this, we use the EPA's cessation lag concept, which assumes that 30% of the health benefits from HAP improvements are observed in the first year; 20% in the second year; and the remaining 50% are equally spread out over the next three years. The lagged values for the five health outcomes are given in Table B5.

We also calculate social health benefits by accounting for a health spillovers factor that accounts for the reduction in morbidity and mortality from ambient air pollution due to reduced household biomass burning.

$Morb_{k\_social} = (\pi) * hhsize \cdot (PAF_0 - PAF_i) \cdot IR_k$ and

$$Mort_{k\_social} = (\pi) * hhsize \cdot (PAF_0 - PAF_i) \cdot MR_k$$

(a) Private Morbidity reductions of health outcome (cases/year)

The following are the calculations for the yearly number of cases of the five health outcomes mentioned previously: COPD, ALRI, IHD, LC and stroke.

$$Partial\ implementation\_morb_{healthoutcome\_k} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * Morb_{k\_priv}$$

$$Full\ implementation\_morb_{healthoutcome\_k} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * Morb_{k\_priv}$$

[20] Parameters for the relative risk functions can be downloaded from here: http://ghdx.healthdata.org/sites/default/files/record-attached-files/IHME_CRCurve_parameters.csv

[21] In transitions where charcoal stoves or kerosene stoves are the baseline technologies, we use the proportion of charcoal users (perc_char_) and proportion of kerosene users (perc_kerosene_), respectively to calculate PAF.

[22] For ALRI, we use the number of children under 5 (*hh*<5) instead of household size.

If applicable, for scaling up in *years 1-2*: $Morbidity\ reductions = 0$

And in *year 3-5 of scale-up*:

$$Morbidity\ reductions = firstyearlag_{healthoutcome_k} * Partial\ implementation_{morb\ healthoutcome_k} * COI * inflation * ndICSsub_{inc} * pctndICS$$

For *full implementation*:

$$Morbidity\ reductions = Full\ implementation_{morb\ healthoutcome_k} * COI * inflation * ndICSsub_{inc} * pctndICS$$

(b) Private Mortality reductions of health outcome (deaths/year)

The following are the calculations for the yearly number of deaths from the five health outcomes mentioned previously: COPD, ALRI, IHD, LC and stroke.

$$Partial\ implementation\_mort_{healthoutcome\_k} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * Mort_{k\_priv}$$

$$Full\ implementation\_mort_{healthoutcome\_k} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * Mort_{k\_priv}$$

If applicable, for scaling up in *years 1-2*: $Mortality\ reductions = 0$

And in *year 3-5 of scale-up*:

$$Mortality\ reductions = firstyearlag_{healthoutcome_k} * Partial\ implementatiot_{healthoutcome_k} * vsl * inflation * ndICSsub_{inc} * pctndICS$$

For *full implementation*:

$$Mortality\ reductions = Full\ implementation_{mort\ healthoutcome_k} * vsl * inflation * ndICSsub_{inc} * pctndICS$$

3. Public Health Benefits

In calculating the total public health benefits, we include a percentage of the cost of illness of each health outcome that is public. The default parameters for this parameter ($pubCOI\_healthoutcome_i$) are based on expert judgment and specifically assume that many more cases of ALRI are treated privately than cases of the other chronic respiratory illnesses, hence a lower fraction (40%) is assumed for that disease relative to the others (65-90%).

$$Public\ health\ benefits_i = (Morbidity\ reductions\_COPD_i * pubCOI\_COPD\_) + (Morbidity\ reductions_{ALRI_i} * pubCOI\_ALRI) + (Morbidity\ reductions_{IHD_i} * pubCOI\_IHD) + (Morbidity\ reductions_{LC_i} * pubCOI\_LC) + (Morbidity\ reductions\_Stroke_i * pubCOI\_Stroke)$$

Where, $i = Year$

Many health economists favor cost-effectiveness ratios using standardized measures of a burden of disease (e.g., Disability-adjusted life years, or DALYs) over presentation of monetized health benefits. DALYs sum up the morbidity and mortality burdens (years of life in disability, or YLD, and years of life lost, or YLL). The public cost of per DALY avoided is then simply the ratio of the public cost of the intervention to the total sum of this disease burden.

$$Morbidity\ reductions\ of\ health\ outcome'i'\ (or\ YLD_i) = Total\ morbidity\ reductions\ of\ health\ outcome'i'over\ 15\ years * \ DALY\ weight\ for\ health\ outcome'i' * \frac{Duration\ of\ case\ of\ health\ outcome'i'}{365}$$

$$Mortality\ reductions\ of\ health\ outcome'i'(or\ YLL_i) = Total\ mortality\ reductions\ of\ health\ outcome'i'over\ 15\ years * (1 - EXP(-social_{discountrate} * LE_{COPD})/social\_discountrate$$

$$Public\ COI\ per\ DALY\ avoided = {Public\ cost}/{\sum_i (Mortality\ reductions\ of\ health\ outcome'i' + Morbidity\ reductions\ of\ health\ outcome'i')}$$

4. Social Health Benefits

Except for the inclusion of health spillovers (i.e. accounting for the contribution of household air pollution to ambient air pollution), the social health benefits calculations (social morbidity reductions and social mortality reductions) are identical to the private health benefits.

(a) Social Morbidity reductions of health outcome (cases/year)

$$Partial\ implementation\_morb\_social_{healthoutcome\_k} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * Morb_{k\_social}$$

$$Full\ implementation\_morb\_social_{healthoutcome\_k} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * Morb_{k\_social}$$

If applicable, for scaling up in <u>years 1-2</u>: $Morbidity\ reductions = 0$

And in <u>year 3-5 of scale-up</u>:

$$Morbidity\ reductions = firstyearlag_{healthoutcome_k} * Partial\ implementation_{morb\_social_{healthoutcome_k}} * COI * inflation * ndICSsub_{inc} * pctndICS$$

For <u>full implementation</u>:

$$Morbidity\ reductions = Full\ implementation_{morb\_social_{healthoutcome_k}} * COI * inflation * ndICSsub_{inc} * pctndICS$$

(b) Social Mortality reductions of health outcome (deaths/year)

$$Partial\ implementation\_mort\_social_{healthoutcome\_k} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * Mort_{k\_social}$$

$$Full\ implementation\_mort\_social_{healthoutcome\_k} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * Mort_{k\_social}$$

If applicable, for scaling up in <u>years 1-2</u>: $Mortality\ reductions = 0$

And in <u>year 3-5 of scale-up</u>:

$$Mortality\ reductions = firstyearlag_{healthoutcome_k} * Partial\ implementation_{mort\_social\_healthoutcome_k} * vsl * inflation * ndICSsub_{inc} * pctndICS$$

For <u>full implementation</u>:

$$Mortality\ reductions = Full\ implementation_{mort\_social_{healthoutcome_k}} * vsl * inflation * ndICSsub_{inc} * pctndICS$$

(c) Public cost/DALY avoided of health outcomes

Many health economists favor cost-effectiveness ratios using standardized measures of a burden of disease (e.g., Disability-adjusted life years, or DALYs) over presentation of monetized health benefits. DALYs sum up the morbidity and mortality burdens (years of life in disability, or YLD, and years of life lost, or YLL). The public cost of per DALY avoided is then simply the ratio of the public cost of the intervention to the total sum of this disease burden.

$$Morbidity\ reductions\ of\ health\ outcome'i'\ (or\ YLD_i) = Total\ morbidity\ reductions\ of\ health\ outcome'i'\ over\ 15\ years * DALY\ weight\ for\ health\ outcome'i' * \frac{Duration\ of\ case\ of\ health\ outcome'i'}{365}$$

$$Mortality\ reductions\ of\ health\ outcome'i'\ (or\ YLL_i) = Total\ mortality\ reductions\ of\ health\ outcome'i'\ over\ 15\ years * (1 - EXP(-social_{discountrate} * LE_{COPD})/social\_discountrate$$

$$Public\ COI\ per\ DALY\ avoided = Public\ cost / \sum_i (Mortality\ reductions\ of\ health\ outcome'i' + Morbidity\ reductions\ of\ health\ outcome'i')$$

5. Climate Benefits

Again as discussed in the supplementary materials to Jeuland et al. (2018), climate-forcing emissions reductions constitute an important potential social benefit of more efficient cookstoves. Cooking with biomass in inefficient stoves produces a range of climate-forcing pollutants. As in the calculation of the economic benefits of health improvements, there are two main components in valuing reductions in these emissions (*Clim*) – the value of the (marginal) changes and the total amount of the reduction.

Calculating the amount of emissions reduction is complicated by the fact that cookstoves emit a range of pollutants, some of which (e.g., black carbon, CO, and CO_2) increase warming, and others of which (namely organic carbon) reduce it. These various emissions must be normalized and expressed in commensurate terms, at least with respect to the time-varying aspects of their overall global warming potential (*GWP*). Our approach builds on Shindell et al. (2015).

To calculate the global warming potential (*GWP)* due to cookstoves using base parameters for the global warming for the main substances these emit, which relates to the energy content of fuels and efficiencies of stoves, we start by multiplying emissions factors $\varepsilon_{j,I}$ of particular gases *j* for various stove-fuel combinations *i,m* (e.g., $\varepsilon_{CO2,i,m}$ in g CO2-eq/MJ), by the GWP_j for those particular gases (GWP_{CO2}).

The first equation shows the GWP_j derivation for a stove-fuel combination *i* that includes only the three greenhouse gases – carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) – that were part of the Kyoto Protocol.

The second equation includes additional pollutants (black carbon (BC), organic carbon (OC), and carbon monoxide (CO). An important detail of this calculation is that the carbon dioxide component of GWP is multiplied by the fraction of non-renewable biomass ψ, since renewable harvesting sequesters carbon at the same rate as it is consumed (it does not affect net emissions). In addition, for charcoal emissions we include emissions produced during the charcoal production process.

$$GWP_{i,m,Kyoto} = \varepsilon_{CO2,i,m} \cdot \psi + \varepsilon_{N2O,i,m} \cdot GWP_{N20} + \varepsilon_{CH4,i,m} \cdot GWP_{CH4}$$

$$GWP_{i,m} = \varepsilon_{CO2,i,m} \cdot \psi + \sum_{j\epsilon K} \varepsilon_{CO2,i,m} \cdot GWP_j, \text{ where } j = CO_2 \notin K$$

To account for the change in GWP of pollutants over time, we derive the present value of radiative forcing associated with different pollutants. The formula for this calculation is shown below:

$$GWP_{j\epsilon K} = \sum_{t=1}^{\infty} \frac{1}{(1+\delta_s)^{t-1}} \cdot RF_{j,t} \Big/ \sum_{t=1}^{\infty} \frac{1}{(1+\delta_s)^{t-1}} \cdot RF_{CO2,t}$$

where radiative forcing in future years is discounted relative to the present using an appropriate social discount rate δ_d, and still is normalized by the forcing from CO_2. To obtain this time-discounted GWP, we simply calculate the time path of radiative forcing for pollutant *j* as a function of time *t* ($RF_{j,t}$ in W/m^2). For our purposes, we limit our time horizon to 100 years. We then substitute this pollutant-specific, time-normalized GWP into the $GWP_{i,m}$ equation above.

We monetize the carbon saved using the social cost of carbon.

(a) Carbon savings (basic)

The carbon savings calculations described below include only the three pollutants included in the Kyoto protocol (i.e. CO_2, CH_4 and N_2O).

$$Partial\ implementation\_carbonsav\_basic = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * usagerate_{ndICS} * \left(fuelusage_{tradstove} * GWC_{tradbasic} * energyconv_{wood} * fueleff_{tradstove}\right) - fuelusage_{ndICS} * (GWC_{ICSnd_{basic}} * energyconv_{wood} * fueleff_{ndICS}))/1000000$$

$$Full\ implementation\_carbonsav\_basic = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * usagerate_{ndICS} * \left(fuelusage_{tradstove} * GWC_{tradbasic} * energyconv_{wood} * fueleff_{tradstove}\right) - fuelusage_{ndICS} * (GWC_{ICSnd_{basic}} * energyconv_{wood} * fueleff_{ndICS}))/1000000$$

$$Carbon\ saving\ unit\ cost = socialcost\_carbon * (1 + inflation\_rate) * (1 + discountfactor\_carbonprice)$$

If applicable, for scaling up in <u>years 1-2</u>: $Carbon\ savings\ (basic) = 0$

And in <u>year 3-5 of scale-up</u>:

$$Carbon\ savings\ (basic) = Partial\ implementation_{carbonsav_{basic}} * carbon\ saving\ unit\ cost * inflation * ndICSsub_{inc} * pctndICS$$

For full implementation:

$$Carbon\ savings\ (basic) = Full\ implementation_{carbonsav_{basic}} * carbon\ saving\ unit\ cost * inflation * ndICSsub_{inc} * pctndICS$$

(b) Carbon savings (full)
The carbon savings calculations described below include the three pollutants included in the Kyoto protocol (i.e. CO_2, CH_4 and N_2O) as well as three additional pollutants, that is BC, OC and CO.

$$Partial\ implementation\_carbonsav\_full = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * usagerate_{ndICS} * \left(fuelusage_{tradstove} * GWC_{tradfull} * energyconv_{wood} * fueleff_{tradstove}\right) - fuelusage_{ndICS} * (GWC_{ICSnd_{full}} * energyconv_{wood} * fueleff_{ndICS}))/1000000$$

$$Full\ implementation\_carbonsav\_full = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * usagerate_{ndICS} * \left(fuelusage_{tradstove} * GWC_{tradfull} * energyconv_{wood} * fueleff_{tradstove}\right) - fuelusage_{ndICS} * (GWC_{ICSnd_{full}} * energyconv_{wood} * fueleff_{ndICS}))/1000000$$

If applicable, for scaling up in years 1-2: $Carbon\ savings\ (basic) = 0$

And in year 3-5 of scale-up:

$$Carbon\ savings\ (full) = Partial\ implementation_{carbonsav_{full}} * carbon\ saving\ unit\ cost * inflation * ndICSsub_{inc} * pctndICS$$

For full implementation:

$$Carbon\ savings\ (full) = Full\ implementation_{carbonsav_{full}} * carbon\ saving\ unit\ cost * inflation * ndICSsub_{inc} * pctndICS$$

5. Environmental Benefits

Per the supplementary materials in Jeuland et al. (2018), the other major category of social benefits is that related to the environmental services lost due to non-sustainable harvesting of biomass, or in the case of sustainable harvesting, the cost of tree replacement (*Bio*). The first type of such costs, associated with non-sustainable harvesting, is very difficult to generalize, and there are few high-quality studies that measure such non-market values well. We can estimate the second category as the product of the cost of timber farming c^f (in $/kg of wood produced) multiplied by the change in renewably harvested biomass (as previously estimated). This is clearly a lower bound for other environmental values since it does not include the value of avoided deforestation or forest degradation (except insofar as this contributes to global warming).

$$Partial\ implementation\_biosavings = \left(\frac{1}{3}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{ndqty}}{ICS_{ndlspan}}\right) * usagerate_{ndICS} * (fuelusage_{tradstove} - fuelusage_{ndICS}) * nr\_biomassfuel$$

$$Full\ implementation\_biosavings = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \ ICS_{ndqty}\right) * usagerate_{ndICS} * (fuelusage_{tradstove} - fuelusage_{ndICS}) * nr\_biomassfuel$$

If applicable, for scaling up in years 1-2: $Bio\ Savings = 0$

And in year 3-5 of scale-up:

$$Bio\ Savings = Partial\ implementation_{biosavings} * tree\ replacement\ cost * inflation * ndICSsub_{inc} * pctndICS$$

For full implementation:

$$Bio\ Savings = Full\ implementation_{biosavings} * tree\ replacement\ cost * inflation * ndICSsub_{inc} * pctndICS$$

Example Scenario 2

Equations for cost-benefit calculations for Transition 2: Traditional biomass stoves to LPG stoves using fuel subsidy policy intervention

POLICY INTERVENTION 2: FUEL SUBSIDY

Assuming no fuel subsidies for biomass fuels, this policy intervention does not apply to the transitions involving ICS (chimney), ICS (biomass natural draft), ICS (forced draft), ICS (charcoal). It also does not apply to biogas stoves since the fuel is generated by households or communities and generally not purchased. Stove notations differ as per transitional/clean cookstoves.

For the **fuel subsidy policy intervention**, the calculation of the costs and benefits are like policy intervention 1 (stove subsidy) except the following differences:

COSTS

1. Government subsidy costs

a. Stove subsidy cost (households)

If the relative adoption of LPG stoves with subsidy ($ICS_{lpgty_{fuelsub}}$) = relative adoption of LPG stoves without subsidy ($ICS_{lpgqty_{nofuelsub}}$), then

$$Partial\ implementation_{stove} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS\_lpgqty}{ICS_{lpglspan}}\right)$$

$$Full\ implementation_{stove} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS\_lpgqty}{ICS_{lpglspan}}\right)$$

Please note that the variables for relative adoption of LPG stoves with ($ICS_{lpgty_{fuelsub}}$) and without subsidy ($ICS_{lpgqty_{nofuelsub}}$) are in the hidden sheet 'Default Parameters' under cells I239 and I237, respectively.

If the relative adoption of LPG stoves with subsidy ≠ relative adoption of LPG stoves without subsidy (default assumption in BAR-HAP), then

$$Partial\ implementation_{stove} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS\_lpgqty}{ICS_{lpglspan}}\right) * (ICS_{lpgty_{fuelsub}}/ICS_{lpgqty_{nofuelsub}})$$

$$Full\ implementation_{stove} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS\_lpgqty}{ICS_{lpglspan}}\right) * (ICS_{lpgqty_{fuelsub}}/ICS_{lpgqty_{nofuelsub}})$$

$$Stove\ subsidy\ unit\ cost = lpgstove\_cost * lpgstove\_subsidy * (1 + stovesubleak)$$

The calculations of the stove subsidy cost over the 15-year time period is similar to those in policy intervention 1.

b. Fuel subsidy cost (households)

If the relative adoption of LPG stoves with subsidy ($ICS_{lpgty_{fuelsub}}$) = relative adoption of LPG stoves without subsidy ($ICS_{lpgqty_{nofuelsub}}$), then

$Partial\ implementation_{fuel} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc\_sfu\right) * (ICS_{lpgqty}/ICS_{lpglspan}\ )$ *(fuelcost_lpgICS-privfuelcostsub_lpgstove)*(1+fuelsubleak_)*usagerate_lpgics

$Full\ implementation_{fuel} = \left(\left(\frac{Popn}{hhsize}\right) * perc\_sfu\right) * (ICS_{lpgqty}/ICS_{lpglspan}\ )$ *(fuelcost_lpgICS-privfuelcostsub_lpgstove)*(1+fuelsubleak_)*usagerate_lpgics

If the relative adoption of LPG stoves with subsidy ≠ relative adoption of LPG stoves without subsidy, then

$Partial\ implementation_{fuel} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc\_sfu\right) * (ICS_{lpgqty}/ICS_{lpglspan}\ )$ *(fuelcost_lpgICS-privfuelcostsub_lpgstove)*(1+fuelsubleak_)*usagerate_lpgics$*$ $(ICS_{lpgqty_{fuelsub}}/ICS_{lpgqty_{nofuelsub}})$

$Full\ implementation_{fuel} = \left(\left(\frac{Popn}{hhsize}\right) * perc\_sfu\right) * (ICS_{lpgqty}/ICS_{lpglspan}\ )$ *(fuelcost_lpgICS-privfuelcostsub_lpgstove)*(1+fuelsubleak_)*usagerate_lpgics$*$ $(ICS_{lpgqty_{fuelsub}}/ICS_{lpgqty_{nofuelsub}})$

$Fuel\ subsidy\ unit\ cost = perc\_lpg$

$where\ Private\ fuel\ cost\ with\ subsidy = fuelusage_{lpgICS} * \left(cost_{lpg} - (lpgfuel_{subsidy}\ * cost_{lpg})\right)$

If applicable, for scaling up in *years 1-2:* $Fuel\ subsidy\ cost = 0$

And in year 3-5 of scale-up:

Fuel subsidy cost = (Partial implementation _fuel * inflation) * lpgfuelsub_inc * pctlpgICS + Fuel subsidy unit cost * lpgfuelsub_inc*(Popn/hhsize) * (fuelcost_lpgICS-privfuelcostsub_lpgstove))

For full implementation:

Fuel subsidy cost = (Full implementation _fuel * inflation) * lpgfuelsub_inc * pctlpgICS + Fuel subsidy unit cost * lpgfuelsub_inc*(Popn/hhsize) * (fuelcost_lpgICS-privfuelcostsub_lpgstove))

c. Program cost (households)

The partial and full implementation program costs are similar to the stove subsidy (households) cost.

The calculations of the program cost over the scale-up period is similar to those in policy intervention 1.

2. Private costs

(a) Stoves (households)

$Stove\ unit\ cost\ (private) = \left(\left(lpgstove_{cost} * \left(1 - lpgstove_{subsidy}\right)\right) - cost_{biotrad}\right)$

As we expect governments to spend initial years planning the program implementation, *if applicable, for scaling up in* *years 1-2:* $Stove\ cost\ (households) = 0$

And in year 3-5 of scale-up:

$Stove\ cost\ (households) = Partial\ implementation_{stove} * Stove\ unit\ cost\ (private) * inflation * lpgfuelsub_{inc} * pctlpgICS$

For full implementation: $Stove\ cost\ (households) = Full\ implementation_{stove} * Stove\ unit\ cost\ (private) * inflation * lpgfuelsub_{inc} * pctlpgICS$

(b) Net fuel cost (households)

If the relative adoption of LPG stoves with subsidy ($ICS_{lpgty_{fuelsub}}$) = relative adoption of LPG stoves without subsidy ($ICS_{lpgqty_{nofuelsub}}$), then

$Partial\ implementation_{fuel} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc\_sfu\right) * (ICS_{lpgqty}/ICS_{lpglspan}$) *(privfuelcostsub_lpgstove – fuelcost_tradstove)*usagerate_lpgics*

$Full\ implementation_{fuel} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu}\right) * ICS_{lpgqty}$ **(privfuelcostsub_lpgstove-fuelcost_tradstove)* usagerate_lpgics*

If the relative adoption of LPG stoves with subsidy ≠ relative adoption of LPG stoves without subsidy, then

$Partial\ implementation_{fuel} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc\_sfu\right) * (ICS_{lpgqty}/ICS_{lpglspan}$) **(privfuelcostsub_lpgstove – fuelcost_tradstove)*usagerate_lpgics* $* (ICS_{lpgqty_{fuelsub}}/ICS_{lpgqty_{nofuelsub}})$

$Full\ implementation_{fuel} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu}\right) *$ ICS_{lpgqty} **(privfuelcostsub_lpgstove–fuelcost_tradstove)* usagerate_lpgics* $* (ICS_{lpgqty_{fuelsub}}/ICS_{lpgqty_{nofuelsub}})$

$Net\ fuel\ unit\ cost = N.A.$

As we expect governments to spend initial years planning the program implementation, *if applicable, for scaling up in years 1-2*: $Net\ fuel\ cost\ (households) = 0$

And in year 3-5 of scale-up:

$Net\ fuel\ cost\ (households) = Partial\ implementation_{fuel} * inflation * lpgfuelsub_{inc} * pctlpgICS$

For full implementation: $Net\ fuel\ cost\ (households) = Full\ implementation_{fuel} * inflation * lpgfuelsub_{inc} * pctlpgICS$

(c) Maintenance cost (households)

The maintenance cost calculations are similar to those in Intervention 1, except that in this policy intervention, there will be use of $Partial\ implementation_{stove}$ and $Full\ implementation_{stove}$ calculated for this policy intervention.

(d) Learning cost (households)

If the relative adoption of LPG stoves with subsidy ($ICS_{lpgty_{fuelsub}}$) = relative adoption of LPG stoves without subsidy ($ICS_{lpgqty_{nofuelsub}}$), then

$$Partial\ implementation_{learning} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS\_lpgqty}{ICS_{lpglspan}}\right) * learning\_hours$$

$$Full\ implementation_{learning} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS\_lpgqty}{ICS_{lpglspan}}\right) * learning\_hours$$

If the relative adoption of LPG stoves with subsidy ≠ relative adoption of LPG stoves without subsidy, then

$$Partial\ implementation_{learning} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS\_lpgqty}{ICS_{lpglspan}}\right) * (ICS_{lpgty_{fuelsub}} / ICS_{lpgqty_{nofuelsub}}) * learning\_hours$$

$$Full\ implementation_{learning} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS\_lpgqty}{ICS_{lpglspan}}\right) * (ICS_{lpgqty_{fuelsub}} / ICS_{lpgqty_{nofuelsub}}) * learning\_hours$$

The learning cost calculations are similar to those in Intervention 1, except that in this policy intervention, there will be use of $Partial\ implementation_{learning}$ and $Full\ implementation_{learning}$ calculated for this policy intervention.

BENEFITS

1. Time Savings

If the relative adoption of LPG stoves with subsidy ($ICS_{lpgty_{fuelsub}}$) = relative adoption of LPG stoves without subsidy ($ICS_{lpgqty_{nofuelsub}}$), then

$$Partial\ implementation_{time\ savings} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS\_lpgqty}{ICS_{lpglspan}}\right) * usagerate\_lpgics * (timecook\_biotrad - timecook\_lpgics) * 365$$

$$Full\ implementation_{time\ savings} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * ICS_{lpgqty}\right) * usagerate\_lpgics * (timecook\_biotrad - timecook\_lpgics) * 365$$

If the relative adoption of LPG stoves with subsidy ≠ relative adoption of LPG stoves without subsidy, then

$$Partial\ implementation_{time\ savings} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{lpgqty}}{ICS_{lpglspan}}\right) * usagerate_{lpgics} * \left(timecook_{biotrad} - timecook_{lpgics}\right) * 365 * \left(ICS_{lpgty_{fuelsub}} / ICS_{lpgqty_{nofuelsub}}\right)$$

$$Full\ implementation_{time\ savings} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * ICS_{lpgqty}\right) * usagerate\_lpgics * (timecook\_biotrad - timecook\_lpgics) * 365 * (ICS_{lpgqty_{fuelsub}} / ICS_{lpgqty_{nofuelsub}})$$

The time savings calculations are similar to those in Intervention 1, except that in this policy intervention, there will be use of_$Partial\ implementation_{learning}$ and $Full\ implementation_{learning}$ calculated for this policy intervention.

2. Private Health Benefits

(b) Private Morbidity reductions of health outcome (deaths/year)

If the relative adoption of LPG stoves with subsidy ($ICS_{lpgty_{fuelsub}}$) = relative adoption of LPG stoves without subsidy ($ICS_{lpgqty_{nofuelsub}}$), then

$$Partial\ implementation\_morb_{healthoutcome\_k} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{lpgqty}}{ICS_{lpglspan}}\right) * Morb_{k\_priv}$$

$$Full\ implementation\_morb_{healthoutcome\_k} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * ICS\_lpgqty\right) * Morb_{k\_priv}$$

If the relative adoption of LPG stoves with subsidy ≠ relative adoption of LPG stoves without subsidy, then

$$Partial\ implementation\_morb_{healthoutcome\_k} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{lpgqty}}{ICS_{lpglspan}}\right) * Morb_{k\_priv} * (ICS_{bioqty_{fuelsub}} / ICS_{bioqty_{nofuelsub}})$$

$$Full\ implementation\_morb_{healthoutcome\_k} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * ICS\_lpgqty\right) * Morb_{k\_priv} * (ICS_{bioqty_{fuelsub}} / ICS_{bioqty_{nofuelsub}})$$

(c) Private Mortality reductions of health outcome (deaths/year)

If the relative adoption of LPG stoves with subsidy ($ICS_{lpgty_{fuelsub}}$) = relative adoption of LPG stoves without subsidy ($ICS_{lpgqty_{nofuelsub}}$), then

$$Partial\ implementation\_mort_{healthoutcome\_k} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{lpgqty}}{ICS_{lpglspan}}\right) * Mort_{k\_priv}$$

$$Full\ implementation\_mort_{healthoutcome\_k} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * ICS\_lpgqty\right) * Mort_{k\_priv}$$

If the relative adoption of LPG stoves with subsidy ≠ relative adoption of LPG stoves without subsidy, then

$$Partial\ implementation\_mort_{healthoutcome\_k} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{lpgqty}}{ICS_{lpglspan}}\right) * Mort_{k\_priv} * (ICS_{bioqty_{fuelsub}} / ICS_{bioqty_{nofuelsub}})$$

$$Full\ implementation\_mort_{healthoutcome\_k} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * ICS\_lpgqty\right) * Mort_{k\_priv} * (ICS_{bioqty_{fuelsub}} / ICS_{bioqty_{nofuelsub}})$$

The health reductions calculations over the 15-year time period are similar to those in Policy Intervention 1. except that in this policy intervention, there will be use of $Partial\ implementation_{morb\_healthoucome}$, $Partial\ implementation_{mort\_healthoucome}$, $Full\ implementation_{morb\_healthoucome}$ and $Full\ implementation_{mort\_healthoucome}$, calculated for this policy intervention.

3. (a) and (b) The calculations for **social morbidity and mortality reductions of health outcomes** are the same as those for private health reductions, except for the multiplication of the health spillovers.

Here again, the health reductions calculations over the 15-year time period are similar to those in Policy Intervention 1.

4. Climate Benefits

(a) Carbon savings (basic)

If the relative adoption of LPG stoves with subsidy ($ICS_{lpgty_{fuelsub}}$) = relative adoption of LPG stoves without subsidy ($ICS_{lpgqty_{nofuelsub}}$), then

$$Partial\ implementation\_carbonsav\_basic = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{lpgqty}}{ICS_{lpglspan}}\right) * usagerate_{lpgICS} * (fuelusage_{tradstove} * GWC_{tradbasic} * energyconv_{wood} * fueleff_{tradstove} - fuelusage_{lpgICS} * (GWC_{lpgstove\_basic} * energyconv_{lpg} * fueleff_{lpgICS}))/1000000$$

$$Full\ implementation\_carbonsav\_basic = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{lpgqty}}{ICS_{lpglspan}}\right) * usagerate_{lpgICS} * (fuelusage_{tradstove} * GWC_{tradbasic} * energyconv_{wood} * fueleff_{tradstove} - fuelusage_{lpgICS} * (GWC_{lpgstove\_basic} * energyconv_{lpg} * fueleff_{lpgICS}))/1000000$$

If the relative adoption of LPG stoves with subsidy ≠ relative adoption of LPG stoves without subsidy, then

$$Partial\ implementation\_carbonsav\_basic = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * ICS\_lpgqty\right) * (ICS_{lpgqty_{fuelsub}} / ICS_{lpgqty_{nofuelsub}}) * usagerate_{lpgICS} * (fuelusage_{tradstove} * GWC_{tradbasic} * energyconv_{wood} * fueleff_{tradstove} - fuelusage_{lpgICS} * (GWC_{lpgstove\_basic} * energyconv_{wood} * fueleff_{lpgICS}))/1000000$$

$$Full\ implementation\_carbonsav\_basic = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * ICS\_lpgqty\right) * (ICS_{lpgqty_{fuelsub}}/ICS_{lpgqty_{nofuelsub}}) * usagerate_{lpgICS} * (fuelusage_{tradstove} * GWC_{tradbasic} * energyconv_{wood} * fueleff_{tradstove}) - fuelusage_{lpgICS} * (GWC_{lpgstove\_basic} * energyconv_{wood} * fueleff_{lpgICS}))/1000000$$

(b) Carbon savings (full)

If the relative adoption of LPG stoves with subsidy ($ICS_{lpgty_{fuelsub}}$) = relative adoption of LPG stoves without subsidy ($ICS_{lpgqty_{nofuelsub}}$), then

$$Partial\ implementation\_carbonsav\_full = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{lpgqty}}{ICS_{lpglspan}}\right) * usagerate_{lpgICS} * (fuelusage_{tradstove} * GWC_{tradfull} * energyconv_{wood} * fueleff_{tradstove}) - fuelusage_{lpgICS} * (GWC_{lpgstove\_full} * energyconv_{lpg} * fueleff_{lpgICS}))/1000000$$

$$Full\ implementation\_carbonsav\_full = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{lpgqty}}{ICS_{lpglspan}}\right) * usagerate_{lpgICS} * (fuelusage_{tradstove} * GWC_{tradfull} * energyconv_{wood} * fueleff_{tradstove}) - fuelusage_{lpgICS} * (GWC_{lpgstove\_full} * energyconv_{lpg} * fueleff_{lpgICS}))/1000000$$

If the relative adoption of LPG stoves with subsidy ≠ relative adoption of LPG stoves without subsidy, then

$$Partial\ implementation\_carbonsav\_full = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * ICS\_lpgqty\right) * (ICS_{lpgqty_{fuelsub}}/ICS_{lpgqty_{nofuelsub}}) * usagerate_{lpgICS} * (fuelusage_{tradstove} * GWC_{tradfull} * energyconv_{wood} * fueleff_{tradstove}) - fuelusage_{lpgICS} * (GWC_{lpgstove\_full} * energyconv_{wood} * fueleff_{lpgICS}))/1000000$$

$$Full\ implementation\_carbonsav\_full = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * ICS\_lpgqty\right) * (ICS_{lpgqty_{fuelsub}}/ICS_{lpgqty_{nofuelsub}}) * usagerate_{lpgICS} * (fuelusage_{tradstove} * GWC_{tradfull} * energyconv_{wood} * fueleff_{tradstove}) - fuelusage_{lpgICS} * (GWC_{lpgstove\_full} * energyconv_{wood} * fueleff_{lpgICS}))/1000000$$

The climate benefits calculations over the 15-year time period are similar to those in Policy Intervention 1, except that in this policy intervention, the partial and full implementation variables included should be those calculated above (for carbon savings-basic and carbon savings-full, respectively).

5. Environmental Benefits

If the relative adoption of LPG stoves with subsidy ($ICS_{lpgty_{fuelsub}}$) = relative adoption of LPG stoves without subsidy ($ICS_{lpgqty_{nofuelsub}}$), then

$$Partial\ implementation_{biosavings} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{lpgqty}}{ICS_{lpglspan}}\right) * usagerate_{lpgICS} * (fuelusage_{tradstove} - fuelusage_{lpgICS}) * nr\_biomassfuel$$

$$Full\ implementation_{biosavings} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * ICS\_lpgqty\right) * usagerate_{lpgICS} * (fuelusage_{tradstove} - fuelusage_{lpgICS}) * nr\_biomassfuel$$

If the relative adoption of LPG stoves with subsidy ≠ relative adoption of LPG stoves without subsidy, then

$$Partial\ implementation_{biosavings} = \left(\frac{1}{scaleup}\right) * \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * \frac{ICS_{lpgqty}}{ICS_{lpglspan}}\right) * (ICS_{lpgqty_{fuelsub}}/ICS_{lpgqty_{nofuelsub}}) * usagerate_{lpgICS} * (fuelusage_{tradstove} - fuelusage_{lpgICS}) * nr\_biomassfuel$$

$$Full\ implementation_{biosavings} = \left(\left(\frac{Popn}{hhsize}\right) * perc_{sfu} * ICS\_lpgqty\right) * (ICS_{lpgqty_{fuelsub}}/ICS_{lpgqty_{nofuelsub}}) * usagerate_{lpgICS} * (fuelusage_{tradstove} - fuelusage_{lpgICS}) * nr\_biomassfuel$$

The environmental benefits calculations over the 15-year time period are similar to those in Policy Intervention 1, except that in this policy intervention, the partial and full implementation variables included should be those calculated above.

POLICY INTERVENTION 3: STOVE FINANCING

In this intervention, the calculation of the costs and benefits are like Policy Intervention 2 except that the adoption of stoves changes. In equation terms, the variable '*ICS_lpgqty*' will be replaced with '*ICS_lpgqty_fin*' for all equations.

POLICY INTERVENTION 4: TECHNOLOGY BAN

In this intervention, the calculation of the costs and benefits are like Policy Intervention 2 except that the adoption of stoves changes. In equation terms, the variable '*ICS_lpgqty*' will be replaced with '*ICS_lpgqty_ban*' for all equations.

POLICY INTERVENTION 5: INTENSIVE BEHAVIOR CHANGE CAMPAIGN

In this intervention, the calculation of the costs and benefits are similar to Policy Intervention 2 except that the adoption of stoves changes. In equation terms, the variable '*ICS_lpgqty*' will be replaced with '*ICS_lpgqty_bcc*' for all equations.

Appendix: Default parameter values

Summary of data inputs specific to the clean cooking tool – default parameterization

(Note: Default parameters that were included in the WHO's NCD costing tool[23] are not included below)

Table A1. Economic/demographic parameters

Parameter	Description	Default Value/Specific worksheet in the BAR-HAP Tool	Source
δ_s	Discount rate (social)	Default Parameters	Jeuland et al. (2018)
δ_p	Discount rate (private)	Default Parameters	Jeuland et al. (2018)
Hhsize	Number of persons per household	Population	UN DESA (2021), Global Data Lab (2021)
Hhunder5	Number of young children (<5 yrs) per household	Population	Calculated from UN DESA (2021) and Global Data Lab (2021)
svaluetime_cooking	Shadow value of time spent cooking (fraction of market wage)	Default Parameters	Jeuland et al. (2018)
wagerate	Unskilled market wage	Default Parameters	Jeuland et al. (2018)
stovesubleak	Subsidy leakage – stove subsidies	25%	By Assumption
fuelsubleak	Subsidy leakage – fuel subsidies	50%	By Assumption
prog	Stove promotion program cost ($/hh covered)	$17	Pattanayak et al. (2019)
bcccost	Intensive behavior change campaign program cost ($/hh covered)	$10	None
fincost	Stove financing program cost (% of private stove cost)	10%	None
vsl	Value of statistical life	VSL and Income	Robinson et al. (2019), World Bank (2021)
π	Health spillover parameter (Fraction of ambient air pollution due to HAP)	13%	WHO estimate

[23] WHO Non-Communicable Diseases (NCDs) Costing Tool is available here: https://www.who.int/ncds/management/c_NCDs_costing_estimation_tool_user_manual.pdf?ua=1

Table A2. General cooking parameters

Parameter	Description	Default value	Source
timecook_biotrad	Time spent cooking on traditional stove (hr/day)	2.6	Jeuland et al. (2018)
fuelusage_tradstove	Fuel usage in traditional biomass stove (kg/hr)	2.6	Jeuland et al. (2018)
firewoodcolltime	Firewood collection time (hr/day)	1.0	Nepal et al. (2011)
χ_i	Percent use of baseline stove	48%	Jeuland et al. (2018)
Maintenencecost_ICS	Cost of ICS maintenance	$3.7/yr	Jeuland et al. (2018)
learning_hours	Hours spent learning use of ICS	27.5	Jeuland et al. (2018)
ε_{trad}	Exposure adjustment parameter for traditional stove	0.51	Pope et al. (*preliminary*)
ε_{ICS}	Exposure adjustment parameter for improved/clean stove	0.71	Pope et al. (*preliminary*)

Table A3. Baseline stove/fuel characteristics

Description	Biomass (Default Value/Specific worksheet in the BAR-HAP Tool)	Charcoal (Default Value/Specific worksheet in the BAR-HAP Tool)	Kerosene wick (Default Value/Specific worksheet in the BAR-HAP Tool)	Source
Pre-intervention users (% of population)	Wood, Crop waste, Dung	Charcoal	Kerosene	Stoner et al. (2021), WHO (2021)
Traditional/transitional stove cost	Stove	Stove	Stove	Clean Cooking Alliance (2021)
Lifespan of technology	Stove	Stove	Stove	Clean Cooking Alliance (2021)
Fuel efficiency (MJ useful energy/MJ heat)	Stove	Stove	Stove	Clean Cooking Alliance (2021)
Energy conversion of fuel	16	30	35	Jeuland et al. (2018)
Maintenance cost ($/yr)	$0	$3.7	$3.7	Jeuland et al. (2018)
Percent buying fuel	23%	100%	100%	Jeuland et al. (2018)
Fuel cost	$0.05/kg	$0.25/kg	$0.89/kg	Jeuland et al. (2018)
PM 2.5 emissions (µg/24 hours)	834	256	55.2	Jeuland et al. (2018); Pope et al. (*preliminary*)
CO2 emissions (g/MJ fuel)	515.64	488.19	151.40	Jeuland et al. (2018)
CH4 emissions (g/MJ fuel)	1.71	2.63	0.02	Jeuland et al. (2018)
N2O emissions (g/MJ fuel)	0.20	0.00	0.06	Jeuland et al. (2018)

CO emissions (g/MJ fuel)	24.25	41.98	1.18	Jeuland et al. (2018)
BC emissions (g/MJ fuel)	0.29	0.16	0.01	Jeuland et al. (2018)
OC emissions (g/MJ fuel)	0.80	0.45	0.01	Jeuland et al. (2018)

Table A4. Transitional/clean stove characteristics (if not above; Default value/ Specific worksheet in the BAR-HAP Tool)

Description	**Natural draft chimney**	**Natural draft biomass**	**Forced draft biomass**	**Pellet**	**Charcoal ICS**	**LPG**	**Ethanol**	**Electric**	**Source**
Traditional/transitional stove cost ($)	Stove	Stove	Stove	Stove	Stove	Stove	Stove	Stove	Clean Cooking Alliance (2021)
Lifespan of stove (yr)	Stove	Stove	Stove	Stove	Stove	Stove	Stove	Stove	Clean Cooking Alliance (2021)
Fuel efficiency (MJ useful energy/MJ heat)	Stove	Stove	Stove	Stove	Stove	Stove	Stove	Stove	Clean Cooking Alliance (2021)
Energy conversion of fuel	16	16	16	16	30	45	45	3.6 MJ/kW-hr	Jeuland et al. (2018)
Time efficiency (relative to trad biomass)	1.00	0.86	0.86	0.86	0.81	0.8	0.8	0.825	Jeuland et al. (2018)
Fuel cost	$0.05/kg	$0.05/kg	$0.05/kg	$0.25/kg	$0.25/kg	$0.73/kg	$0.80/kg	$0.07/kW-hr	Jeuland et al. (2018)
PM 2.5 emissions (μg/24 hours)	390	450	325	207	185	43	125	41	Jeuland et al. (2018) Pope et al. (*preliminary*)
CO2 emissions (g/MJ fuel)	515.64	351.28	180.96	180.96	562.67	140.15	140.15	483.62	Jeuland et al. (2018)
CH4 emissions (g/MJ fuel)	1.71	1.43	1.00	1.00	1.24	0.03	0.03	15.09	Jeuland et al. (2018)
N2O emissions (g/MJ fuel)	0.20	0.08	0.04	0.04	0.07	0.21	0.21	5.97	Jeuland et al. (2018)
CO emissions (g/MJ fuel)	24.25	21.78	10.60	10.60	16.74	0.48	0.48	0.08	Jeuland et al. (2018)
BC emissions (g/MJ fuel)	0.29	0.14	0.14	0.14	0.01	0.00	0.00	0.02	Jeuland et al. (2018)
OC emissions (g/MJ fuel)	0.80	0.46	0.46	0.46	0.40	0.00	0.00	0.04	Jeuland et al. (2018)

Table A5. Health parameters (Default value/ Specific worksheet in the BAR-HAP Tool)

Description	COPD	ALRI	IHD	Lung cancer	Stroke	Source
Incidence/prevalence of disease *k (cases/100)*	Prevalence & Incidence_GBD Data	Prevalence & Incidence_GBD Data	Prevalence & Incidence_GBD Data	Prevalence & Incidence_GBD Data	Prevalence & Incidence_GBD Data	GBD (2021)
Mortality rate due to disease *d (deaths/10000)*	Mortality Rate_GBD Data, WHO Mortality Rate	Mortality Rate_GBD Data, WHO Mortality Rate	Mortality Rate_GBD Data, WHO Mortality Rate	Mortality Rate_GBD Data, WHO Mortality Rate	Mortality Rate_GBD Data, WHO Mortality Rate	GBD (2021), WHO (2021)
Cost of illness ($/case)	103.1	38.5	45.0	2431	3970	Ding et al. (2016)
Disability weight	.225	.133	.041	.049	.316	Jeuland et al. (2018)
Duration of case (days)	365	78	365	365	365	Jeuland et al. (2018)
Lag impacts – year 1	0.3	0.7	0.2	0.2	0.2	Jeuland et al. (2018)
Lag impacts – year 2	0.2	0.1	0.1	0.1	0.1	Jeuland et al. (2018)
Lag impacts – years 3-5	0.167	0.067	0.233	0.233	0.233	Jeuland et al. (2018)
Cost of illness that is public (%)	80	40	65	95	95	Expert judgment (Jeuland)

Table A6. Environmental parameters

Parameter	Description	Default value	Source
$socialcost\_carbon\_$	Cost of carbon emissions (per ton)	$18.69	Jeuland et al. (2018)
nr_biomassfuel	% of biomass harvesting that is non-renewable	52.8%	Bailis et al. (2015)

References

Bailis, R., Drigo, R., Ghilardi, A., & Masera, O. (2015). The carbon footprint of traditional woodfuels. Nature Climate Change, 5(3), 266-272.

Clean Cooking Alliance. (2021). The Clean Cooking Catalog. Product and Performance Data for the Clean Cooking Sector. Available from http://catalog.cleancookstoves.org/

Das, I., Lewis, J. J., Ludolph, R., Bertram, M., Adair-Rohani, H., & Jeuland, M. (2021). The benefits of action to reduce household air pollution (BAR-HAP) model: A new decision support tool. *Plos one*, *16*(1), e0245729.

Ding, D., Lawson, K. D., Kolbe-Alexander, T. L., Finkelstein, E. A., Katzmarzyk, P. T., Van Mechelen, W., ... & Lancet Physical Activity Series 2 Executive Committee. (2016). The economic burden of physical inactivity: a global analysis of major non-communicable diseases. The Lancet, 388(10051), 1311-1324.

Global Burden of Disease Study Results. (2021). Global Burden of Disease Collaborative Network, Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2021. Available from http://ghdx.healthdata.org/gbd-results-tool.

Global Data Lab (2021). GDL Area Database (4.0). Free Sub-National Development Indicators. Available from https://globaldatalab.org/areadata/hhsize/

Jeuland, M., Soo, J. S. T., & Shindell, D. (2018). The need for policies to reduce the costs of cleaner cooking in low income settings: Implications from systematic analysis of costs and benefits. *Energy Policy*, *121*, 275-285.

Kaur, P., Kwatra, G., Kaur, R., & Pandian, J. D. (2014). Cost of stroke in low and middle income countries: a systematic review. *International Journal of Stroke*, *9*(6), 678-682.

Nepal, M., Nepal, A., & Grimsrud, K. (2011). Unbelievable but improved cookstoves are not helpful in reducing firewood demand in Nepal. *Environment and Development Economics*, *16*(1), 1-23.

Pattanayak, S. K., Jeuland, M., Lewis, J. J., Usmani, F., Brooks, N., Bhojvaid, V., ... & Ramanathan, N. (2019). Experimental evidence on promotion of electric and improved biomass cookstoves. *Proceedings of the National Academy of Sciences*, 201808827.

Pope D, Johnson M, Fleeman N, Jagoe K, Ludolph R, Lewis J, Adair-Rohani A. (2020). Impact of household stove and fuel technologies on particulate and carbon monoxide concentration and exposures, a systematic review and analysis. In preparation.

Robinson, L. A., Hammitt, J. K., Cecchini, M., Chalkidou, K., Claxton, K., Cropper, M., ... & Wong, B. (2019). Reference case guidelines for benefit-cost analysis in global health and development. Boston, MA: Center for Health Decision Science, Harvard TH Chan School of Public Health.

Shindell, D. T. (2015). The social cost of atmospheric release. *Climatic Change*, *130*(2), 313-326.

Stoner, O., Lewis, J., Lucio Martínez, L., Gumy, S., Economou, T., Adair-Rohani, H. (2021). What fuels the fire? Cooking fuel estimates at global, regional and country level for 1990-2030. *Nature Communications* (accepted)

United Nations. (2021). Department of Economic and Social Affairs. Population Dynamics. World Population Prospects 2019. Available from https://population.un.org/wpp/

United Nations. (2021). Department of Economic and Social Affairs. Population. Household Size & Composition, 2019. Available from https://population.un.org/Household/index.html#/countries/840

World Bank. (2021). World Bank Open Data. Available from https://data.worldbank.org/

World Health Organization. (2021). WHO household energy database. Available from https://www.who.int/data/gho/data/themes/air-pollution/who-household-energy-db

World Health Organization. (2021). The Global Heath Observatory. Cause-specific mortality 2000-2019. Available from https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates/ghe-leading-causes-of-death

World Health Organization. (2021). Global Heath Observatory data repository. Life tables by country. Available from https://apps.who.int/gho/data/node.main.LIFECOUNTRY?lang=en