Technical note on assessing black carbon reductions using the Long-range Energy Alternatives Planning (LEAP) system with an Integrated Benefits Calculator (LEAP-IBC)

Oil and Gas Initiative of the Climate and Clean Air Coalition (CCAC)

Prepared for the CCAC Oil and Gas Initiative
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1. Introduction

This report outlines the data needs, modelling and scenario development undertaken using the Long range Energy Alternatives Planning (LEAP) system with Integrated Benefits Calculator (LEAP-IBC) in order to carry out an assessment of the potential reductions in methane and black carbon (BC) emissions from the cessation of flaring and venting of gas in Mexico and Colombia.

Short-lived climate pollutants (SLCPs) are harmful air pollutants that also contribute significantly to climate change. The main SLCPs are black carbon (or soot), methane (CH_4), tropospheric ozone (O_3) and some hydrofluorocarbons (HFCs). They obtain their name by virtue of the fact that they remain in the atmosphere for only a relatively short time and controlling them can give climate benefits in the shorter-term (tens of years as opposed to hundreds for CO_2). SLCPs can also be quickly controlled and reduced with existing technology.

The oil and gas (OAG) sector accounts for more than 20% of all anthropogenic emissions of CH_4 globally and is also a source of BC. The two main processes that contribute to this are flaring and venting of gas. Flaring takes place where excess gas is combusted without utilisation of the energy that is released. Other pollutants are emitted during flaring in addition to methane and black carbon. These include: nitrogen oxides (NO_x) and non-methane volatile organic compounds (NMVOC), as well a sulphur dioxides (SOx), carbon monoxide (CO), heavy metals (HM) and particulate matter (PM).

Gas flaring is carried out on both on-shore and off-shore oil and gas (OAG) platforms usually as a safety measure to release any dangerous build-up of gas. Some flaring is also done at the start of oil well operations and during their maintenance. This gas is also referred to as ‘associated gas’. These flaring activities can be considered non-routine as they can happen intermittently. Routine flaring usually takes place where the oil field operation has insufficient capacity to process the gas in situ or lack of transport to move it to a processing facility. This is typically the case for off-shore platforms and for smaller OAG installations that would require large capital investments for which there would only be limited economic benefit.

Whilst flaring actually fell globally by about 18 percent between 2005 and 2011, approximately 300 million tons of carbon dioxide as well as other GHGs such as methane are still produced every year (World Bank, 2015). The scale of impact has an effect elsewhere on the environment and in particular the Arctic where BC strongly influences radiative forcing due to changes in the albedo of snow and ice where it is deposited darkening the surface. Whilst globally, flaring contributes about 3 percent of black carbon emissions, in the Arctic it can contribute as much as much as 52 per cent according to study by Klimont (2015). There is the potential for gas flaring to increase in the future due to expansion of oil production in countries such as Iraq and other countries where new locations are opened up for oil and gas shale production. This includes increasing exploitation of reserves in the Arctic.

Flaring has an impact at different scales. Firstly, local populations can be exposed directly to air pollutants from the flare in the form of non-combusted material (primarily soot and particulate matter). These particles can cause respiratory problems and other associated diseases including cardiovascular disease. The number of people exposed to emissions is dependent on the type of flaring activity, the meteorological conditions and the location of the population i.e. whether they are downwind from the flare site. The relative risk to individuals of these emissions will also be dependent on socio-economic factors, including their age and poverty level especially in urban areas, and on whether there are other emission sources co-located such as industry, brick kilns, heavy traffic and waste burning. Epidemiological studies looking specifically at the health risks from BC emissions from flaring in the OAG industry are lacking.

When gas is flared at an installation it is moved a distance away from the platform through a series of pipes connected to a flare tip which is usually located in a chimney stack. Under ideal conditions, flaring converts all the methane into carbon dioxide and water vapour. The efficiency of the combustion process can be in the region of 98 per cent for a well-designed and operated flare. However, these conditions seldom exist depending on factors such as the gas velocity (efficiency of the flare), local meteorology and type of flare burner. Whilst these factors can be measured at the site they rarely are.

Not only does flaring contribute to climate change impacts, it actually represents a huge economic loss in terms of the potential revenue that could be achieved through the sale of by-products that could have been made from the gas. For example, the gas can be converted into liquefied gas and used as an energy source or to power vehicles or it can be converted into products such as animal feedstocks and fertilisers. Thirdly, it can be socio-economically beneficial to local communities if for example, the gas is used for electricity generation to power homes, schools, health centres. An example where there has been success is in the Republic of Congo where an Italian energy company Eni, invested in the production of electricity through the utilization of associated gas which was previously flared. This provided electricity for the community including providing street lighting (Eni, 2015).

Therefore, it is clear that reducing flaring can offer multiple co-benefits but this requires multinational oil and gas companies and national governments to pave the way by increasing awareness and understanding, improving monitoring and assessment, and developing and enforcing regulations. A new initiative to end routine flaring by 2030 was put forward by the World Bank in May 2015 (World Bank, 2015) to address mounting international concern. Forty countries, companies and organisations signed up to the initiative at its launch (See Appendix 1). This now stands at 45 in 2016 with the U.S. and Canada also agreeing to cease flaring. The Climate and Clean Air Coalition (CCAC) is supporting the efforts of major oil companies and governments to reduce wasteful flaring by seeking alternative uses for the gas and identifying ways to overcome the barriers that inhibit more flare gas utilization.

1.1 Overview of LEAP-IBC

The Long-range Energy Alternatives Planning (LEAP) system[1] is a widely-used software tool for energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute. LEAP is an integrated scenario-based modeling tool that can be used to track energy consumption, production and resource extraction in all sectors of an economy. In addition, it can account for both energy and non-energy sector greenhouse gas (GHG) emission sources and sinks. LEAP can also analyze emissions patterns of local and regional air pollutants, including short-lived climate pollutants (SLCPs), making it well-suited to studies of the climate co-benefits of air pollution emissions reductions, and vice versa.

LEAP-IBC is a new application that combines the LEAP platform with an ‘integrated benefits calculator’ (IBC) that allows the emissions to be converted into concentrations of fine particulate matter ($PM_{2.5}$) and ozone (O_3), which can then be used to calculate the

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[1] www.energycommunity.org/default.asp?action=introduction

climate impacts (changes in radiative forcing and temperature), the human health impacts (premature mortality) and the crop impacts (yield losses of four staple crops: wheat, rice, maize and soy) resulting from these air pollutants. With the LEAP-IBC tool, emissions can be calculated for a base year and then scenarios generated to assess the potential of different policies or mitigation strategies to reduce emissions and impacts of air pollutants, for instance, the impact of the initiative to reduce routine flaring from the OAG industry by 2030.

The LEAP-IBC tool was developed through collaboration between SEI and US EPA, and highlights the potential for visualising the benefits of national mitigation planning. It was developed for the Supporting National Action and Planning (SNAP) on Short-Lived Climate Pollutants (SLCPs) initiative of the CCAC. It has been used to help with the development of National Action Plans in countries and for assessing the benefits of mitigation measures in regional assessments e.g. Latin America (LAC) Assessment. The long-term goals of this initiative are to: support integration of SLCPs into existing national planning; to identify and prioritize strategies that countries can undertake and can be implemented through existing air quality, climate change and development policy and regulatory frameworks; and identify ways to overcome barriers and to build capacity in countries for their strategic planning.

The use of the LEAP-IBC tool in the context of the Oil and Gas Initiative activity is to identify the air quality and climate benefits of reducing flaring and venting and to help countries identify pathways leading to reduced emissions and impacts. The tool allows the user to estimate current levels of emissions at existing flaring sites in the country, to create a ‘business-as-usual’ scenario and then compare this with mitigation scenarios in which flaring has been reduced either through control measures such as using regulation that introduces the implementation of technology to capture gas. Thus, the output from the tool provides a means of assessing different mitigation alternatives in terms of their relative efficacy in reducing adverse impacts compared with the business-as-usual scenario.

1.2 Main features of the LEAP Integrated Benefits Calculator (LEAP-IBC)

The LEAP-IBC tool has two extra features in addition to the base LEAP software[2]. These features i) allow for the calculation of an SLCP-focussed emission inventory (LEAP-IBC default SLCP template), and ii) use this inventory to estimate impacts on human health, crop yield and climate.

LEAP-IBC default SLCP template

Based on the Global Atmospheric Pollution Forum (GAP Forum) emission inventory guidebook (https://www.sei-international.org/gap-the-global-air-pollution-forum-emission-manual), a default tree structure has been constructed in LEAP-IBC which represents all major source sectors of SLCP-relevant emissions. These source sectors include the major energy-consuming emission sources, energy production source sectors (e.g. electricity generation), but also non-energy emission sources, such as agricultural emissions, waste emissions etc.

To calculate emissions from a particular source sector, the user is required to input a value for activity rate and an emission factor. However, the default SLCP template has been pre-loaded with emission factors for 10 pollutants. These default emission factors are fully referenced, and generally derive from sources such as the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories[3], or the EMEP/EEA Air Pollutant Emission Inventory Guidebook[4]. They can easily be replaced by the user with more appropriate emission factors if these exist for the target country.

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[2] LEAP is the Long range Energy Alternatives Planning System, and is a widely-used software tool for energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute. LEAP has been adopted by thousands of organizations in more than 190 countries worldwide. Users of the tool include government agencies, academics, non-governmental organizations, consulting companies, and energy utilities. It has been used at many different scales ranging from cities and states to national, regional and global applications. LEAP is increasingly being used by countries undertaking integrated resource planning, greenhouse gas (GHG) mitigation assessments, and Low Emission Development Strategies (LEDS) especially in the developing world. Many of these countries have also chosen to use LEAP as part of their commitment to report to the U.N. Framework Convention on Climate Change (UNFCCC).

[3] http://www.ipcc-nggip.iges.or.jp/public/2006gl/

[4] http://www.eea.europa.eu/publications/emep-eea-guidebook-2016

The Integrated Benefits Calculator (IBC)

Using the default template, LEAP calculates emission inventories for current and future years for all relevant pollutants. These emissions are then used to estimate atmospheric concentrations of fine particulate matter ($PM_{2.5}$) relevant for human health, and surface ozone (O_3), relevant for human health and vegetation. The concentrations are calculated using output (called coefficients) from the GEOS-Chem Adjoint model (undertaken by Daven Henze at the University of Colorado through a collaboration with the US EPA). GEOS-Chem is a global 3-D model of atmospheric composition driven by assimilated meteorological observations from the Goddard Earth Observing System (GEOS) of the NASA Global Modeling Assimilation Office (GMAO). This atmospheric chemistry transport model calculates the sensitivity of $PM_{2.5}$ and O_3 concentrations in the target country to emissions of each $PM_{2.5}$ and O_3 precursor in each grid-square in the world. For example, the sensitivity of population-weighted $PM_{2.5}$ in the target country to changes in NOx, SO_2, NH_3, BC, OC, and other PM emissions in each grid square is calculated, and the sensitivity to NOx, VOC, CH_4 and CO emissions for the health, and vegetation O_3 metrics (population-weighted maximum 3-month daily 1h average concentration for health, and average daily 12h concentration over 3-month growing season for crops). These coefficients from GEOS-Chem Adjoint are used in combination with the LEAP-derived emissions for the target country, and default emissions for the rest of the world (IIASA ECLIPSE emission inventory) to derive pollutant concentrations for the base year (2010), baseline scenario (2010-2050), and any policy scenarios.

The benefits calculated relate to human health (from exposure to $PM_{2.5}$ and ground-level ozone), crop yield from ground-level ozone, and changes to radiative forcing and temperature, both globally and for four latitudinal bands. Premature mortality is currently the only health impact incorporated, but other health outcomes will be included in the near future e.g. Years of life lost (YLLs) etc. The calculator currently uses a log-linear relationship between concentration and mortality. The crop yield loss from exposure to ozone is calculated from relationships for yield loss related to the 7 or 12 hour means of daylight ozone concentrations during the growing season for the appropriate crop. At the moment it only includes the response of four staple crops – wheat, rice, soybean and maize. To estimate climate impacts, the tool currently calculates the radiative forcing (RF) related to changes in emissions and, from this RF, resulting equilibrium temperatures can be estimated.

1.3 Default LEAP-IBC Global Emission data

Inputs to the Integrated Benefits Calculator include gridded (2° x 2.5°) global default emissions data for the base year 2010 and estimates for 2030 and 2050 for a Reference Scenario (i.e. 'business as usual' with no further mitigation measures beyond those already planned and assuming energy and fuel demand as projected by the International Energy Agency (IEA)). This default emissions data set was re-gridded to 2° x 2.5° from the original emission data set (0.5° x 0.5°) of the ECLIPSE[5] (Evaluating the Climate and Air Quality Impacts of Short-Lived Pollutants) project which was created with the GAINS (Greenhouse gas – Air pollution Interactions and Synergies; http://gains.iiasa.ac.at) model (Amann et al., 2011). When configuring the tool for a particular target country, population-weighted country masks are then used to identify those 2° x 2.5° grid-cells that overlay that country together with the proportion of each grid-cell's total population belonging to that country. This then enables the default ECLIPSE emissions data for the target country to be replaced by LEAP emissions data using population as an allocation proxy.

1.4. Data requirements and modelling

The LEAP-IBC software interface consists of a collection of folders arranged in a tree structure within which the user can enter information about the country, and about the different activities within the country which result in emissions of air pollutants (Figure 1.1). The first part of the tree contains the key drivers of growth in emissions such as GDP and Population for the base year, 2010. Also included here are the (pre-loaded) Benefit Calculator Inputs which show all the parameters required to calculate human health and crop impacts for the country. For health impacts, these include the proportion of the total population aged over 30 years, the baseline mortality rates for cardiopulmonary disease, lung cancer and respiratory disease (the health effects included in LEAP-IBC as being affected by exposure to air pollution); the relative risks (RR) for these diseases (representing the increased risk of mortality due to these causes due to increases in $PM_{2.5}$ and ozone exposure). For crop losses, these are the annual crop yields for the four staple crops: Rice, Wheat, Maize and Soy. These parameters can be substituted with nationally relevant values.

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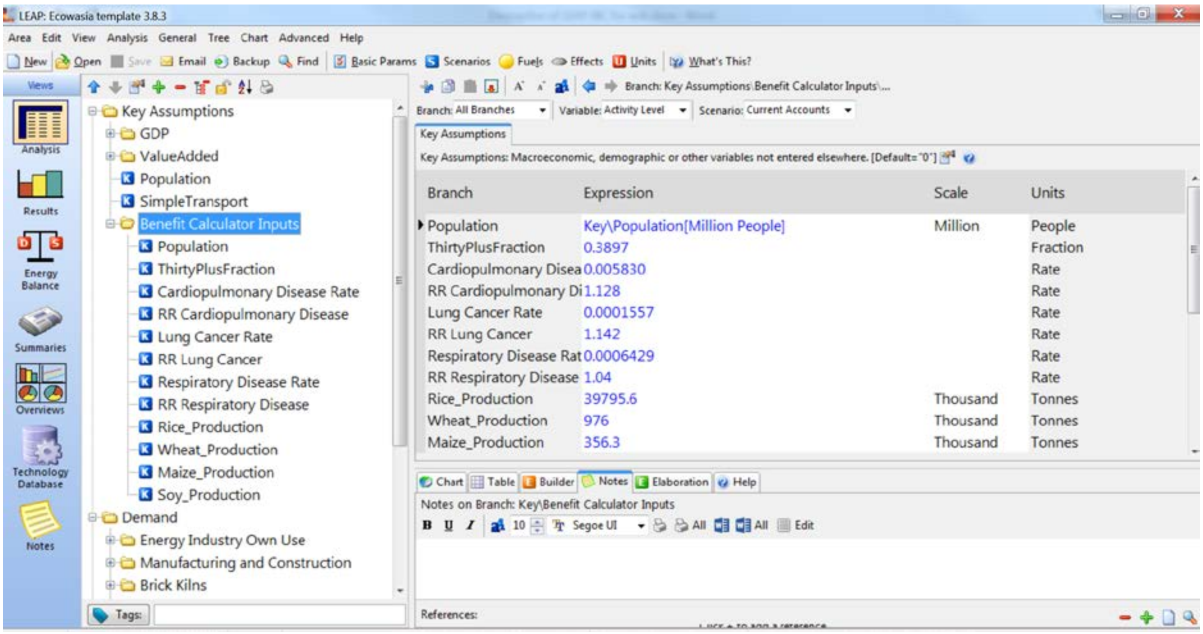
[5] http://www.iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv5a.html



Branch: Key Assumptions\Benefit Calculator Inputs\...

Branch: All Branches Variable: Activity Level Scenario: Current Accounts

Key Assumptions: Macroeconomic, demographic or other variables not entered elsewhere. [Default="0"]

Branch	Expression	Scale	Units
Population	Key\Population[Million People]	Million	People
ThirtyPlusFraction	0.3897		Fraction
Cardiopulmonary Disea	0.005830		Rate
RR Cardiopulmonary Di	1.128		Rate
Lung Cancer Rate	0.0001557		Rate
RR Lung Cancer	1.142		Rate
Respiratory Disease Rat	0.0006429		Rate
RR Respiratory Disease	1.04		Rate
Rice_Production	39795.6	Thousand	Tonnes
Wheat_Production	976	Thousand	Tonnes
Maize_Production	356.3	Thousand	Tonnes

Notes on Branch: Key\Benefit Calculator Inputs

Figure 1.1 LEAP-IBC tree structure showing Key Assumptions and Benefit Calculator Inputs

The first stage of any modelling work involves compiling data (e.g. fuel consumption, fertilizer use, brick production, numbers of livestock) for each sector modelled by LEAP in that country for a base year which for this project is 2010. This is called the 'Current Accounts'. Much of the data relates to energy use and can come from national data as well as internationally recognised data sources such as the International Energy Agency (IEA).

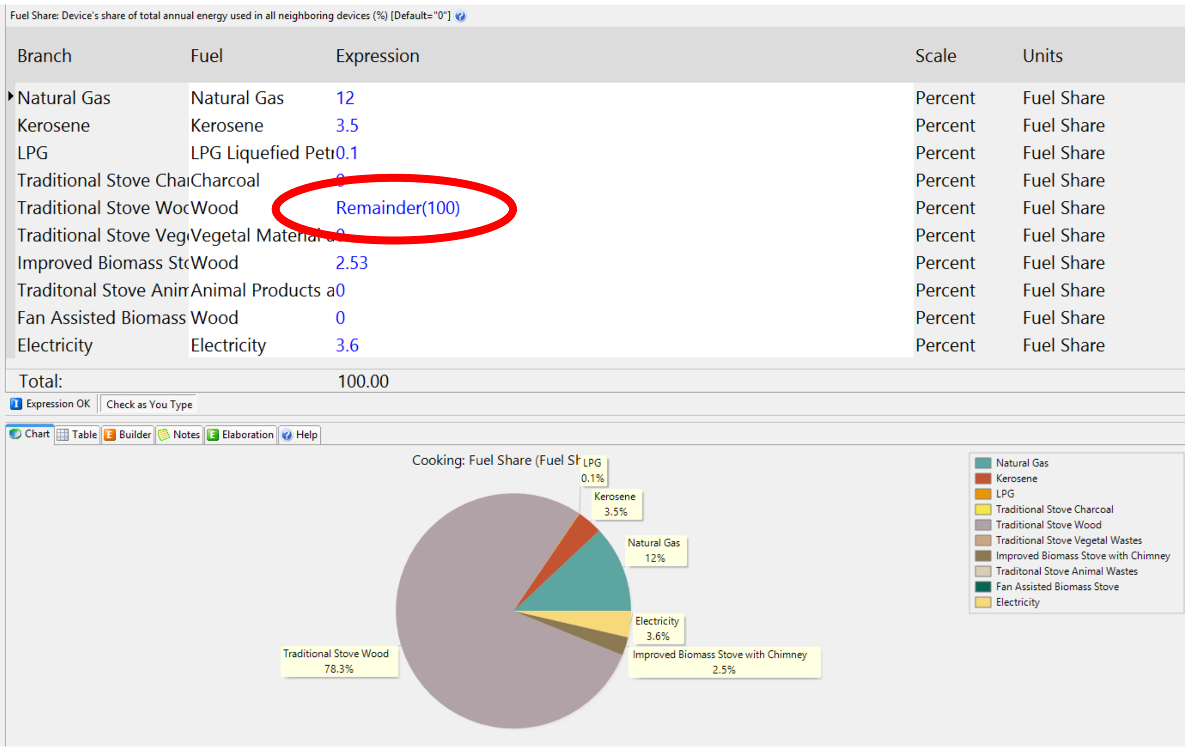
Detailed energy data is required for the following sectors:

- Energy Industry Own Use
- Manufacturing and Construction
- Brick Kilns
- Transport
- Residential
- Agriculture, Forestry and Fishing
- Commercial and Public Services
- Energy Transformation

The reason for their inclusion in this project relates to the use of the tool for country level assessments of mitigating SLCPs.

1.5 Calculation of emissions

There are three folders in LEAP-IBC which contain all the major source sectors of air pollutants. The first folder is called ‘Demand’, and this contains the source sectors where energy is required (i.e. ‘demanded’) and then used. In general terms, emissions are calculated by multiplying the activity for a particular source by an emission factor for that source. For the Demand sectors, the activity variable is the amount of energy consumed by each source sector. The total energy use for that sector is then split between each of the fuels used in that sector in the fuel share tab (see Figure 1.2 below).



Fuel Share: Device's share of total annual energy used in all neighboring devices (%) [Default="0"]

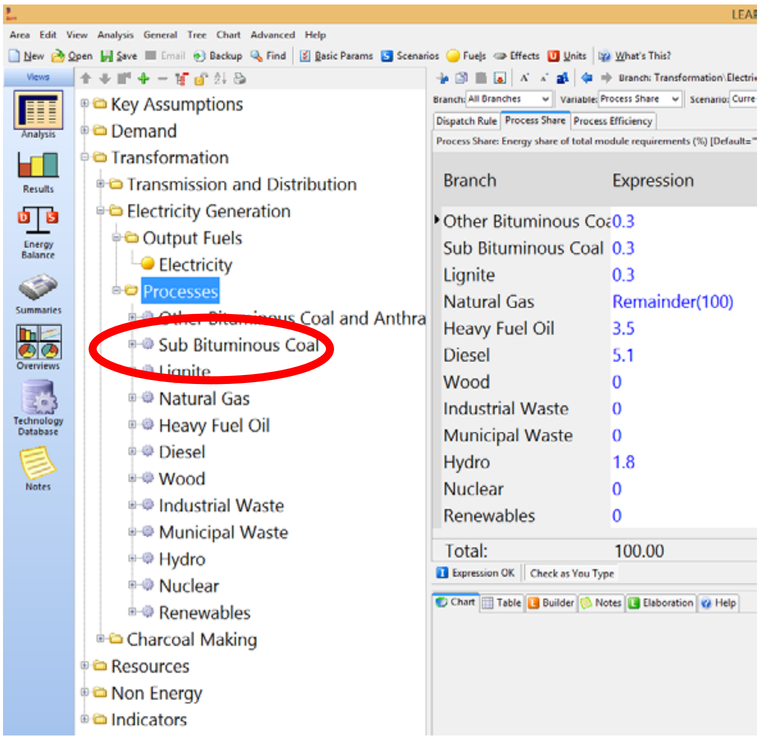
Branch	Fuel	Expression	Scale	Units
Natural Gas	Natural Gas	12	Percent	Fuel Share
Kerosene	Kerosene	3.5	Percent	Fuel Share
LPG	LPG Liquefied Petı	0.1	Percent	Fuel Share
Traditional Stove Chai	Charcoal	0	Percent	Fuel Share
Traditional Stove Woc	Wood	Remainder(100)	Percent	Fuel Share
Traditional Stove Veg	Vegetal Material a	0	Percent	Fuel Share
Improved Biomass Stc	Wood	2.53	Percent	Fuel Share
Traditonal Stove Anim	Animal Products a	0	Percent	Fuel Share
Fan Assisted Biomass	Wood	0	Percent	Fuel Share
Electricity	Electricity	3.6	Percent	Fuel Share
Total:		100.00		

Figure 1.2 Data entry for fuel share

Default emission factors (termed ‘*Environmental Loading*’ for fuel combustion sectors in LEAP) are pre-loaded into LEAP-IBC (with full referencing) but these can be overwritten by alternative factors (e.g. locally determined) if the user considers these to be more appropriate. For each fuel type, LEAP multiplies the ‘Environmental Loading’ emission factor by the activity (fuel use) to calculate emissions from that sector for the base year.

The demand for certain types of energy (electricity, charcoal) required by the sectors in the

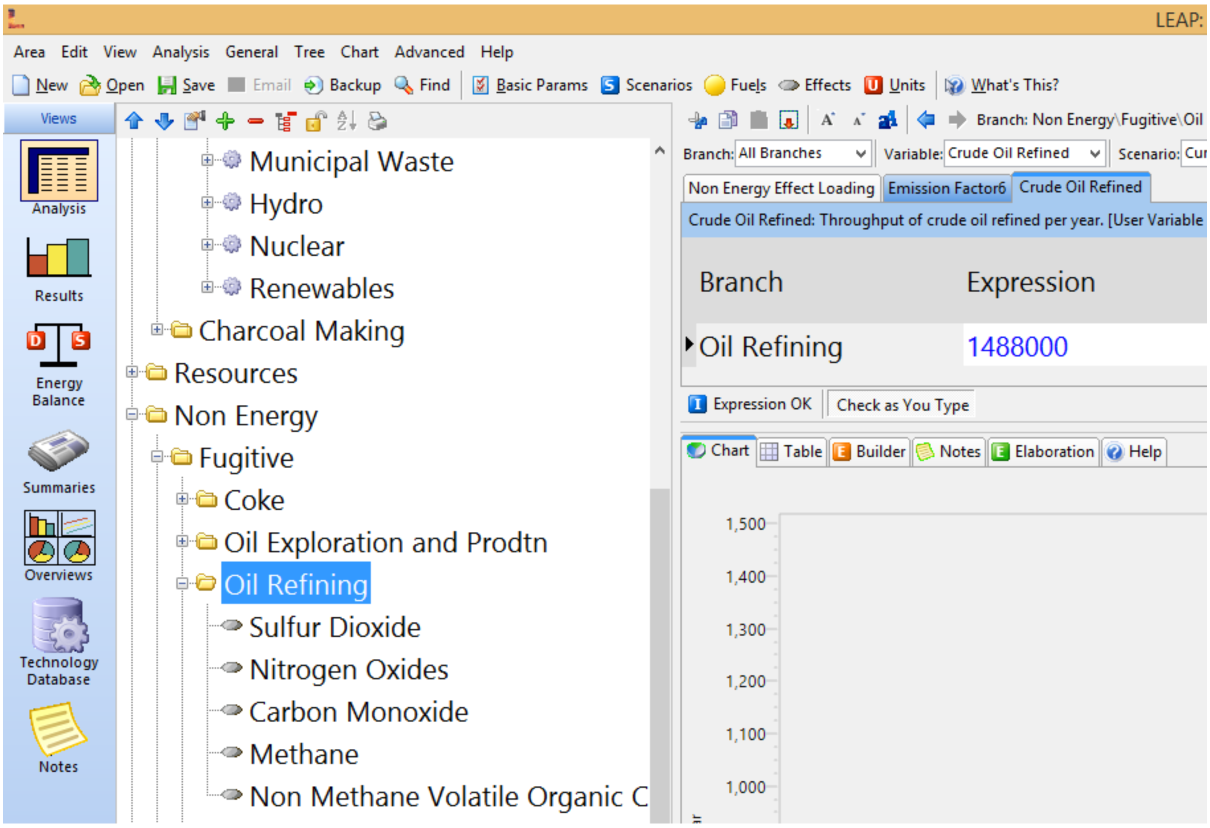
'Demand' folder is met by energy production in the 'Transformation' folder. For Electricity Generation, the user must specify how much electricity is produced from the different sources (Figure 1.3) whereas for Charcoal Making, wood is the only feedstock fuel.



Branch	Expression
Other Bituminous Coa	0.3
Sub Bituminous Coal	0.3
Lignite	0.3
Natural Gas	Remainder(100)
Heavy Fuel Oil	3.5
Diesel	5.1
Wood	0
Industrial Waste	0
Municipal Waste	0
Hydro	1.8
Nuclear	0
Renewables	0
Total:	100.00

Figure 1.3 Energy transformation tab

Finally, the Non-Energy folder contains source sectors which are not linked to fuel combustion. These sectors are varied and wide ranging, and include fugitive emissions from oil and gas industries, a detailed method for calculating transport emissions, industry, agriculture and waste sectors. The principle for calculating emissions in each of these sectors is the same, each source sector requires and activity variable, and an emission factor for each pollutant. For example, to calculate emissions from 'Oil Refining', you simply enter the tonnes of oil refined per year, and the default emission factors can be used to calculate emissions of each pollutant (see Figure 1.4)



Branch: Non Energy\Fugitive\Oil

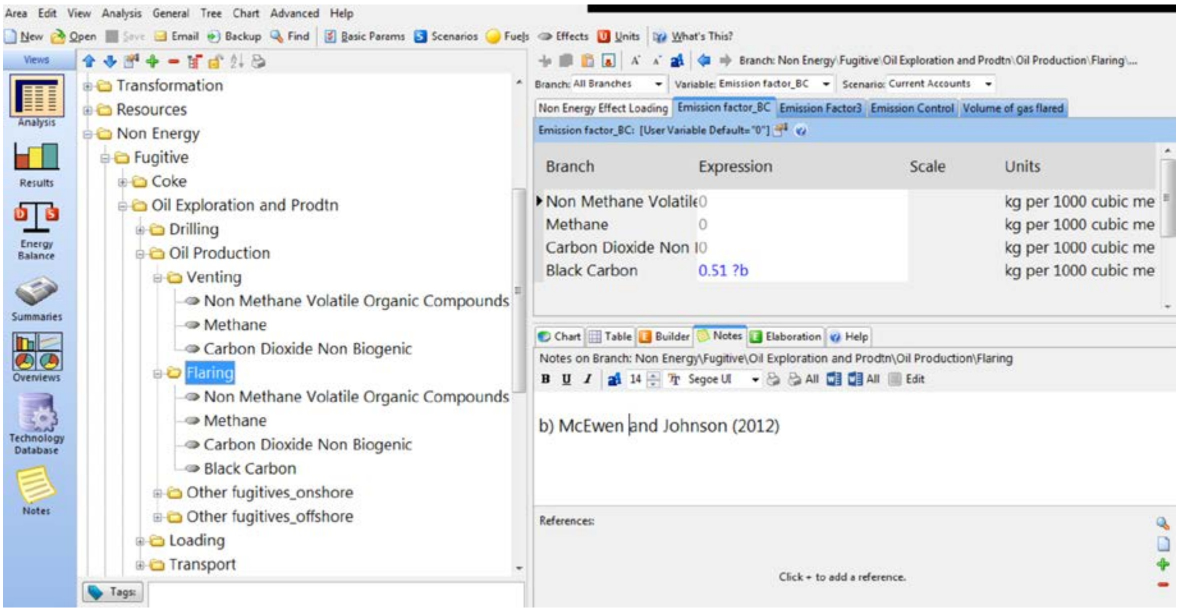
Branch: All Branches Variable: Crude Oil Refined Scenario: Cur

Crude Oil Refined: Throughput of crude oil refined per year. [User Variable

Branch	Expression
Oil Refining	1488000

Figure 1.4 Data entry tab for oil refining

The tab where the emission factor for BC from flaring is entered is highlighted below in Figure 1.5. This can be updated if new factors are developed. These could relate to different types of flaring activity or based on the type of oil being extracted (light or heavy oil).



Branch: Non Energy\Fugitive\Oil Exploration and Prodtn\Oil Production\Flaring\...

Branch: All Branches Variable: Emission factor_BC Scenario: Current Accounts

Emission factor_BC: [User Variable Default="0"]

Branch	Expression	Scale	Units
Non Methane Volatile	0		kg per 1000 cubic me
Methane	0		kg per 1000 cubic me
Carbon Dioxide Non I	0		kg per 1000 cubic me
Black Carbon	0.51 ?b		kg per 1000 cubic me

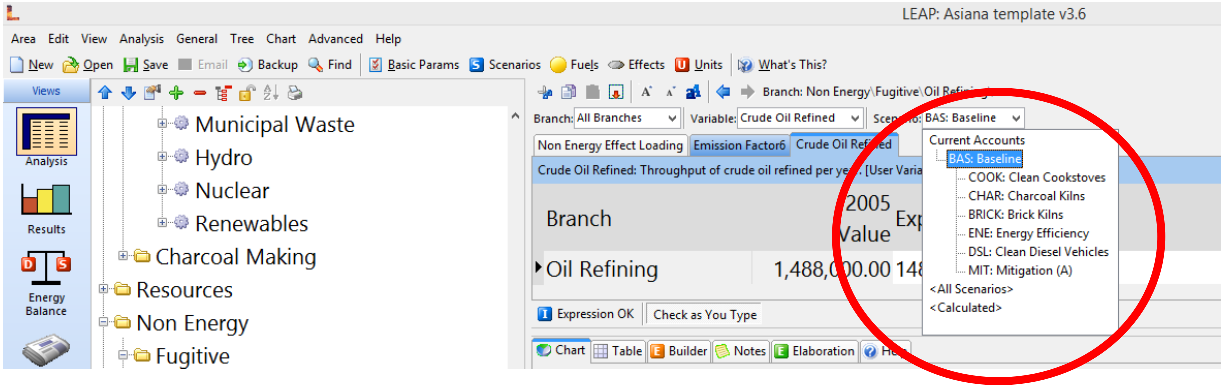
Notes on Branch: Non Energy\Fugitive\Oil Exploration and Prodtn\Oil Production\Flaring

b) McEwen and Johnson (2012)

References:

Figure 1.5 Emission factor tab for BC flaring from oil production

Once data have been entered for the base year it is then necessary to create the baseline scenario, which describes how emissions will change in the future up to 2050 if current trends continue (see Figure 1.6).



Branch: Non Energy\Fugitive\Oil Refining

Branch: All Branches Variable: Crude Oil Refined Scenario: BAS: Baseline

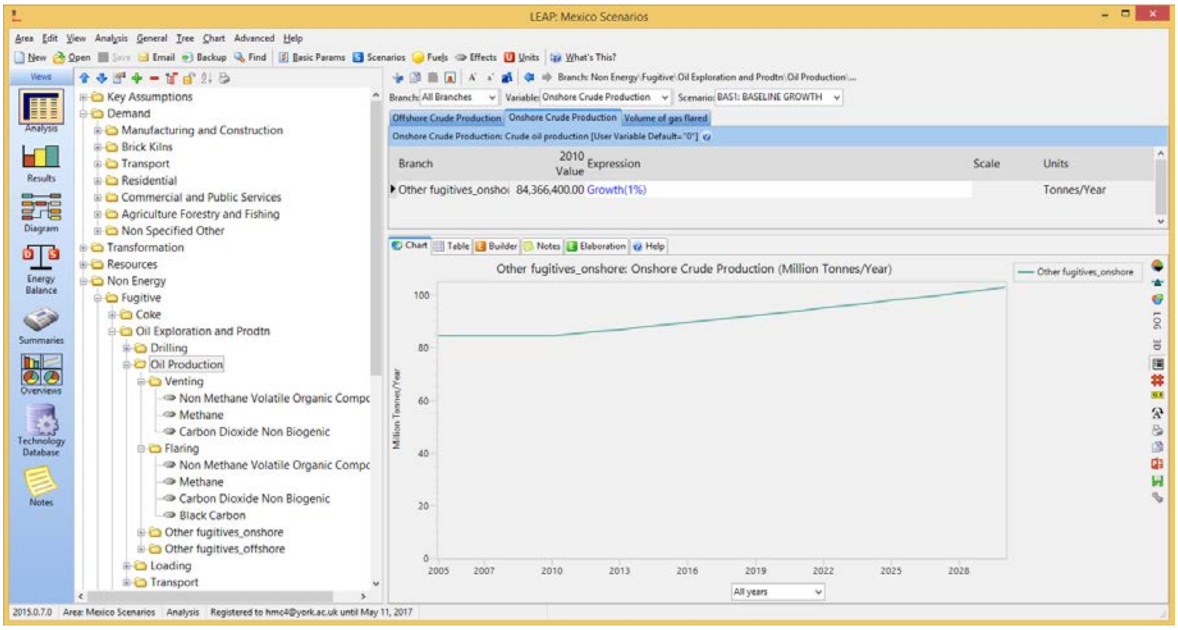
Crude Oil Refined: Throughput of crude oil refined per year. [User Varia

Branch	2005 Value	Exp
Oil Refining	1,488,000.00	148

Current Accounts
  BAS: Baseline
    COOK: Clean Cookstoves
    CHAR: Charcoal Kilns
    BRICK: Brick Kilns
    ENE: Energy Efficiency
    DSL: Clean Diesel Vehicles
    MIT: Mitigation (A)
<All Scenarios>
<Calculated>

Figure 1.6 Pull down menu for selection of scenarios

For each of the activity variables input for the base year 2010, it is necessary to specify an equation to describe how this will change over time in the baseline scenario. For example, for the *Onshore Oil Production* category, we have specified it will grow at 1 per cent per annum, but any equation to describe how the activity of each source sector will change based on the information available (see Figure 1.7) can be used. Once the changes over time for each source sector activity variable have been specified, the baseline scenario has been created and the results can be produced.



Branch: Non Energy\Fugitive\Oil Exploration and Prodtn\Oil Production\...

Branch: All Branches Variable: Onshore Crude Production Scenario: BAS1: BASELINE GROWTH

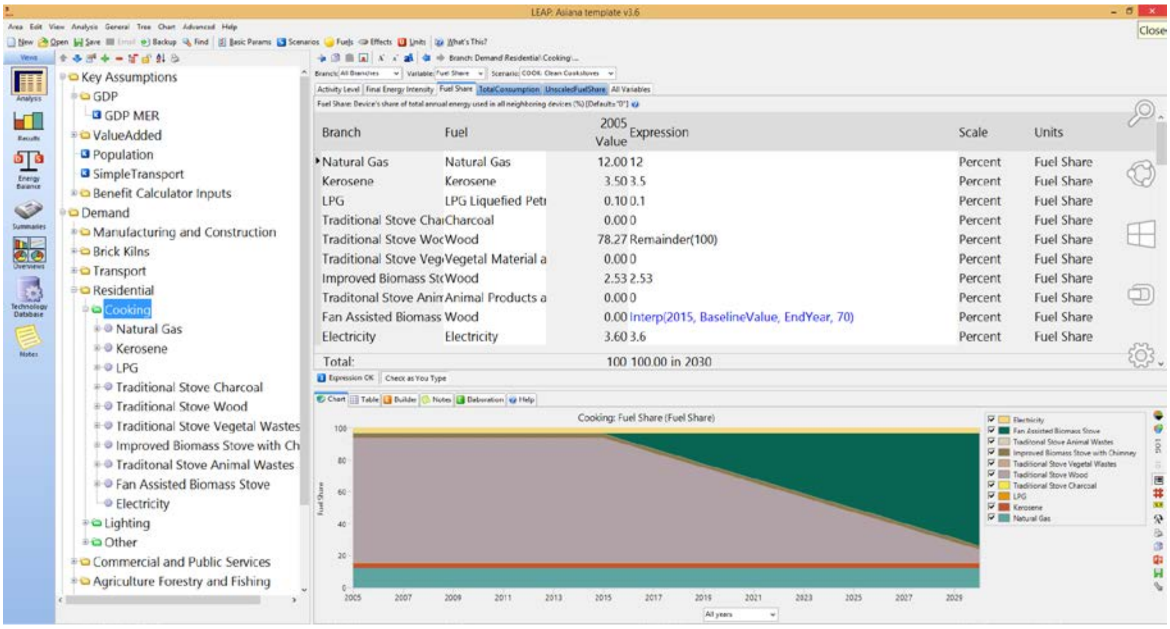
Onshore Crude Production: Crude oil production [User Variable Default="0"]

Branch	2010 Value	Expression	Scale	Units
Other fugitives_onsho	84,366,400.00	Growth(1%)		Tonnes/Year

Figure 1.7 Creation of baseline scenario – change of values over a specific timeframe

1.6 Scenario development

As well as the baseline scenario, a key use of LEAP-IBC is to calculate how emissions and impacts will change as a result of policies and interventions aimed at reducing air pollution impacts. Within LEAP-IBC, new scenarios are created and compared with the baseline, to show the benefits which could result from emissions reductions. All the variables which were input for the base year and baseline scenario are kept in the new scenario. This means that all that is needed to create a policy scenario is to change those variables in the source sectors which are of interest, and everything else is left the same. The same procedure is done for each scenario, where the variables which will change are selected and an equation for how they will change is specified, different to the one entered for the baseline scenario (see Figure 1.8).



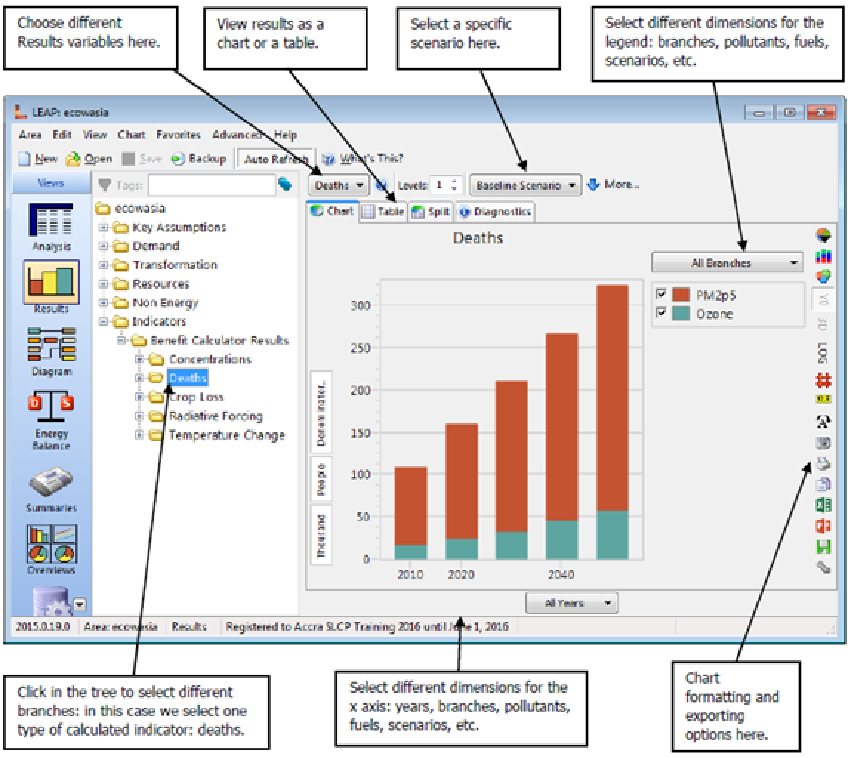
Fuel Share: Device's share of total annual energy used in all neighboring devices (%) [Default='0']

Branch	Fuel	2005 Value	Expression	Scale	Units
Natural Gas	Natural Gas	12.00	12	Percent	Fuel Share
Kerosene	Kerosene	3.50	3.5	Percent	Fuel Share
LPG	LPG Liquefied Petı	0.10	0.1	Percent	Fuel Share
Traditional Stove Chai	Charcoal	0.00	0	Percent	Fuel Share
Traditional Stove Woc	Wood	78.27	Remainder(100)	Percent	Fuel Share
Traditional Stove Vegı	Vegetal Material a	0.00	0	Percent	Fuel Share
Improved Biomass Stı	Wood	2.53	2.53	Percent	Fuel Share
Traditonal Stove Anim	Animal Products a	0.00	0	Percent	Fuel Share
Fan Assisted Biomass	Wood	0.00	Interp(2015, BaselineValue, EndYear, 70)	Percent	Fuel Share
Electricity	Electricity	3.60	3.6	Percent	Fuel Share
Total:		100	100.00 in 2030		

Figure 1.8 Data entry for different scenarios

1.7 Calculation of impacts

The benefit calculator results for current and future emissions and impacts can be shown by using LEAP's Results View. All the impacts are stored in the 'Indicators' folder. For example, clicking on the 'Deaths' folder shows the number of premature deaths in a given year as shown below for premature mortality from outdoor exposure to $PM_{2.5}$ and ozone for the country of interest (Figure 1.9). This can be further split into contributions from national emissions, the rest of the world and natural background.



Choose different Results variables here.

View results as a chart or a table.

Select a specific scenario here.

Select different dimensions for the legend: branches, pollutants, fuels, scenarios, etc.

Click in the tree to select different branches: in this case we select one type of calculated indicator: deaths.

Select different dimensions for the x axis: years, branches, pollutants, fuels, scenarios, etc.

Chart formatting and exporting options here.

Figure 1.9 Results from LEAP-IBC –Premature deaths associated with $PM_{2.5}$ and O_3

By selecting a particular scenario from the menu, the number of premature deaths in the scenario can be compared to the baseline, with the white box showing the number of avoided deaths in each year, if the scenario was implemented (see Figure 1.10).

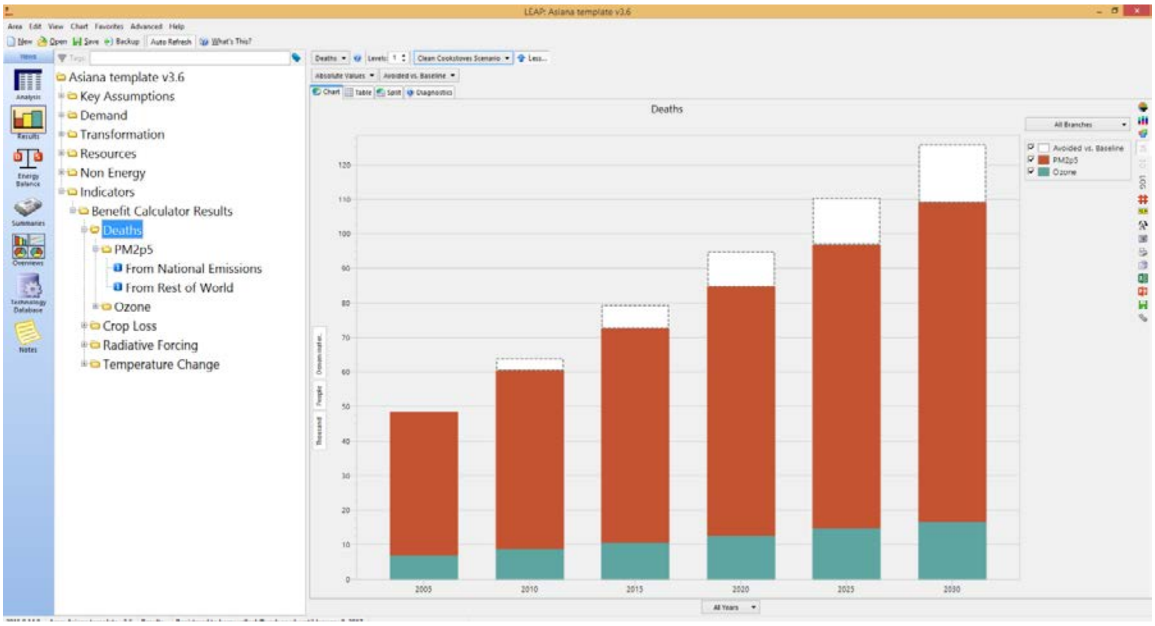


Figure 1.10 Comparison of different scenarios showing number of deaths avoided

2. USE OF LEAP-IBC FOR ASSESSING THE IMPACTS OF THE OIL AND GAS SECTOR

2.1 Data requirements

LEAP-IBC is a relatively simple 'reduced form' model which requires data from different sources to be compiled. The principle for calculating emissions for sectors not linked to energy production and use is the same, each source sector requiring an activity variable, and an emission factor for each pollutant. For example, to calculate emissions from 'Oil Refining', you simply enter the tonnes of oil refined per year, and the default emission factors are then used by LEAP to calculate the emissions of each pollutant. For national scale analysis, default data can be obtained through readily available datasets such as the International Energy Agency's (IEA) Statistics and Balances, although nationally derived data may be preferable and more accurate.

The data requirements pertinent to oil and gas components in LEAP (*Non-Energy Fugitive Emissions*) are:

- Number of oil wells drilled
- Oil transported through pipelines
- Volume of gas flared
- Gas Production
- Offshore/Onshore Crude oil production (tonnes)
- Oil loaded onto tankers and land transport
- Gas Processing
- Gas Distribution

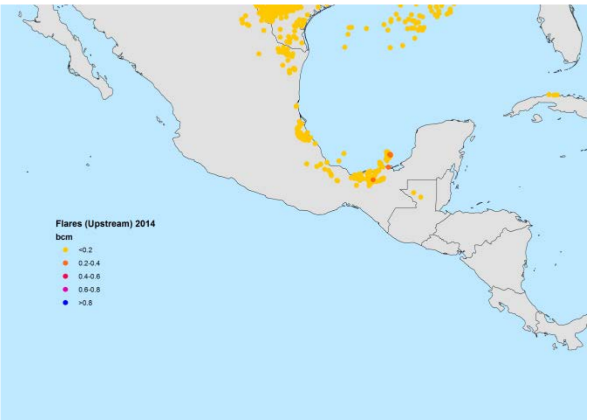
LEAP contains a default database of emission factors which are taken from the literature. For oil and gas production, methane, NMVOC and CO_2 emissions from venting are calculated using IPCC Tier 1 emission factors. For flaring, the default emission factors for methane, NMVOC and CO_2 are also IPCC Tier 1 whereas the black carbon (BC) emission factor of 0.51 kg per 1000 m^3 flared is based on research by McEwen and Johnson (2012). The emission factor for black carbon can be changed by the user to reflect the flaring characteristics based on local measurements.

Data is entered for the current situation 'Baseline' (e.g. 2010) and a scenario is developed on which the expected changes in variables over the next years are specified. This can be based on previous trends or forecasts published by the industry e.g. increase in oil well drilling. Further scenarios can then be developed, such as reducing flaring to zero and the effects of such interventions on emissions, health impacts and climate change can be compared to the baseline scenario.

3. APPLICATION OF LEAP-IBC IN TWO CASE STUDY SCENARIOS

3.1 Overview

Two focal countries under the CCAC Oil and Gas Initiative are Mexico and Colombia. Both of these are major oil producers and are closely controlled by their respective Governments. The maps in Figures 3.1a and b show where flaring is taking place in the two countries using NASA satellite imagery for 2014 (Elvidge, 2015).



Figures 3.1a Flaring in Mexico

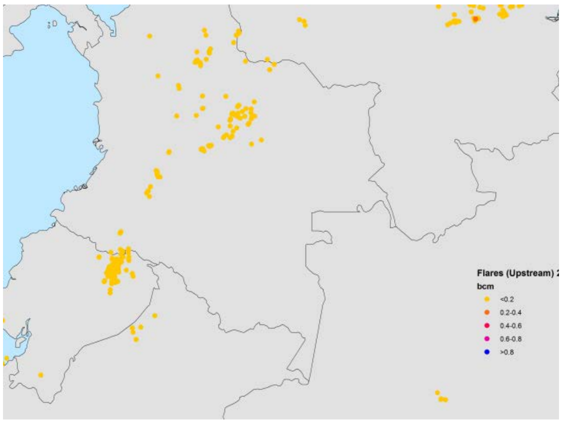


Figure 3.1b Flaring in Colombia (Elvidge, 2015)

3.2 Case Study - Mexico

Mexico is one of the largest oil producers in the World; ranking 9th in terms of crude oil reserves although in recent years oil production has been on the decline. One reason for this is that the main production, located in the Cantarell oil field, has decreased significantly. Petróleos Mexicanos (PEMEX) is the state-owned company that carries out exploration and extraction of petroleum as well as processing and distribution. PEMEX has six refineries, eight petrochemical and nine gas processing plants and produces approximately 2.5 million barrels of oil daily and more than 6 million of cubic feet of natural gas. Half of oil production (see Figure 3.2) is heavy oil which is usually harder to extract.

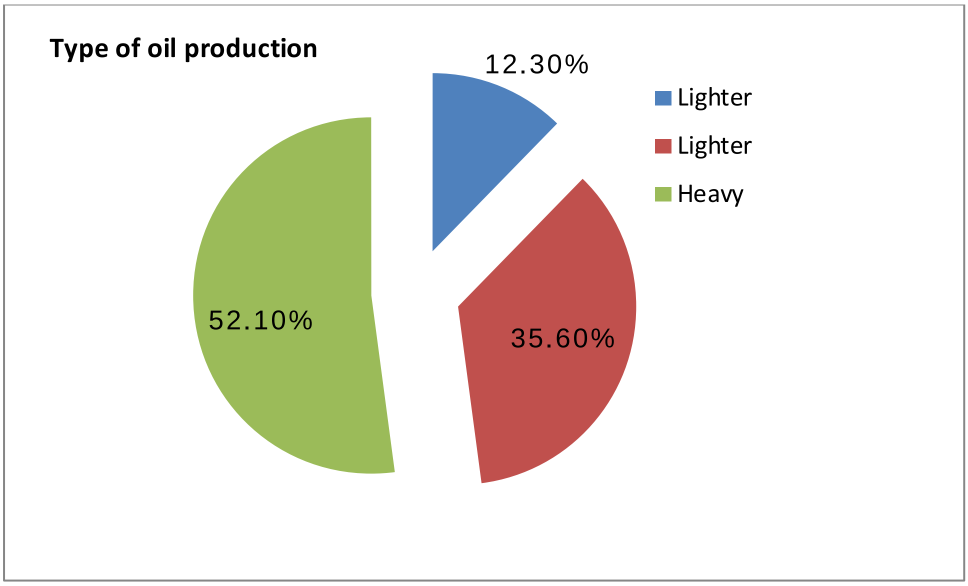


Figure 3.2 Oil production by type 2014. Source PEMEX Statistical year Book 2014

The petroleum industry in Mexico has also recently been opened up to private companies to begin exploration and production.

In terms of flaring, Mexico is ranked 15th in the world according to the World Bank (GGFR, 2012). Peak levels were recorded in 2008 with approximately 3.5 billion cubic meters (bcm) flared whereas current levels are approximately 2.8 bcm (PEMEX and the Ministry of Energy). There was a steep rise in emissions due to the need to flare gas at the Cantarell oil field, as high nitrogen concentration in the oil could not be utilised for other purposes and therefore had to be flared. The Mexican Government also sets annual limits for flaring and venting and imposes fines for breaching them.

3.2.1 Data input

The current accounts data used as the baseline scenario is for 2010. Demographic data has been taken from the World Bank statistical dataset for Mexico (World Bank, online) - Variables include population, GDP, production share are shown in Table 3.1

GDP: $1051.129 billion Population: 118 million	*Activity* Agriculture: 3.5% Services: 35.1% Industry: 61.5%

Table 3.1. Key assumption data for Mexico current accounts (Source: World Bank)

The input data required by LEAP-IBC's benefit calculator for deriving impacts on health and crops are pre-loaded into the tool separately for each country; the data for Mexico are summarized in the Table 3.2.

ThirtyPlusFraction	46%
Cardiopulmonary Disease Rate	0.0036
RR Cardiopulmonary Disease	1.128
Lung Cancer Rate	0.000179
RR Lung Cancer	1.142
Respiratory Disease Rate	0.000611
RR Respiratory Disease	1.04
Rice Start Month	May
Wheat Start Month	February
Maize Start Month	April
Soy Start Month	April
Rice_Production	216.676 kt
Wheat_Production	3676.707 kt
Maize_Production	23928.97 kt
Soy_Production	167.665 kt

Table 3.2 LEAP-IBC benefit calculator input data used for Mexico

The activity data used in calculating emissions from fuel combustion in the demand sectors is primarily taken from the IEA database. For 'Non-energy' sectors, industrial data needed for calculating process emissions are taken from UN Data, and the USGS Minerals database. Some data was unavailable although these would not be affected under the scenarios developed for looking at oil and gas. Petroleum Coke production data is from UN Data and Coal production from EIA. Coke – assumed traditional method – data from - Energy Information System Petróleos Mexicanos http://sie.energia.gob.mx/

Within LEAP-IBC, transport emissions can be calculated two ways: one way is to use a detailed fleet inventory for all modes and includes detailed splits by vehicle type, performance and fuel type; the second is to use the simple transport sub-model which does not break the transport modes into sub-categories of vehicles. The simpler model was chosen.

Data for oil and gas production is taken from the PEMEX annual statistics (PEMEX Annual Statistical Yearbook, 2014). These are produced for each oil field and aggregated. Data on flaring was taken from the World Bank dataset published in 2012. PEMEX only provides a combined value of flaring and venting. The data used for the scenario is shown in Table 3.3.

SOURCES	**VARIABLE**	**VALUE**
Oil Exploration and Production\ Drilling		
	Wells drilled per year	994
Oil Exploration and Production\ Oil Production		*Mcm/yr*
	Volume of Gas flared	2,800
		tonnes/yr
	Onshore Crude Production	32,474,050
	Offshore Crude Production	99,215,760
	Crude Oil loaded onto Marine Tankers	69,393,800
Oil Transport		*tonnes/yr*
	Oil Transported in Pipelines	530,517
Oil Refining		
	Crude Oil Refined	60,860,100
Gas Production, Processing and Distribution		*TJ/yr*
	Gas Production	2,700,164
	Gas Processing	1,807,559
	Gas Distribution	3,323,646

Table 3.3 Variables related to Oil and Gas used in LEAP-IBC for Mexico

3.2.2 Scenarios

Once the current account data has been entered, two scenarios were modelled. These are named *Baseline Growth* and *Maximum Reduction*:

The *Baseline Growth* scenario considers the potential for further oil exploration and only a slight annual increase in oil production (1% per annum). This is based on current industry expectations (EIA, 2015), however in practice speculation in oil production is fraught with uncertainty. It can be highly variable depending on a number of factors such as market conditions, locations of productive oil and gas fields as well as regulatory impacts. In addition, in many countries, political instability can affect production. Therefore, in this scenario, growth was also constrained due to uncertainty in the market due to low prices of the gas and also low uptake of new technology due to lack of investment.

Flaring and venting have been reducing since 2008 partly as a consequence of Mexico’s energy reform. Significant investments in gas handling and its use for re-injection such as in the case of Cantarell primarily have led to this reduction. A growing domestic demand for gas has also increased uptake. This has required more gas processing and distribution facilities to meet such demand. In addition, Mexico is investing in new technologies to capture and process the gas.

The *Maximum Reduction* scenario includes substantial reduction in venting through improved operations and re-use of the gas (methane). The scenarios assume the methane capture technology has been developed and used to convert the methane into other products such as Liquid Natural Gas (LNG), used as a catalyst in bio-refineries or made into fertilizer. The scenario does not assume that all the methane is captured though some will be still vented due to logistical and infrastructural constraints and also through leakage. Flaring is also reduced according to the World Bank zero routine-flaring initiative of reaching zero flaring by 2030. There may still be some non-routine flaring for operational and safety reasons. The reduction in flare volume is shown in Table 3.4.

	Flaring volume (Mcm/yr)		
Scenarios	***2010***	***2020***	***2030***
Baseline Growth	2,800	4,813	5,316
Maximum Reduction	2,800	1,120	-

Table 3.4 Reduction of flaring in Mexico under two scenarios

3.2.3 Results

The purpose of running the model was to determine the potential reduction in BC emissions by eliminating flaring and methane reductions by reducing venting. Both scenarios were run over a 20 year time-frame (2010-2030) to coincide with the anticipated cessation of flaring. Results in Table 3.5 show that overall BC emissions are small under the Baseline Growth scenario (under 2 tonnes per year). However, when considering the total amount of emissions over the time-period, BC has reduced by 3 tonnes (65 per cent).

	Black Carbon Emissions (tonnes)			
Scenarios	***2010***	***2020***	***2030***	***Total 2010-2030***
Baseline Growth	1,428	1,577	1,742	4,747
Maximum Reduction	1,428	235	-	1,663

Table 3.5 Reduction in Black Carbon from flaring

In comparison, methane reductions at approximately 150 kt are significant (Table 3.6) as much of the methane is assumed to have been captured and converted. Not all the methane is captured as some will be still vented due to logistical and infrastructural constraints and also through leakage. There are other impacts associated with methane emission reductions including global warming temperature change and its effect on crops.

Crop yield losses will also reduce as a result of implementing the *Maximum Reduction* scenario although this effect largely comes as a result of a reduction in climate change impact than direct impact on crop health. The reduction in crop yield losses is approximately 0.5 per cent or 21,000 tonnes by 2030 for all crops. Maize accounts for 94 per cent (19,900 tonnes) of these reductions.

Under the *Maximum Reduction* scenario reductions in emissions from carbon dioxide, aerosols and ozone could see radiative forcing reduced by 2% by 2030, declining from 48.2 w/m^2 [6] to 47.2 4/m^2 compared to the *Baseline Growth* scenario. This is primarily due the effect of reducing methane, which is a precursor to Ozone and which also has a higher global warming potential.

		Methane Emissions		
		2010	***2020***	***2030***
			(kts)	
Baseline Growth	**Flaring**	8.9	13.8	19.3
	Venting	257.6	399.9	557.0
	Total	266.5	413.7	576.3
Maximum Reduction	**Flaring**	8.9	12.1	14.4
	Venting	257.6	350.3	416.3
	Total	266.5	362.5	430.7

Table 3.6 Methane reductions under two scenarios in Mexico

In terms of global temperature change, if measures were implemented to reduce flaring and venting then temperatures would reduce by approximate 0.2 mK[7] in 2030 that is to say there will be a very negligible effect.

LEAP-IBC does not attribute any deaths due to BC from oil and gas flaring however in terms of Particulate Matter (PM$_{2.5}$) the model predicts 190 deaths saved over the time-period.

3.3 Case Study – Colombia

Colombia is the third-largest oil producer in Latin America. Most of Colombia's crude oil production occurs in the Andes foothills and the eastern Amazonian jungles. Rubiales is the largest oil field in the country, located in the centre of Colombia (EIA, 2015). Colombia has

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[6] watts per square metre

[7] mlliKelvin

seven major oil pipelines crossing the country: (Bicentennial , Ocensa; Cano-Limon; Llanos Orientales; Alto Magdalena; Colombia Oil and Transandino) four of which connect oil and gas fields to the Caribbean coast export terminal. Similar to the oil sector, natural gas production has risen substantially in the last few years, owing to greater investment at existing fields, rising domestic consumption, and new export opportunities

Oil production has increased significantly in Colombia from 2010 after a period of decline as a result of the government introducing a series of regulatory reforms. The national target is to produce 1 million barrels per day (bls/d) up from 686,000 bls/d in 2009. Similar to PEMEX, Ecopetrol was a fully state-owned company but is now part-privatised to attract investors, primarily in upstream production**.** Recently, new pipelines and refining capacity has helped increased oil production especially off-shore. Most oil production is on-shore (80 per cent of production) although it is estimated that offshore exploration in the country could increase six times and triple the size of gas reserves off the Colombian Caribbean coast (PwC, 2014). Security remains a major problem for the industry where attacks on pipelines have led to production stopping as recently as March 2016.

Chevron is the largest gas producer and most of the production is located in two fields the Llanos and Guajira basins. Recently, gas production has increased due to investment in existing fields and increased domestic energy demand. Previously, the majority of the gas was re-injected to increase oil production. Compared to Mexico the amount of flaring in Colombia is small (0.6 bcm per annum compared to 2.8 bcm per annum for Mexico in 2010). Ecopetrol has a programme of environmental measures to capture and market methane gas released at drilling sites and also capturing of natural gas escaping at well sites and its conversion to electricity for further production.

3.3.1 Data input

Oil and gas production data were available from BP Statistical Review of World Energy (2015) and flaring volume for 2010 was taken from the World Bank GGFR flaring database. Data for other sectors is based on the same data sources outlined for Mexico in section 3.2.1. Population, GDP, production share values used for the scenario are shown in Table 3.7.

GDP: $183 billion Population: 45.9 million	*Activity* Agriculture: 7.2% Services: 32.7% Industry: 60.1%

Table 3.7 Key assumption data for Colombia current accounts (Source: World Bank)

Benefit calculator inputs data for Colombia are summarized in the Table 3.8.

ThirtyPlusFraction	46%
Cardiopulmonary Disease Rate	0.0034
RR Cardiopulmonary Disease	1.128
Lung Cancer Rate	0.000175
RR Lung Cancer	1.142
Respiratory Disease Rate	0.000178
RR Respiratory Disease	1.04
Rice Start Month	May
Wheat Start Month	February
Maize Start Month	April
Soy Start Month	April
Rice_Production	1988 kt
Wheat_Production	15 kt
Maize_Production	14227 kt
Soy_Production	54 kt

Table 3.8 LEAP-IBC Benefits Calculator input data for Colombia

SOURCES	**VARIABLE**	**VALUE**
Oil Exploration and Production\ Drilling		
	Wells drilled per year	112
Oil Exploration and Production\ Oil Production		*Mcm/yr*
	Volume of Gas flared	2,800
		tonnes/yr
	Onshore Crude Production	32,108,000
	Offshore Crude Production	8,027,000
	Crude Oil loaded onto Marine Tankers	12,414,733
Oil Transport		*tonnes/yr*
	Oil Transported in Pipelines	38,387,244
Oil Refining		
	Crude Oil Refined	15,387,000
Gas Production, Processing and Distribution		*TJ/yr*
	Gas Production	438,454
	Gas Processing	112,135
	Gas Distribution	166,593

Table 3.9 Oil and gas data for Colombia used for scenarios

3.3.2 Scenarios

In a similar way that was employed for the Mexico case study, two scenarios were investigated to compare the *Baseline Growth* with the *Maximum Reduction* scenarios. The baseline scenario followed similar a growth pattern however additional gas production is envisaged as domestic demand is foreseen to increase and further off-shore oil production is expected as new fields are opened up for foreign companies to explore and develop.

Both scenarios envisage oil production increasing in line with the US Energy Information Administration's predicted growth of 1% per annum between 2011 and 2035 whilst gas production will increase by 1.4% (EIA, 2015).

Under the *Maximum Reduction* scenario flaring will reduce by 98 per cent (taking into account some non-routine flaring taking place). In addition control measures to reduce venting by 60 per cent will be introduced. These measures include reductions in venting where methane is captured and converted for sale to market or for energy production as well as reduction of fugitive emissions e.g. leakages from valves.

3.3.3 Results

Due to the relatively low flaring activity in Colombia it follows that there is only a relatively small decrease in total BC emissions achievable if zero routine flaring were to be attained in 2030. Table 3.10 shows that under the *Baseline Growth* scenario, BC emissions increase from 0.3 tonnes to 0.5 tonnes over the time period and the overall BC emissions saved as flaring ceases under the *Maximum Reduction* scenario are approximately 1.6 tonnes.

	Black Carbon Emissions			
	2010	***2020***	***2030***	***Total 2010-2030***
	(tonnes)			
Baseline Growth	0.29	0.41	0.52	2.03
Maximum Reduction	0.29	0.11	-	0.45

Table 3.10 Baseline Growth scenario for Colombia

The comparison between the two scenarios shows that methane emission reductions across all parts of the oil and gas industry would be possible, approximately 181kilotonnes over the time period 2010-2030 (Table 3.11).

	Methane Emissions		
	2010	***2020*** (kt)	***2030***
Baseline Growth	188	414	683
Maximum Reduction	188	357	502

Table 3.11 Reduction in Methane emissions under two scenarios for Colombia

The additional co-benefits from reducing flaring and venting under the scenarios are also very marginal. For example, the reduction in global mean temperature is 0.065mK in 2030. The overall reduction in radiative forcing is 0.14 w/m^2, again with ozone contributing the greatest reduction due to less methane produce. The results for the scenarios undertaken for Colombia also show that there are no deaths attributable to the emissions from oil and gas.

4. ANALYSIS

This project has used the LEAP-IBC tool to model the reduction in black carbon (BC) emissions from flaring and methane emissions from venting in Mexico and Colombia. Scenario modelling undertaken in this assessment takes into account current levels of emissions at existing flaring rates and then scenarios constructed comparing business-as-usual case (Baseline scenario) to those where flaring has reduced either through control measures (regulation) or through implementation of technology to capture gas. However, the output from the model can provide a relative measure to compare different mitigation options against the business as usual.

Whilst BC emissions from flaring alone in each country are relatively small when added together with other sources – transport, brick production, waste burning and cooking stoves then the overall contribution by each country is important. Other CCAC initiatives have demonstrated how BC can be reduced and the associated benefits activities can yield.

BC emissions are relatively small in Colombia. Much of the gas from the oil and gas industry is re-injected to increase pressure to enable greater oil extraction. Similar to Mexico there could be potential to reduce methane emission significantly depending on the scale of technology that is introduced to process it for example into Liquefied Natural Gas (LNG).

5. RECOMMENDATIONS

What is clear from the development of the scenarios is the lack of detailed measurements from oil and gas installations on which to develop the scenarios. There does not appear to be a verifiable emission inventory for the sector in Colombia. In Mexico, flaring and venting is disaggregated and reported by PEMEX at a production region level.

Most global datasets that are available provide only national estimates of flaring volumes or, in other words, territorial emissions. Countries which operate state-operated oil exploration facilities may have greater control and accountability to produce accurate emission inventories. The issue of attaching responsibility to the volumes can be further misleading as the flaring activity might be from non-National sources i.e. foreign companies, multi-nationals.

There is lack of regulation or enforcement of regulations to make companies comply with any legislation to report flaring and venting. There needs to be a means of verification and where the facilities are off-shore, this will be particularly difficult to measure. Satellite data can aid verification but this also requires local expertise in processing and analysing the data. Whilst the satellite data can detect where flaring is occurring to a reasonable level of accuracy it cannot yet successfully quantify the emissions from individual flares. As a consequence there is a large amount of uncertainty in any assessments.

Overall there is a need for better data collection and measurement either on-site or remotely although this may improve as new technologies are introduced.

Such data gathering includes:

- production and flaring data at each site (platform/well)
- different hydrocarbon constituents and conditions related to combustion efficiency of flares
- improved understanding of flare constituents and derivation of emission factors related to different type of crude oil
- what control measures employed or technology used to capture and convert gas

- associated meteorological data measurements e.g. wind speed

- measurement of venting and detection of methane from satellite

This can only be achieved through international efforts which require companies and countries to report detailed measurements. Undertaking these types of assessments are costly and could still be open to high levels of uncertainty. Therefore, one recommendation would be to include reporting of flaring and venting emissions as a requirement of the signatories to the Zero Routine Flaring Initiative of the World Bank.

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World Bank statistical dataset -http://data.worldbank.org/country/mexico

APPENDIX 1.

Signatories to the World Bank Initiative to cease routine flaring by 2030

GOVERNMENTS	COMPANIES	ORGANISATIONS
• Angola • Azerbaijan • Cameroon • Canada • Republic of Congo • France • Gabon • Germany • Kazakhstan • Mexico • Netherlands • Norway • Perú • Russian Federation • State of California, United States • Turkmenistan • United States • Uzbekistan	• BP • Eni • Entreprise Tunisienne d'Activités Pétrolières (ETAP – Tunisia) • Galp Energia (Portugal) • KazMunayGaz (Kazakhstan) • Kuwait Oil Company • MOL Group • Niger Delta Petroleum Resources Ltd. (Nigeria) • ONGC (India) • Petroamazonas EP (Ecuador) • Royal Dutch Shell • Seven Energy (Nigeria) • Societé Nationale des Hydrocarbures (SNH – Cameroon) • Societé Nationale des Petroles du Congo (SNPC) • Sonangol (Angola) • State Oil Company of the Azerbaijan Republic (SOCAR) • Statoil • TOTAL • Uzbekneftegaz (Uzbekistan) • Wintershall	• African Development Bank (AfDB) • Agence Française de Développement (AFD) • Asian Development Bank (ADB) • ECOWAS Bank for Investment and Development (EBID) • European Bank for Reconstruction and Development (EBRD) • Inter-American Development Bank (IDB) • Islamic Development Bank (IsDB) • OPEC Fund for International Development (OFID) • United Nations Sustainable Energy for All (SE4All) • West African Development Bank (BOAD) • World Bank Group