A HIGH RESOLUTION TECHNOLOGY-BASED BOTTOM-UP EMISSIONS INVENTORY FOR NEPAL

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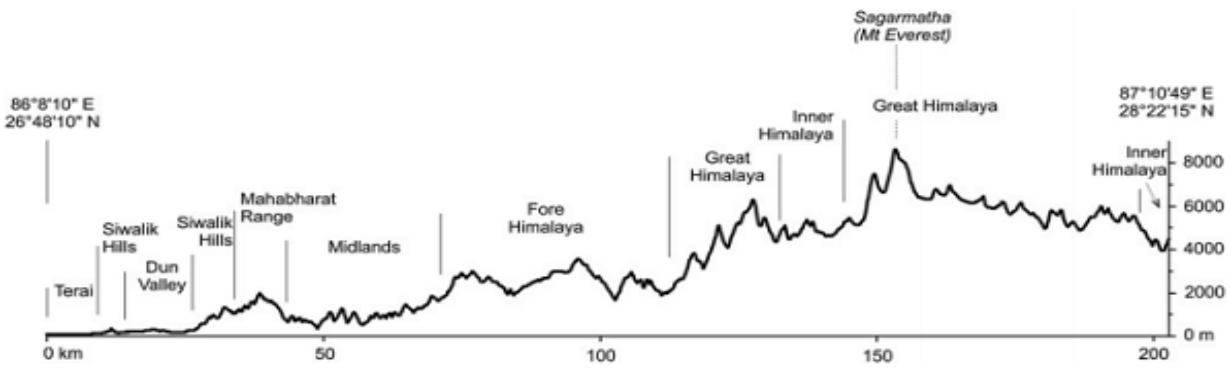
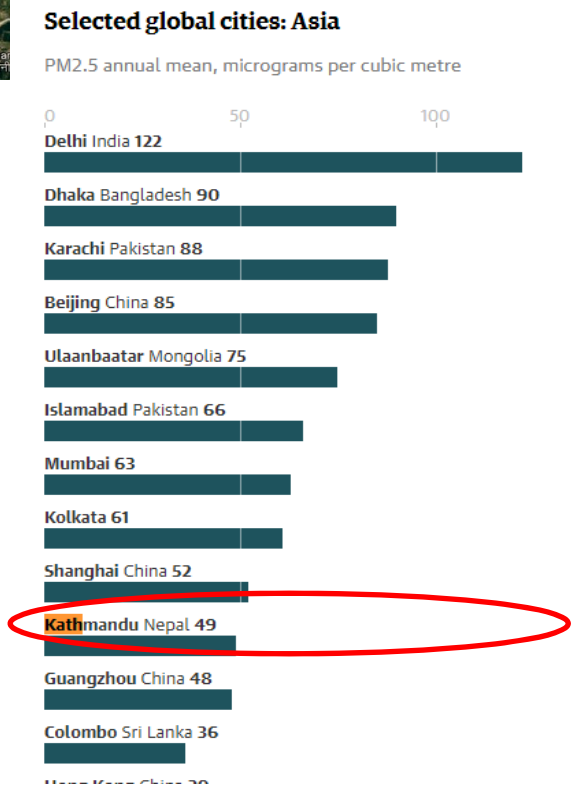
Background and motivation



- Population 26 Million in 2011. 10% resides in Valley.
- Complex topography, heavy rely on biomass and imports of fossil fuel makes it crucial to understand the landlocked country in the Himalayas.
- Studies over Nepal voids in understanding the energy consumption nationally, albeit few studies have strived with Tier I approach at sectoral level. [Bhattarai and Jha, 2015; Malla 2013; Shrestha and Rajbhandari, 2010]
- Regional inventory are unable to capture the variablity in spatial distribution



Guardian graphic | Source: WHO database, updated 2016.

Source: Dhital, 2015: p26;

Objectives/Goals of Emission Inventory

- Comprehensive understanding of the energy and emissions from energy-use sectors with combustion technology details.
  - Develop bottom-up methodologies within each sector to estimate present day technology-based energy consumption.
  - Quantify technology-linked emissions for short-lived climate forcers, ozone precursors ($PM_{2.5}$, BC, OC, SO_2, NO_X, CO, NMVOC and CH_4) and greenhouse gases (CO_2 and N_2O).
  - Understand trends in energy use pattern and emissions 2005 - Present using activities at coherent sources
  - Develop a tool to understand the energy and emission sources in order to frame mitigation policies for Kathmandu Valley.

Emission inventory details

Features	Details
Base year	2011 (Trend: 2005-----**2011**----2016)
Region	75 districts as per Census 2011
Sectors (5) sub-sectors (17)	**Residential (4):** Cooking, lighting, space heating, water heating and boiling **Industry (3):** Brick production, Point sources of cement, basic iron, structural metal, pharmaceutical, tea and coffee, grain mill, noodles and area sources of small industries **Transport (4):** Private passenger vehicles, public passenger vehicles and public freight vehicles, off-road vehicles **Commercial (2):** Diesel genset users (Academic institutions, hospitals, financial institutions, government offices), barrack canteens, hotels and restaurants **Agriculture (4):** Agricultural residue burning, diesel pumps, tractors, power tillers and threshers
Species	Aerosols and constituents: $PM_{2.5}$, BC and OC Ozone precursors and other gases: NO_X, CO, NMVOC and SO_2 Greenhouse gases: CO_2, CH_4 and N_2O
Spatial resolution	1 km × 1 km
Temporal resolution	Monthly

Combustion technologies

Sector	Sub-sector/Activities	Fuel	Combustion & Process technology	#
RESIDENTIAL	Cooking	Firewood	Traditional mud cookstove (TCS), Improved cookstove (ICS)	9
		Dungcakes		
		LPG	LPG stove	
		Kerosene	Kerosene pressure stove	
		Biogas	Biogas stove	
	Lighting	Kerosene	Kerosene wick lamp	
		Biogas	Biogas lamp	
	Water heating and boiling	Firewood	TCS	
		Kerosene	Kerosene pressure stove	
		LPG	LPG stove	
	Space heating	Firewood (In)	TCS	
		Firewood (Out)	Open burning	
		Dungcakes	Open burning	
INDUSTRY	Brick kilns	Coal, wood	Fixed Bulls' Trench Kiln, Clamps	11
	Cement production	Coal	Rotary kilns	
	Basic Iron	Furnace oil	Reheating furnace	
	Industries	Coal, wood	Furnace	
		Rice husk	Boiler	
		Diesel	Diesel generator, oil boiler	
		Furnace oil	Oil boiler	

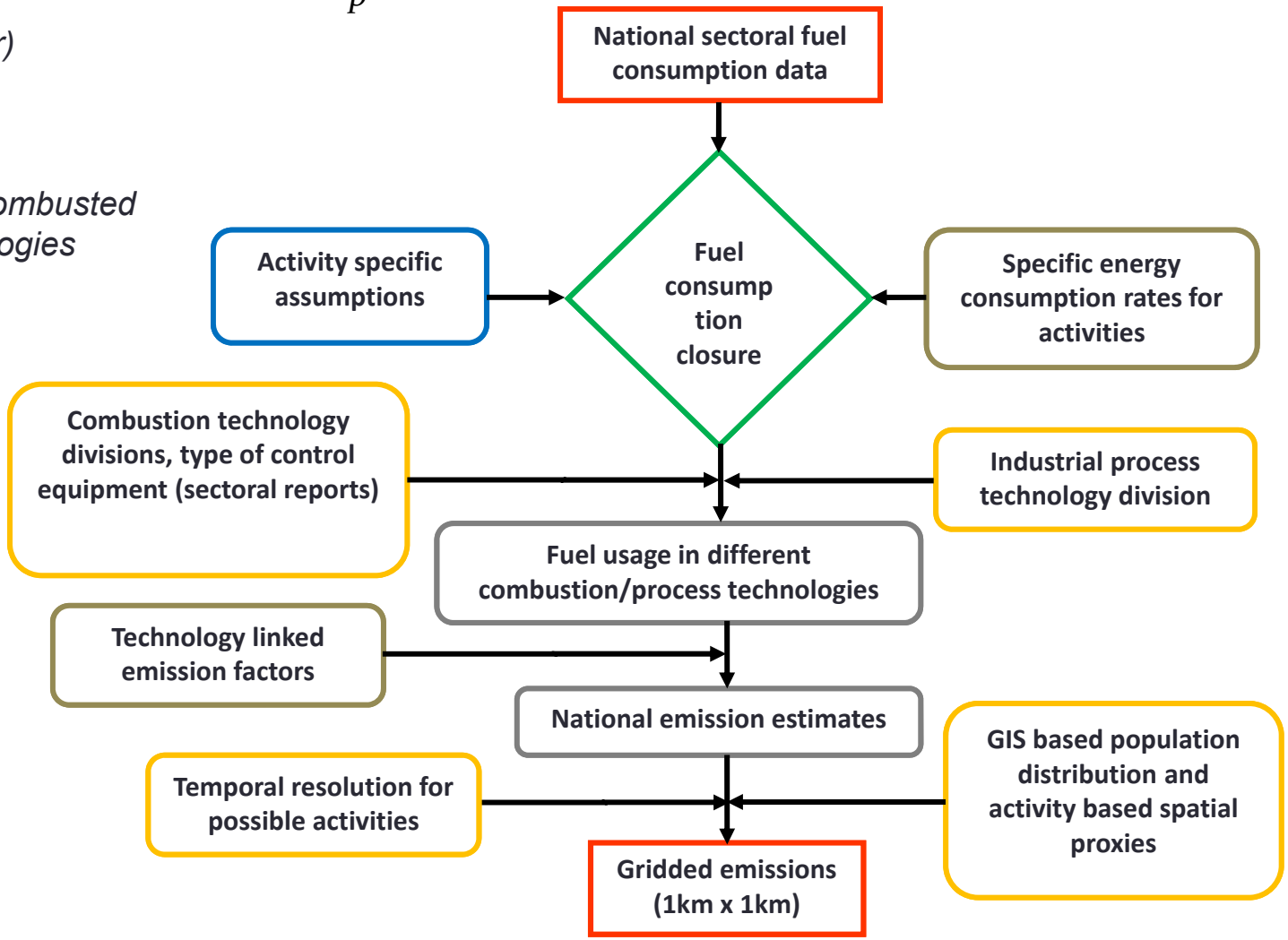
Combustion technologies

Sector	Sub-sector/Activities	Fuel	Combustion & Process technology	#
COMMERCIAL	Academic institutions, government offices, hospitals, financial institutions and other service sectors	Diesel	Diesel generator	2
	Barrack canteen, Hotel, Restaurants	Coal/Wood	Residential furnace	
		Kerosene	Kerosene pressure stove	
		LPG	LPG stove	
		Diesel	Diesel generator and oil boiler	
AGRI-CULTURE	Agricultural residue burning	Biomass	Open burning	5
	Irrigation Pumps	Diesel/Gasoline	Diesel pump/Gasoline pump	
	Tractors	Diesel	Diesel tractor	
	Power tiller	Diesel	Diesel power tillers	
	Thresher	Diesel	Diesel engines	
TRANS-PORT	Private passenger	Gasoline	Two wheeler, Cars	9
	Public passenger	Diesel	Jeep/Taxi, Microbus/Minibus, Bus	
	Public freight	Diesel	Pick-up/Mini truck, Trucks, Others	
	Off-road vehicles	Diesel	Tractors, power tillers	
	TOTAL COMBUSTION TECHNOLOGIES			**36**

Methodology for energy and emissions

$$E_{i,s} = \sum_{f,t} F_{s,f,t} \times EF_{i,s,f,t} + \sum_{p} A_{s,p} \times EF_{i,s,p}$$

E = Emissions in (Gg/yr)
i^{th} = Pollutant
s = Sector
F = Fuel consumption
f = Type of fuel being combusted
t = Combustion technologies
A = Activity
p = Process/fugitive
EF = Emission factor



Vehicular emissions methodology

$$E_i = \sum_c \sum_v \sum_{c,v} V_{c,v} \times P_c \times FE_c \times EF_{i,c,v}$$

Currently α and L_{50} from Pandey and Venkataraman, 2014. α and L_{50} *will be* estimated for Nepal case.

$V_{C,V}$ – On-road vehicle population for category *'c'* and vintage *'v'*

$V_{C,V}$ = *Sales(yy)* × *SuF(s)*

$$Su(s) = \frac{1}{1 + \exp\left[\alpha_{ret}\left(1 - s/L_{50,ret}\right)\right]}$$

[*Yan et al.,* 2011; Pandey and Venkataraman, 2014]

SuF(s) – Survival fraction = Su(s)/Su(0)

Su(s) – survival rate; α *– shape factor;*

L_{50} *– age at which 50% vehicles have retired;*

P_C – Passenger VKT ------- NEPAL Study

Modelled using the Shreejan et al., 2013 for different vehicle categories
(# vehicles survey were 700 for two wheelers, taxis, buses, vans and three wheelers)

FE_C – Fuel efficiency (km/l) ------ NEPAL Study

Compiled and averaged from literature reporting fuel efficiency for Nepal vehicles

EF_C – Emission factors (g/kg) ------- Indian Study

Currently the Indian dynamometer measured emission factors are used from Pandey and Venkataraman, 2014. For Nepal these needs to be examined and estimated.

Emission Factors

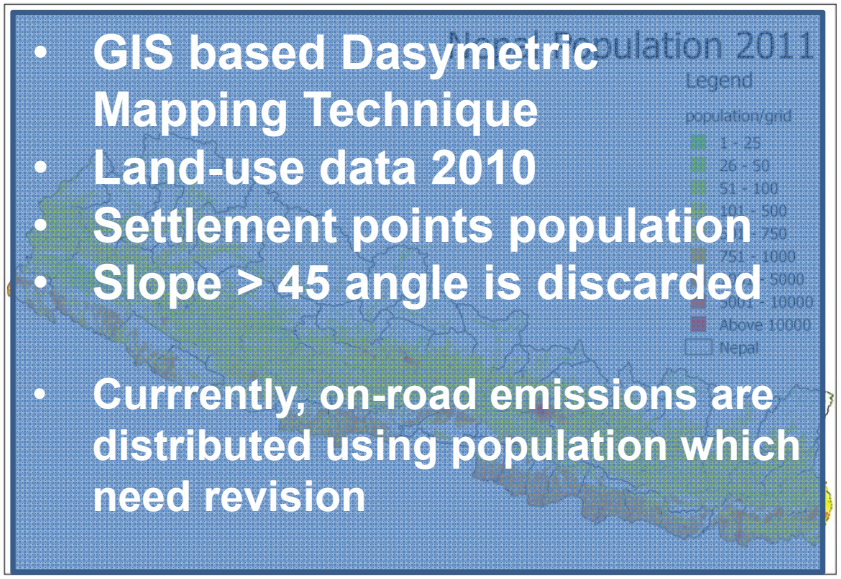
Reference	Activities/Technologies	Species
---NAMASTE Campaign--- Stockwell et al., (2016) Jayarathane et al., (2016)	-Cooking TCS (wood, dungcakes, ag.res.) -Cooking biogas stove -Cooking ICS (wood) -Open burning (dungcakes) -Brick kiln (Clamps, Zig-zag) -Diesel generators -Diesel pumps	CO_2, CH_4, NO_X, CO, NMVOC, $PM_{2.5}$, BC, OC and SO_2
Smith K., (2000) Habib et al., (2008)	-LPG stove, Kerosene stove	Gases Aerosols
Lam et al., (2012)	-Kerosene lamps	Aerosols, CO

Salient features:

- Field measured emission factors for Nepal region.
- Emission factor for cookstoves were a factor 2-5 higher for PM2.5 and OC/EC ratios were 1-2 factor high than lab measurement studies.
- SO2 emissions from fossil fuel were estimated using sulphur content of the fuel.
- N2O default emission factors from IPCC

Proxy for residential, industrial area source & transport

- GIS based Dasymetric Mapping Technique
- Land-use data 2010
- Settlement points population
- Slope > 45 angle is discarded
- Currrently, on-road emissions are distributed using population which need revision

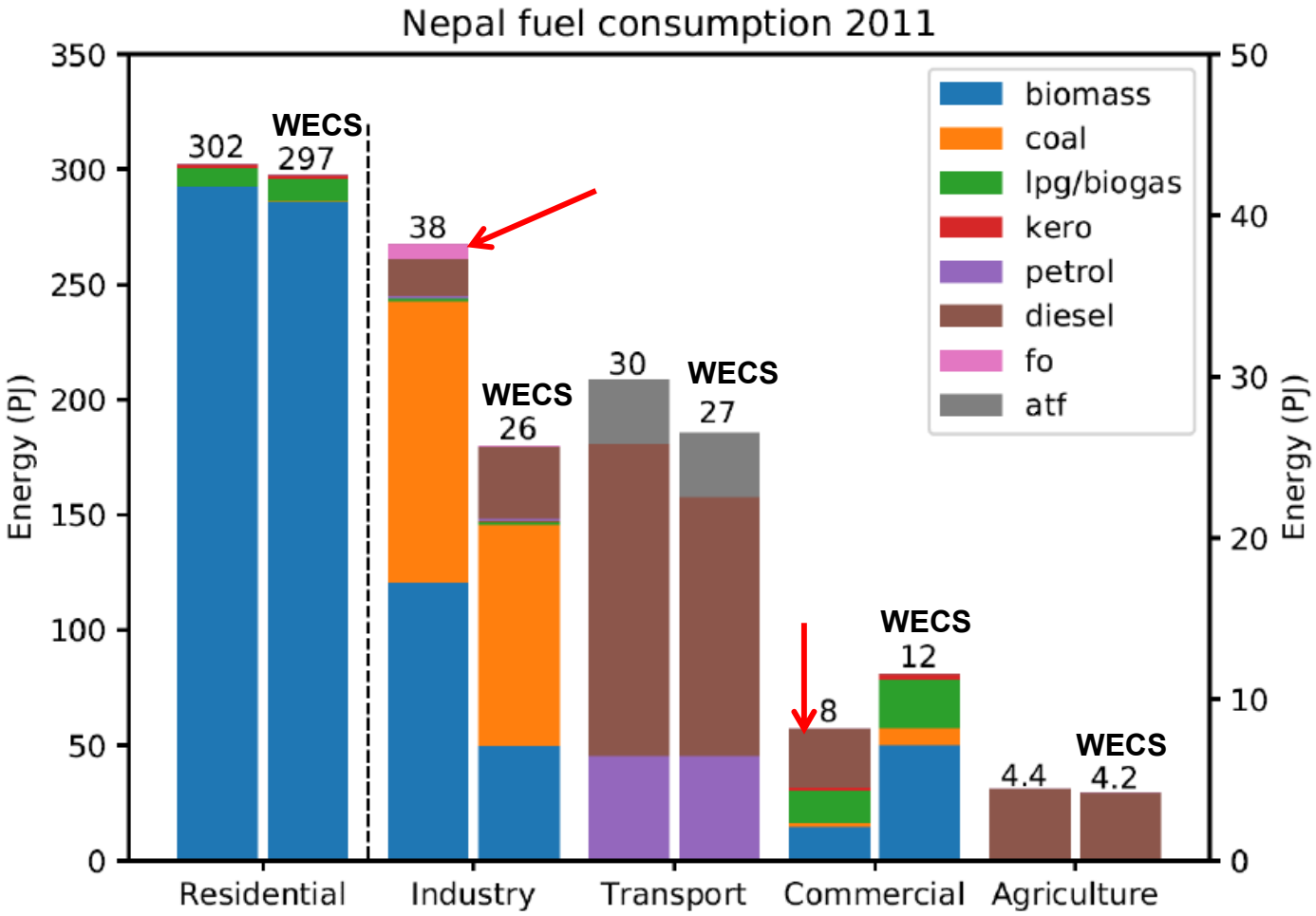


- 1512 point source out of 4076 industries
- Brick industry locations were identified using google maps (450 kilns out of 600 reported)
- Other point sources were identified using their address

- Institutional reports were used to identify the locations of tourist hotels, hospitals, banks, academic institutions while rest commercial sector was treated as area source

- Land use land cover for distributing emissions from agricultural residue burning, pumps, tractors, power tillers

National Energy consumption for 2011



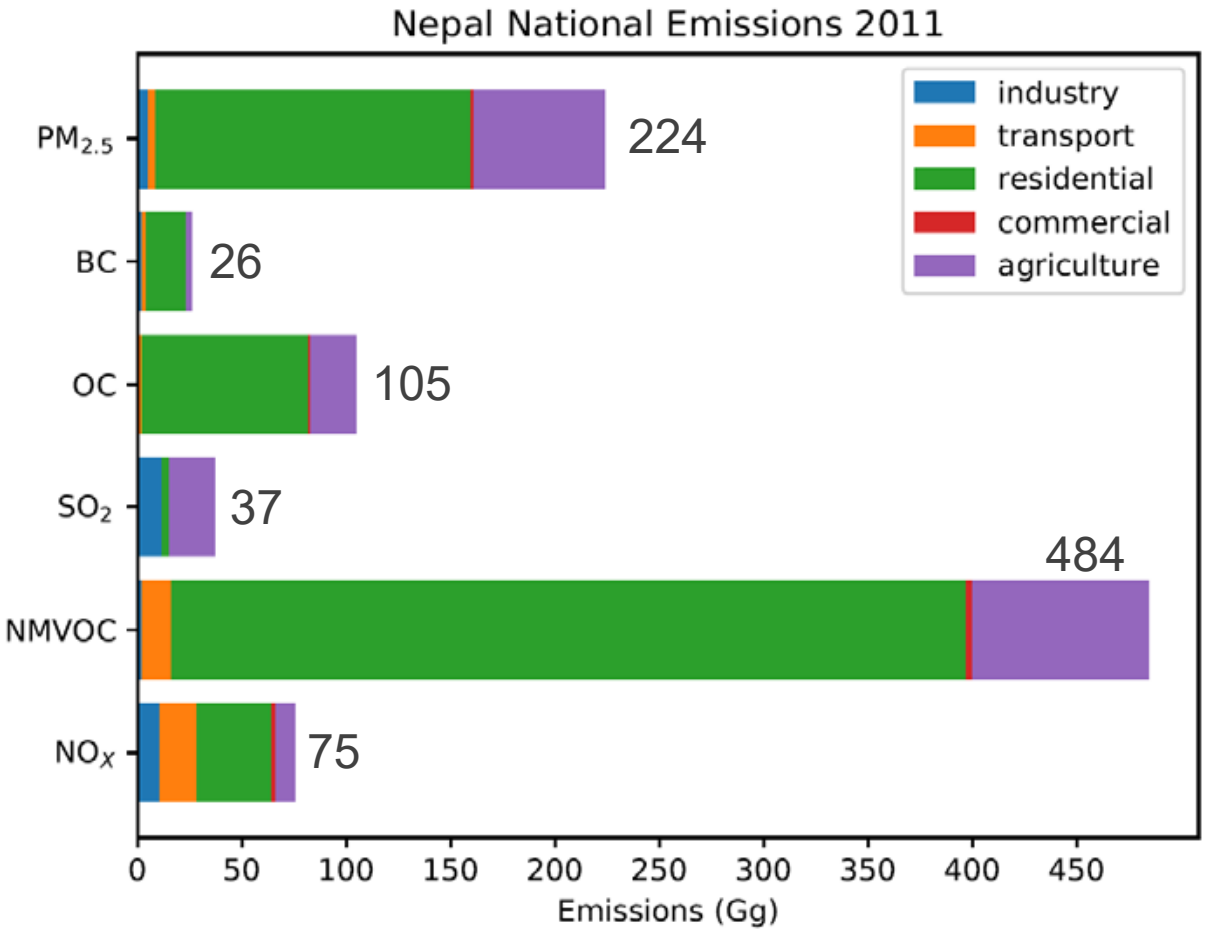
Residential sector is the highest consumer of energy 78.9%, followed by industry 10%, transport 7.8%. Biomass attribute to 81.6% while 18.4% from imported fossil fuel.

Industry: Fuel consumption like coal, ricehusk and furnace oil in point sources like brick, cement industries, sugar, paper have been corrected using the specific fuel consumption for Nepal. Furnace oil accounted using the trade statistics.

Commercial: Use of diesel in DG sets was corrected based on the electricity demand.

Ag. Diesel estimates were in agreement with WECS.

National emissions for 2011 and comparison

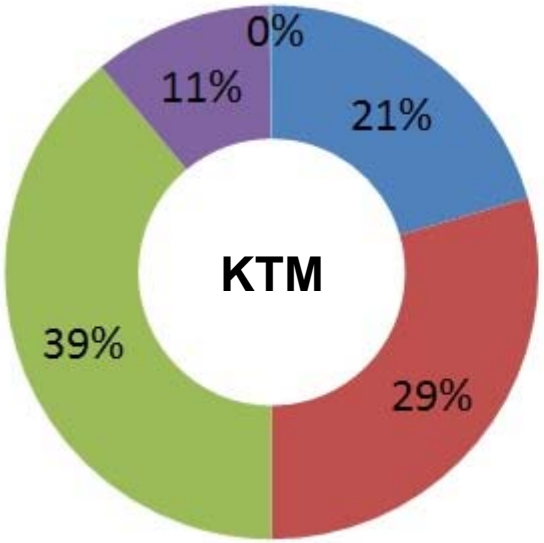


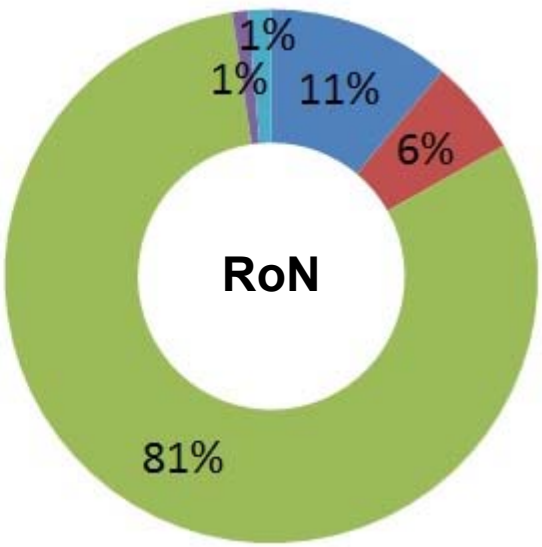
- Cooking emit around 45% to 55% of total emissions for all species except NO_X & SO_2.
- Water heating 7-10% and Space heating 12-15%
- In agriculture sector mainly crop residue burning emit >90%, while 10% from diesel use in pumps, tractors/tillers.
- High SO_2 emissions from ag.residue and coal use in bricks and cement industry.
- NMVOC emission from transport also includes running evaporates.
- Industries (cement) and transport (diesel passenger) also contribute significantly to NOX emissions (42%).

Emission in Gg except CO2. Tg

	CO2	CH4	N2O	NOx	CO	NMVOC	PM2.5	BC	OC	SO2
MIX HTAP	34.0	90.0	1.5	83.0	2109.0	376.7	139.0	27.0	105.0	30.0
This Study	35.0	107.7	2.1	67.9	1514.9	400.5	161.7	23.6	83.0	15.6

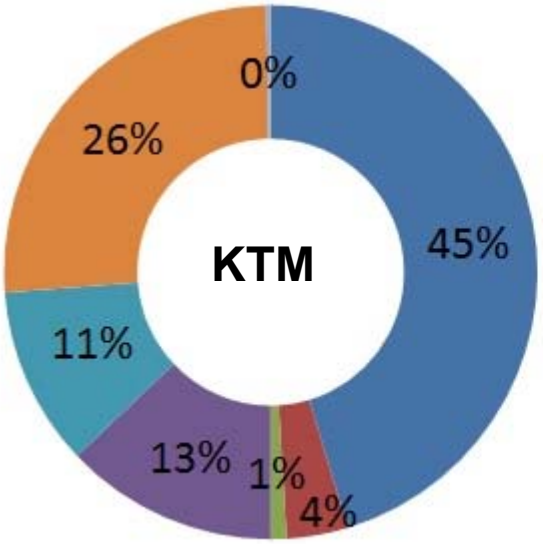
Emissions comparison Kathmandu and RoN

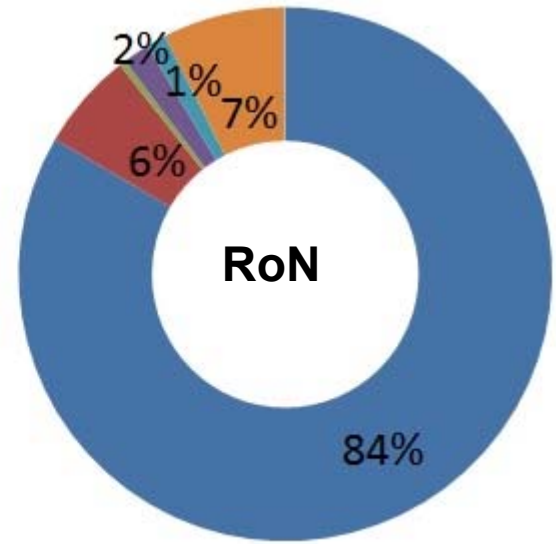




Emission	SO2
Kathmand	1.1
Rest of Ne	14

Ra





Sectors/sub										SO2
Brick produc										0.08
Industry poi										0.04
Industry are										0.59
Cooking										0.01
Lighting										0.07
Space heatir										0.03
Water heati										0.09
Commercial										0.65
Ag. diesel pu										0.00
Ag. diesel tr										0.01
Gasoline Vel										1.07
Diesel Vehic										0.44
Diesel Vehicles (Freight)	0.49	0.42	0.45	0.51	0.45	0.47	0.45	0.45	0.45	0.45

Renewable energy programmes and implications

Alternative Energy and Promotion Centre (AEPC)
Centre for Rural Technology, Nepal (CRT/N)

Renewable Energy Technologies (RET)

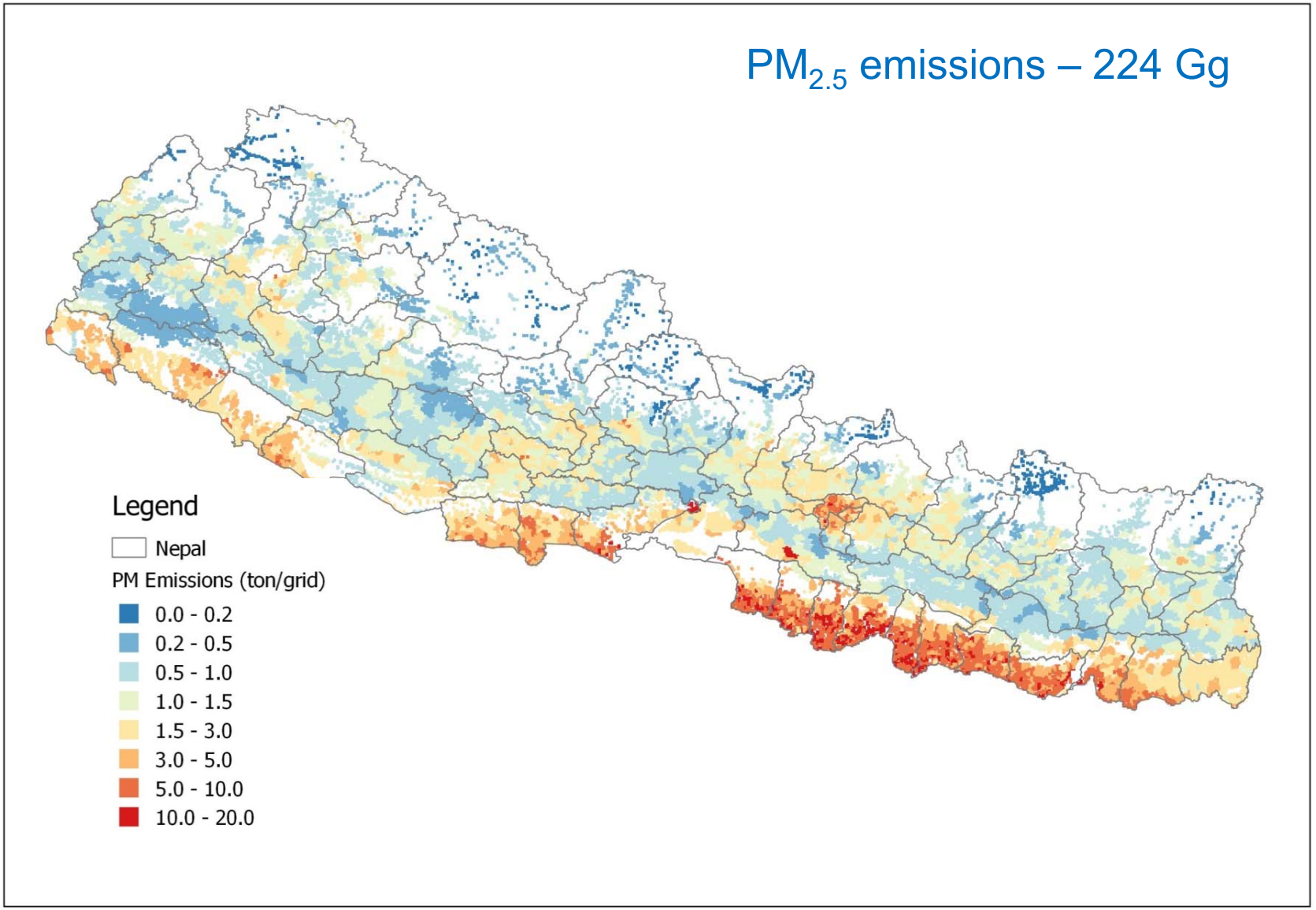
1	Mini/Micro/Pico Hydro including Improved Water Mills
2	Solar Photovpltaic and Solar Termal
3	Biogas
4	Biomass Energy including IM-ICS
5	Wind Energy
6	Biofuel
7	Energy Efficiency

0.3 Million ICS were disseminated till 2011/12

$PM_{2.5}$: -16%
BC: -13%
OC: -16%
NMVOC: -17%

Reduction in emissions from cooking

$PM_{2.5}$ Emissions for 2011 (unit: ton/grid)



Conclusion and future work

- ***Conclusion:***
  - An attempt has been made to compile all the scattered information on activities to estimate energy
  - Detailed energy and emissions from all the possible activities have been considered in this work including the energy efficiency programmes
  - Emissions were estimated using recent on-field measured emission factors
  - Spatial variability of emissions has been improved using sub-sector and activity based proxies.

- ***Future work:***
  - Uncertainty estimates
  - Improvement in spatial distribution of transport emissions
  - Trend estimates
  - Model read files
  - Decision support tool in the approach to improve the air quality