Nepal Emission Inventory (NEEMI): a high resolution technology-based bottom-up emissions inventory for Nepal 2001-2016

Pankaj Sadavarte*[a], Maheswar Rupakheti*[a], Prakash V. Bhave[b], Kiran Shakya[b], Mark G. Lawrence[a]

[a]Institute for Advanced Sustainability Studies (IASS), Berliner Str. 130, 14467 Potsdam, Germany
[b]International Centre for Integrated Mountain Development (ICIMOD), Lalitpur, Nepal

Supplementary Information

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Table S1. Crop types for agricultural residue burning

Cereals	Pulses	Oilseeds	Fibrecrops	Sugarcane
• Rice • Maize • Millet • Wheat • Barley • Buckwheat	• Gram • Tur • Others	• Groundnut • Soyabean • Others	• Jute • Cotton	• Sugarcane

Table S2. Emission factors for residential sector (g/kg fuel)

Activities	**Fuel**	**CO_2**	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**$PM_{2.5}$**	**BC**	**OC**	**SO_2**
Cooking/W.heating											
Traditional cookstove[k]	Wood	1462.42[a]	5.16[a]	0.09[i]	1.53[a]	77.24[a]	22.86[a]	7.97[b]	1.11[b]	3.16[b,m,g,n]	0.08[f]
Improved cookstove	Wood	1608.67[a]	0.54[a]		1.69[a]	20.03[a]	2.03[a]	1.97[l]	0.32[a]	1.08[l]	0.08[f]
Kerosene stove[k]	Kerosene	2985.00[h]	0.68[h]	0.09[h]		39.88[h]	17.03[h]	0.61[g,h]	0.17[g]	0.33[g]	0.02[d]
LPG stove[k]	LPG	3085.00[h]	0.05[h]	0.15[h]		14.90[h]	18.80[h]	0.32[g,h]	0.01[g]	0.05[g]	0.01[j]
Traditional cookstove	Dungcake	1129.30[a]	6.65[a]	0.31[h]	2.17[a]	80.87[a]	33.20[a]	15.93[b,m]	0.75[b]	6.15[b,m,g,h,i,o]	0.88[f]
Biogas stove	Biogas	2736.49[a]	2.54[a]	0.10[h]	1.70[a]	2.54[a]	1.12[a]	0.53[h]	0.02[e]	0.09[e]	0.01[j]
Traditional cookstove	Ag.residue	1302.00[h]	7.58[h]	0.05[h]	2.43[a]	133.56 [m]	8.49[h]	13.99[m]	1.20[m]	6.85[m]	0.16[f]
Lighting											
Kerosene lamps	Kerosene	2770.00[c]	0.68[h]	0.08[c]		11.00[c]	17.03[h]	93.00[c]	90.00[c]	0.52[c]	0.02[c]
Biogas lamps	Biogas	2736.49[a]	2.54[a]	0.10[h]	1.70[a]	2.54[a]	1.12[a]	0.53[h]	0.02[e]	0.09[e]	0.01[j]
Space heating											
Open burning	Wood	1462.42[a]	5.16[a]	0.09[i]	1.53[a]	77.24[a]	22.86[a]	7.97[b]	1.11[b]	3.16[b,m,g,n]	0.08[f]
Open burning	Dungcake	1073.63[a]	6.55[a]	0.31[h]	2.34[a]	96.58[a]	33.20[a]	20.00[b]	0.09[b]	12.98[b]	0.88[f]

[a]Stockwell et al., 2016; [b]Jayarathne et al., 2017; [c]Lam et al., 2012; [d]Zhang et al, 2000; [e]For biogas, BC/PM and OC/PM assumed same as LPG; [f]Habib et al., 2004; [g]Habib et al., 2008; [h]Smith et al, 2000; [i]MacCarty et al, 2008; [j]SO_2 based on sulfur content of the fuel; [k]Combustion technologies also considered for water heating stove-fuel; [l]Jaiprakash et al., 2016; [m]Pandey et al., 2016,[n]Saud et al., 2012,[O]Roden et al., 2009

Table S3. Emission factors for industrial combustion technologies (g/kg fuel)

Combustion technology	Fuel	CO_2	CH_4	N_2O	NO_X	CO	NMVOC	$PM_{2.5}$	BC	OC	SO_2
FC boiler	Coal	2376[h]	0.03[a]	1.75[a]	2.50[a]	9.00[a]	0.03[a]	1.90[a]	0.38[d]	0.08[d]	8.22[a]
Cement kiln	Clinker	900[j]			2.10[j]	1.80[j]	0.059[j]	0.04[j]			0.54[j]
Hand fed Furnace	Coal	2376[h]	2.50[a]	0.02[a]	4.55[a]	137.50[a]	5.00[a]	1.90[a]	0.95[d]	0.76[d]	8.22[a]
Furnace	Wood	1404.33[b]	0.15[b]	0.09[b]	3.53[b]	4.32[b]	0.12[b]	2.23[b]	0.11[d]	0.45[d]	0.18[b]
Furnace	Ricehusk	1404.33[b]	0.15[b]	0.09[b]	3.53[b]	4.32[b]	0.12[b]	2.23[b]	0.11[d]	0.45[d]	0.18[b]
Oil boiler	Diesel	3186.30[h]	0.031[c]	0.03[i]	2.89[c]	0.72[c]	0.05[c]	0.12[c]	0.03[d]	0.02[d]	0.68[e]
Oil boiler	Furnace oil	3126.96[h]	0.129[c]	0.06[i]	7.10[c]	0.65[c]	0.04[c]	1.88	0.55[d]	0.25[d]	80.00[e]
Furnace	Furnace oil	3126.96[h]	0.129[c]	0.06[i]	7.10[c]	0.65[c]	0.04[c]	1.88	0.55[d]	0.25[d]	80.00[e]
Gas furnace	LPG	3085.00[f]	0.05[f]	0.15[f]		14.90[f]	18.80[f]	0.32[g]	0.01[g]	0.05[g]	0.01[e]
Oil boiler	Gasoline	3186.30[h]	0.031[c]	0.03[i]	2.89[c]	0.72[c]	0.05[c]	0.12[c]	0.03[d]	0.02[d]	0.68[e]

[a]Coal Combustion emission factors, from AP42

[b]Wood Combustion emission factors, Table 1.6-1, Table 1.6-2, Table 1.6-3 from AP42

[c]Fuel Oil Combustion emission factors, Table 1.3-7 from AP42

[d]Fraction of BC and OC from Bond et al., 2004

[e]SO_2 based on sulfur content and 22.5% retention

[f]Smith et al, 2000

[g]Habib et al, 2008; Smith et al, 2000

[h]Default based on carbon content, IPCC 2006

[i]Default based on net calorific value (NCV), IPCC 2006

[j]Process based emission factors from AP42

Table S4. Emission factors for brick production (g/kg fuel)

	Kiln technologies	CO_2	CH_4	N_2O[d]	NO_X	CO	NMVOC	$PM_{2.5}$[a]	BC	OC[a]	SO_2
COAL + FW	Fixed BTK	2123[a]	2.34[e]	0.017	0.64[e]	36.50[a]	1.83[e]	4.40	3.70[a]	0.15	15.5[f]
	Moving BTK	2123[a]	2.34[e]	0.017	0.64[e]	36.50[a]	1.83[e]	4.40	3.70[a]	0.15	15.5[f]
	Zig-zag kiln	2179[c]	2.34[b]	0.017	0.64[b]	10.68[c]	1.83[b]	2.33	0.23[c]	0.33[g]	12.70[b]
	Clamps	1858[c]	19.50[b]	0.017	0.30[b]	74.75[c]	31.21[b]	3.00	0.56[c]	3.57[g]	13.00[b]
	VSBK	1355[a]	2.34[e]	0.017	0.64[e]	44.50[a]	1.83[e]	1.30	0.04[a]	0.35	15.5[f]
COAL	Fixed BTK	2280[a]	2.34[e]	0.017	0.64[e]	40.10[a]	1.83[e]	2.70	2.25[a]	0.11	15.5[f]
	Moving BTK	2280[a]	2.34[e]	0.017	0.64[e]	40.10[a]	1.83[e]	2.70	2.25[a]	0.11	15.5[f]
	Zig-zag kiln	1959[a]	2.34[b]	0.017	0.64[b]	24.63[a]	1.83[b]	2.80	0.22[a]	0.17	12.7[b]
	Clamps	1858[c]	19.50[b]	0.017	0.30[b]	74.75[c]	31.21[b]	3.00	0.56[c]	3.57[g]	13.00[b]
	VSBK	1355[a]	2.34[e]	0.017	0.64[e]	44.50[a]	1.83[e]	1.30	0.04[a]	0.35	15.5[f]
FW	Clamps	1858[c]	19.50[b]	0.017	0.30[b]	74.75[c]	31.21[b]	3.00	0.56[c]	3.57[g]	13.00[b]

[a]Weyant et al., 2014
[b]Stockwell et al., 2016
[c]Emfacs averaged from Weyant et al., 2014 and Stockwell et al., 2016
[d]Emfac's equivalent to coal stokers (AP42)
[e]Assumed similar to zig-zag kiln
[f]SO_2 emfac based on coal sulfur content and 22.5% retention
[g]Emfacs averaged from Weyant et al., 2014 and Jayarathane et al., 2017

Table S5. Emission factors for power station and irrigation pump (g/kg fuel)

	CO_2[a]	CH_4[a]	N_2O[e]	NO_X[a]	CO	NMVOC[a]	$PM_{2.5}$[b]	BC[b]	OC[b]	SO_2[d]
Genset (Diesel & FO)	3101.65	0.27	0.03	23.60	28.31[c]	2.62	9.17	0.58	7.31	0.68
Irrigation Pumps (Diesel)	3132.00	2.61	0.03	12.29	16.70[a]	5.91	7.12	0.24	5.48	0.68

[a]Stockwell et al., 2016
[b]Jayarathne et al., 2017
[c]Average Stockwell 2016 and Shah 2006
[d]SO_2 based on sulfur content of the fuel with no retention
[e]IPCC 2006

Table S6. Emission factors for agricultural residue burning sector (g/kg crop residue)

Species	CO_2	CH_4	N_2O	NOx	CO	NMVOC	$PM_{2.5}$	BC	OC	SO_2
Rice straw	1474.35[f]	1.21[f]	0.07	0.99[f]	31.43[f]	11.07[c,e]	8.28[e]	0.33[f]	2.87[a,b,e]	2.83[f]
Cereals res.	1440.39[f]	1.98[f]	0.07	2.27[f]	51.07[f]	11.07[c,e]	8.28[e]	0.59[f]	2.87[a,b,e]	2.29[f]
Pulses res.	1458.24[c,f]	2.74[c,f]	0.07	2.43[c,f]	82.17[c,f]	15.70[c]	8.71[a]	0.77[a,f]	5.43[a]	1.47[c,f]
Oilseed res.	1454.78[c,f]	2.83[c,f]	0.07	2.35[c,f]	84.49[c,f]	15.70[c]	4.64[a]	1.18[a,f]	1.73[a]	2.29[c,f]
Fibre crop res.	1415.84[b,c,f]	2.74[c,f]	0.07	2.42[b,c,f]	85.62[b,c,f]	15.70[c]	12.77[a]	0.78[a,b,f]	9.12[a,b]	1.47[c,f]
Sugarcane res.	1515.00[c,f]	2.70[c,f]	0.00	2.50[c,f]	92.00[c,f]	15.70[c]	3.92[a]	0.60[a,f]	1.50[a]	0.40[c,f]

[a]Turn et al., 1997, calculated as geometric mean of emission factors reported for cereals and sugarcane

[b]Cao et al., 2008, Emission Factor for field crop residue burnings from China for Rice straw, Wheat straw, corn stover and cotton stalk

[c]Andrae and Merlet, 2001

[d]Kim Oanh et al. Emission factors from 2010

[e]Li et al., Emission factors for wheat straw and corn stover in China

[f]Stockwell et al., 2016

Table S7. Emission factors for transport sector (g/kg fuel)

Vehicle type	Fuel	CO_2	CH_4	N_2O	NO_X	CO	NMVOC	$PM_{2.5}$	BC	OC	SO_2[d]
2-Wheeler	Gasoline	1831[a]	7.17[a]	0.15[e]	2.42[a]	735.5[a]	111.13[b]	4.76[a]	0.21[a]	3.89[a]	0.10
Cars	Gasoline	1820[g]	15.03[b]	0.14[b]	27.62[b]	623.92[b]	73.57[b]	0.29[b]	0.10[c]	0.10[c]	0.10
Cars/Jeeps/Van	Diesel	1746[g]	0.13[f]	0.02[b]	43.00[e]	38.00[e]	9.00[e]	5.38[e]	3.55[c]	1.13[c]	0.10
Micro/Minibus	Diesel	1875[g]	0.59[f]	0.02[b]	15.94[b]	14.14[b]	2.01[b]	3.71[b]	2.45[c]	0.78[c]	0.10
Bus	Diesel	3467[g]	0.02[f]	0.23[b]	55.00[e]	56.66[b]	14.25[b]	1.49[e]	0.98[c]	0.31[c]	0.10
MiniTruck/PickUp	Diesel	2045[g]	0.65[f]	0.02[b]	17.39[b]	15.42[b]	2.20[b]	4.04[b]	2.67[c]	0.85[c]	0.10
Truck	Diesel	3291[g]	0.12[f]	0.21[b]	43.00[e]	50.57[b]	12.71[b]	6.00[e]	3.96[c]	1.26[c]	0.10
Tractor/Tiller	Diesel	2045[g]	0.65[f]	0.02[b]	17.39[b]	15.42[b]	2.20[b]	4.04[b]	2.67[c]	0.85[c]	0.10
Superemitter	Gasoline							2[c]	0.68[c]	0.72[c]	
	Diesel							10[c]	6.6[c]	2.1[c]	

[a]Stockwell et al., 2016 and Jayarathane et al., 2017

[b]Shrestha et al., 2011

[c]BC and OC fraction | Super-emitter fraction | Bond et al., 2004

[d]SO_2 based on sulfur content of the fuel and zero retention

[e]Pandey et al., 2014, MOBILE based emission factors modelled for Indian vehicles

[f]Using CH4:CO2 emission factor ratio from Sadavarte and Venkataraman, 2014 and Automotive Research Association of India (ARAI), 2008

[g]Automotive Research Association of India (ARAI), 2008

Table S8. Energy consumption across different sectors (TJ/yr)

Fuel type (2001)	Residential	Industry	Transport	Commercial	Agriculture	Total
Biomass						
Fuelwood	174064	2544		1934		178542
Dungcake	15458					15458
Agr.res/ricehusk	42109	6276				48385
Biogas	556					556
Fossil fuel						
Coal		14478		47		14525
Diesel		1244	7817	315	1932	11308
Petrol		68	2150			2218
Kerosene	8384	390		989		9763
LPG	1978	17		308		2303
Furnace oil		580				580
Aviation fuel			1718			1718
Total	**242550**	**25598**	**11685**	**3593**	**1932**	**285357**

Fuel type (2005)	Residential	Industry	Transport	Commercial	Agriculture	Total
Biomass						
Fuelwood	193394	2532		2164		198090
Dungcake	17271					17271
Agr.res/ricehusk	45532	6055				51587
Biogas	703					703
Fossil fuel						
Coal		14067		80		14147
Diesel		1162	9489	316	2061	13027
Petrol		49	2986			3035
Kerosene	3922	92		568		4582
LPG	3205	33		509		3747
Furnace oil		785				785
Aviation fuel			2403			2403
Total	**264028**	**24775**	**14877**	**3637**	**2061**	**309378**

Fuel type (2011)	Residential	Industry	Transport	Commercial	Agriculture	Total
Biomass						
Fuelwood	223885	8018		1983		233886
Dungcake	20642					20642
Agr.res/ricehusk	46036	8650				54686
Biogas	913					913
Fossil fuel						
Coal		20643		152		20795
Diesel		2264	14374	4887	3738	25262
Petrol		85	6630			6715
Kerosene	1193	34		115		1342
LPG	6982	212		1271		8465
Furnace oil		937				937
Aviation fuel			3995			3995
Total	**299651**	**40843**	**24998**	**8408**	**3738**	**377638**

Fuel type (2016)	Residential	Industry	Transport	Commercial	Agriculture	Total
Biomass						
Fuelwood	244690	27481		1881		274052
Dungcake	20232					20232
Agr.res/ricehusk	44239	12431				56670
Biogas	1329					1329
Fossil fuel						
Coal		30505		167		30673
Diesel		4641	31906	2493	5258	44298
Petrol		166	13192			13358
Kerosene	514	35		44		594
LPG	10624	2407		1792		14823
Furnace oil		1052				1052
Aviation fuel			5991			5991
Total	**321628**	**78719**	**51089**	**6378**	**5258**	**463072**

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Table S9. Comparing sectoral emissions from NEEMI and REAS for 2008 (All units in tons/yr except CO_2 in kT/yr)

REAS 2008	CO_2	CH_4	N_2O	NO_X	CO	NMVOC	$PM_{2.5}$	BC	OC	SO_2
Industry	1598	0.96	0.03	3.65	73.7	2.78	5.98	0.35	1.03	6.13
	(4.8)	(1)	(2.1)	(4.5)	(3.5)	(0.7)	(4.4)	(1.3)	(1)	(20.6)
Transport	938	0.14	0.05	12.08	29.29	13.09	1.49	0.36	0.37	3.45
	(2.8)	(0.1)	(3.2)	(15.2)	(1.4)	(3.5)	(1.1)	(1.4)	(0.3)	(11.6)
Residential	29776	85.69	1.39	62.72	1957.93	347.26	126.38	24.94	100.27	18.8
	(90.2)	(97.9)	(93.7)	(78.8)	(94.1)	(94.8)	(93.7)	(96.5)	(97.9)	(63.3)
Commercial	473	0.66	0.01	0.83	17.79	2.54	0.94	0.17	0.7	0.24
	(1.4)	(0.7)	(0.7)	(1)	(0.8)	(0.6)	(0.7)	(0.6)	(0.6)	(0.8)
Agriculture	221	0.03	0	0.2	1.45	0.59	0.06	0	0	1.03
	(0.6)	(0)	(0.1)	(0.2)	(0)	(0.1)	(0)	(0)	(0)	(3.5)

NEEMI 2008	CO_2	CH_4	N_2O	NO_X	CO	NMVOC	$PM_{2.5}$	BC	OC	SO_2
Industry	3766	1.57	0.08	7.77	30.27	1.8	4.08	1.83	0.63	9.27
	(12.2)	(1.5)	(3.8)	(14.7)	(1.9)	(0.5)	(2.3)	(7.9)	(0.7)	(73.3)
Transport	782	1.01	0.05	9.92	69.37	10.98	1.57	0.89	0.47	0.17
	(2.5)	(1.0)	(2.4)	(18.7)	(4.3)	(2.7)	(0.9)	(3.8)	(0.5)	(1.4)
Residential	25676	101.99	1.82	31.95	1501.19	367.8	178.76	20.43	76.58	3.07
	(83.0)	(97.0)	(92.7)	(60.3)	(93.1)	(96.0)	(95.8)	(87.4)	(97.6)	(24.3)
Commercial	520	0.52	0.01	2.07	10.31	2.77	1.54	0.15	0.79	0.09
	(1.7)	(0.5)	(0.9)	(3.9)	(0.6)	(0.7)	(0.9)	(0.7)	(1.0)	(0.7)
Agriculture	183	0.10	0.00	1.26	1	0.33	0.33	0.07	0.21	0.04
	(0.6)	(0.1)	(0.1)	(2.4)	(0.1)	(0.1)	(0.2)	(0.3)	(0.2)	(0.3)

Parenthesis shows sectoral contribution in % to national emissions.

Table S10. Comparing Kathmandu Valley emissions for 2011 and 2016 (All units in tons/yr)

	CO_2	CH_4	N_2O	NOx	CO	NMVOC	$PM_{2.5}$	BC	OC	SO_2
2011	2170294	4005	117	8088	103641	21719	7019	1363	2695	933
2016	3421641	4430	247	16379	155234	28881	8292	1956	2865	2026
2016/2011	1.58	1.11	2.10	2.03	1.50	1.33	1.18	1.43	1.06	2.17

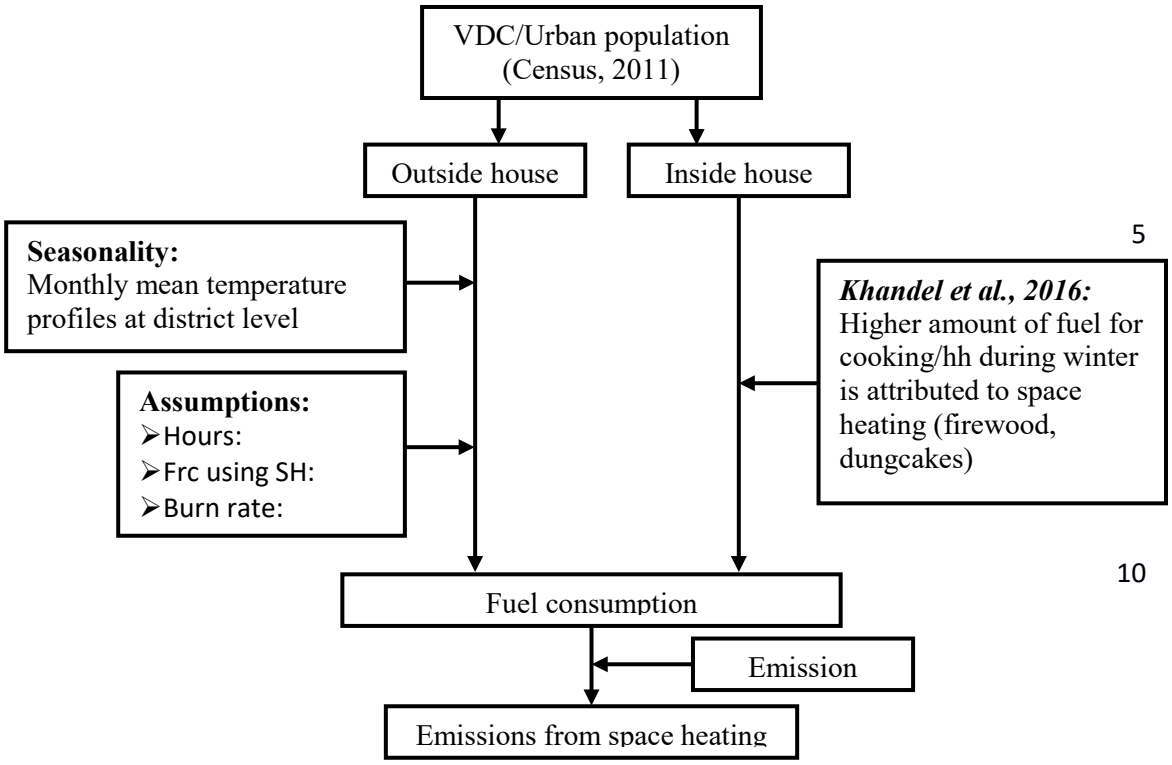

Figure S1. Flowsheet for space heating

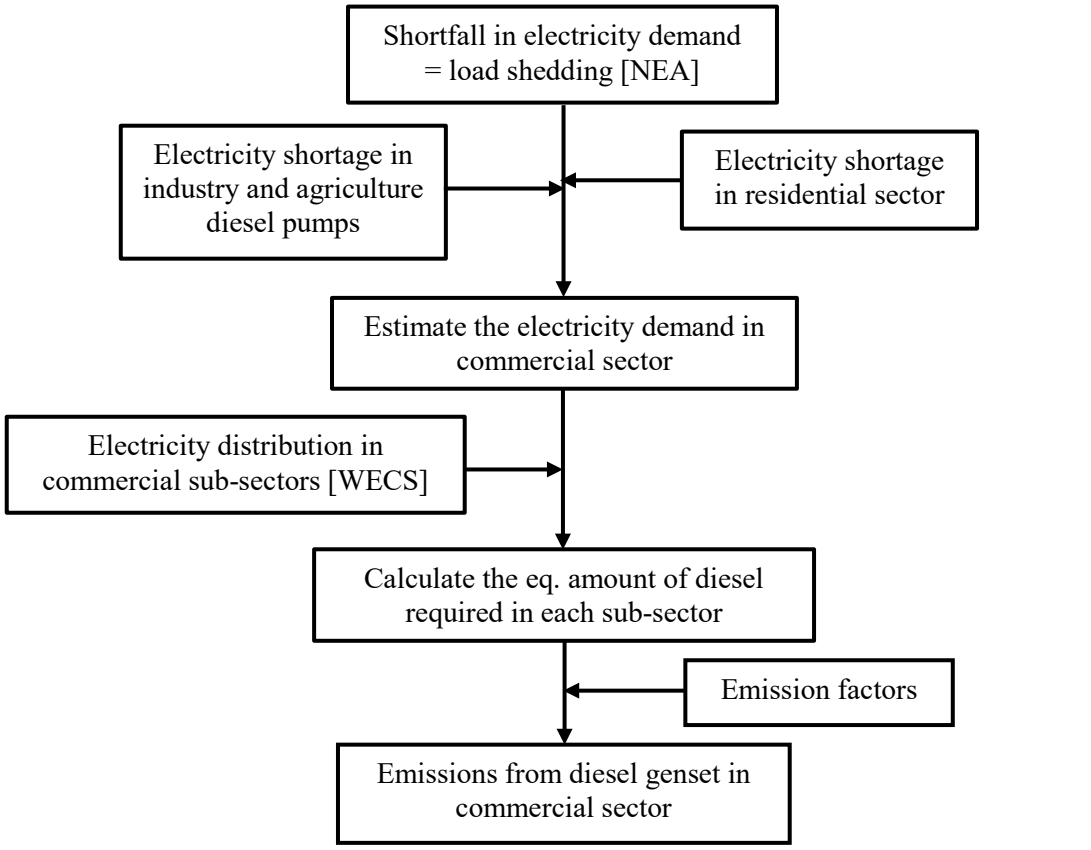

Figure S2. Flowsheet for diesel generator set

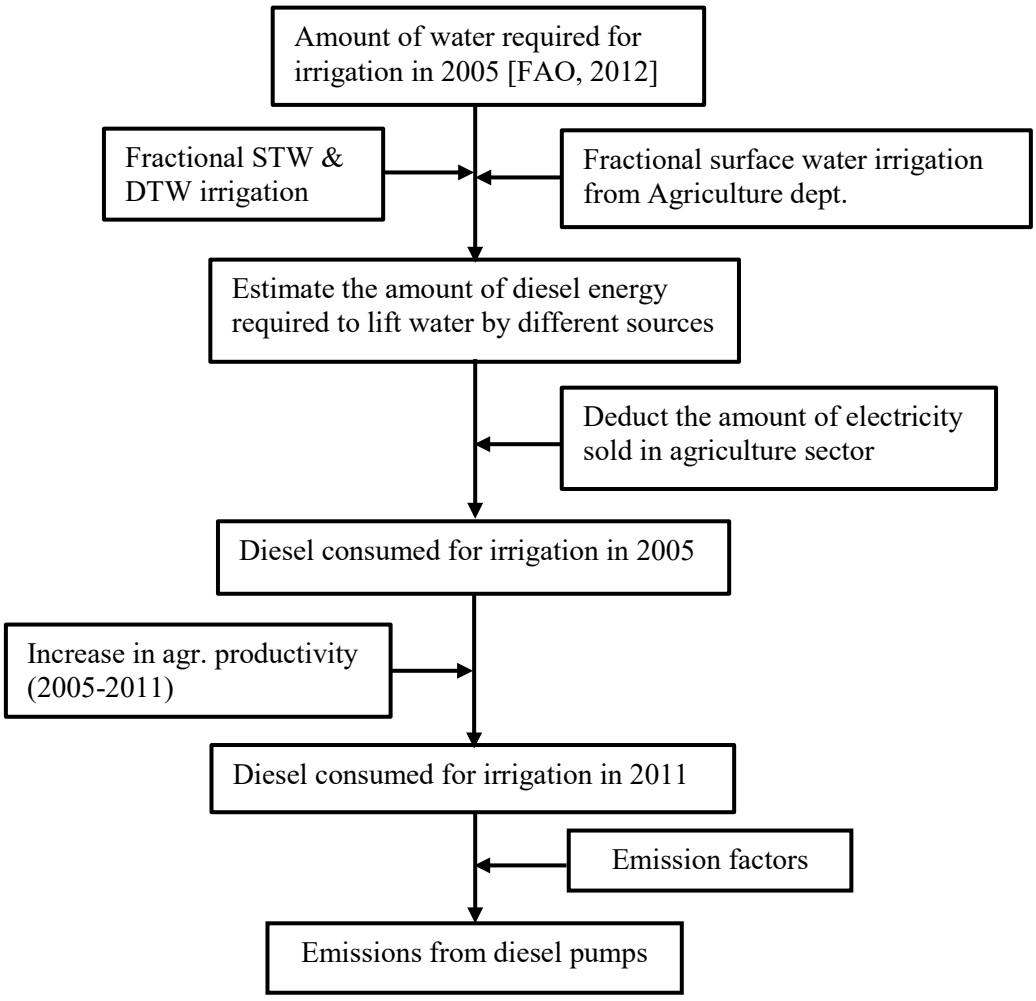

Figure S3. Flowsheet for diesel irrigation pump

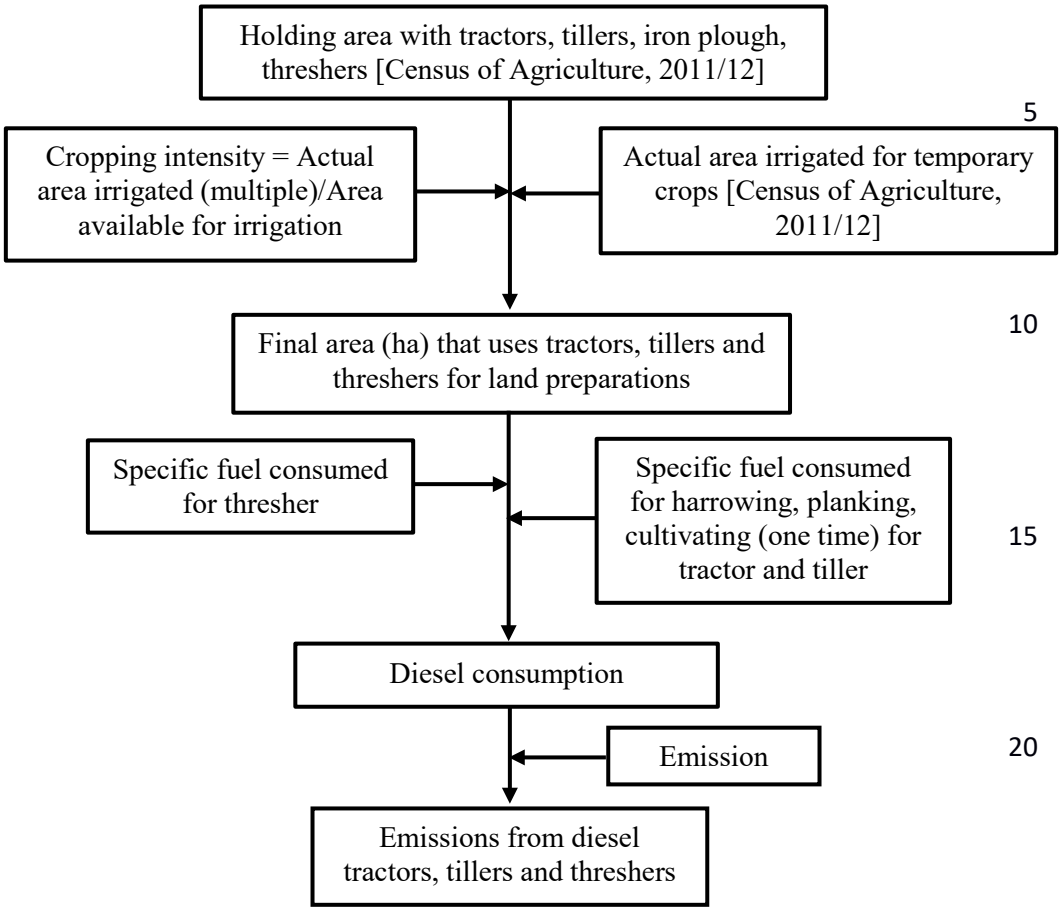

Figure S4. Flowsheet for diesel tractors, tillers and threshers

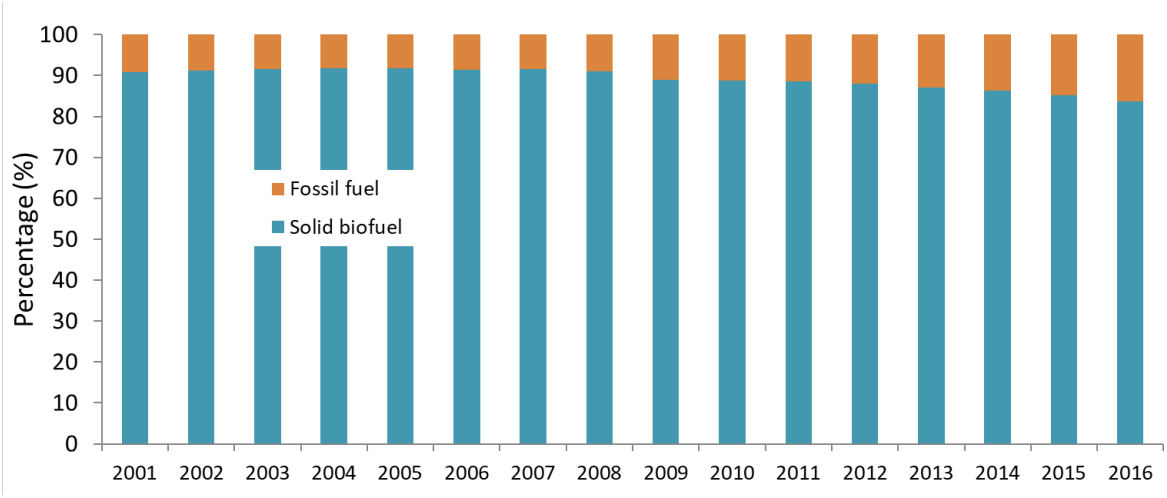

Figure S5. Fraction of national energy contributed by fossil fuel and solid biofuel.

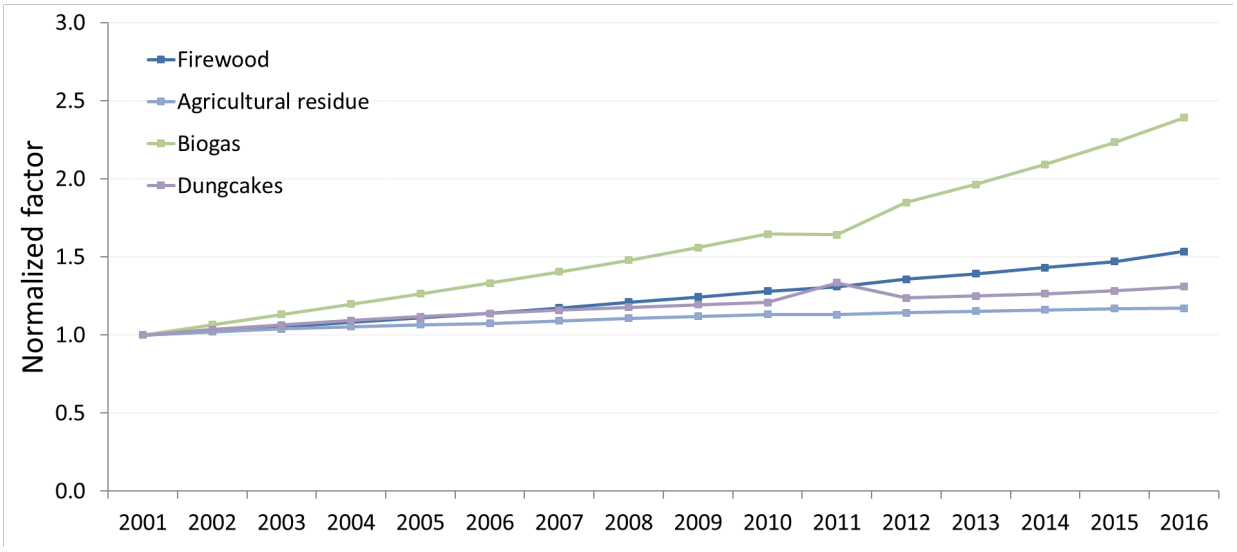

Figure S6. National biomass consumption normalized with respect to year 2001

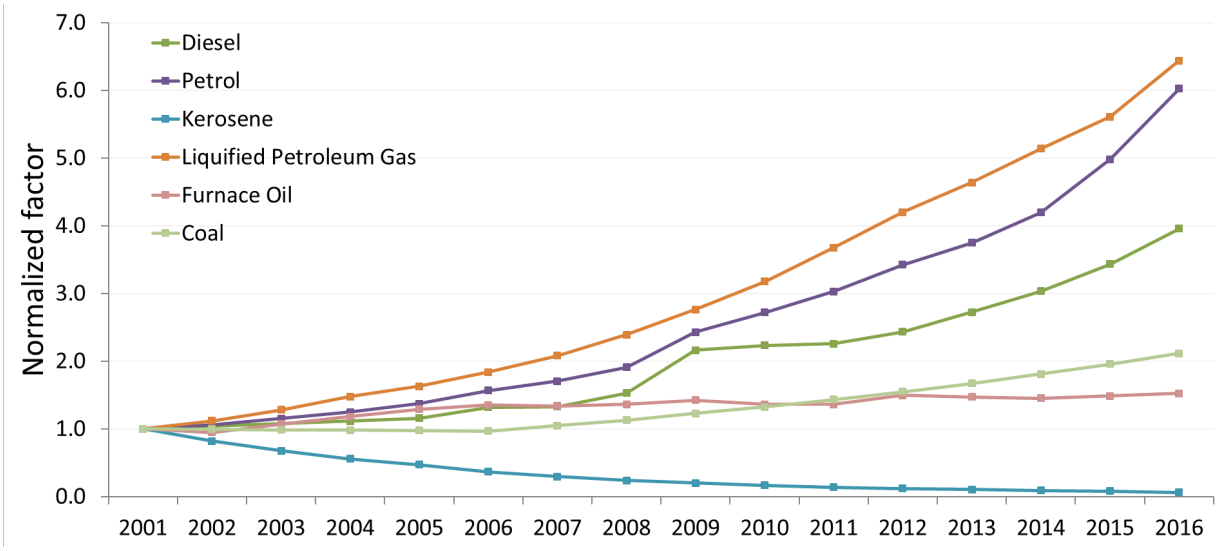

Figure S7. National fossil fuel consumption normalized with respect to year 2001

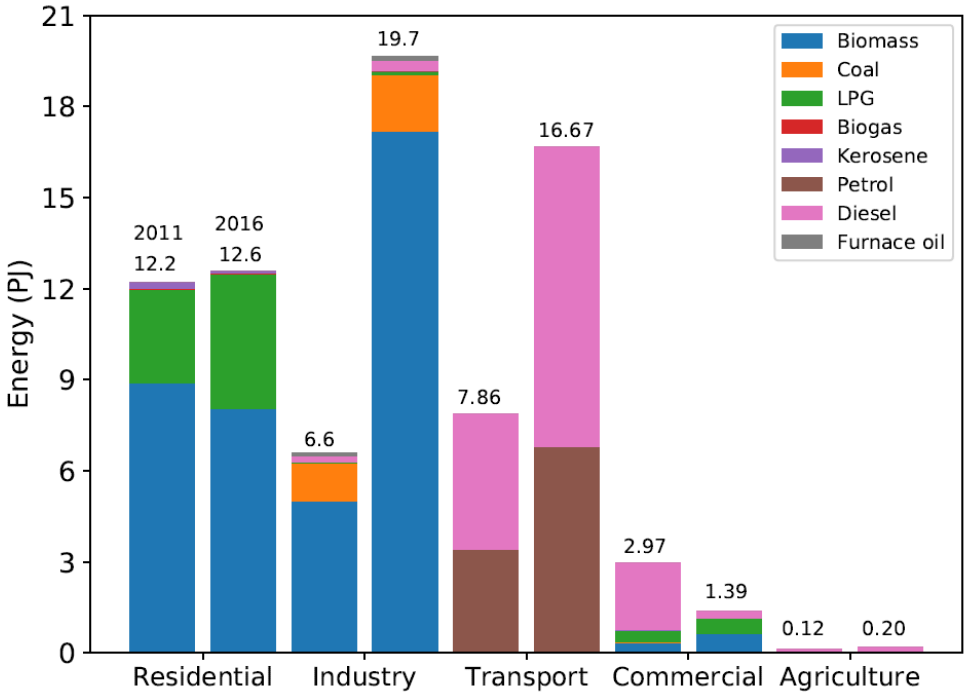

Figure S8. Sectoral energy comparison for 2011 and 2016 for Kathmandu Valley

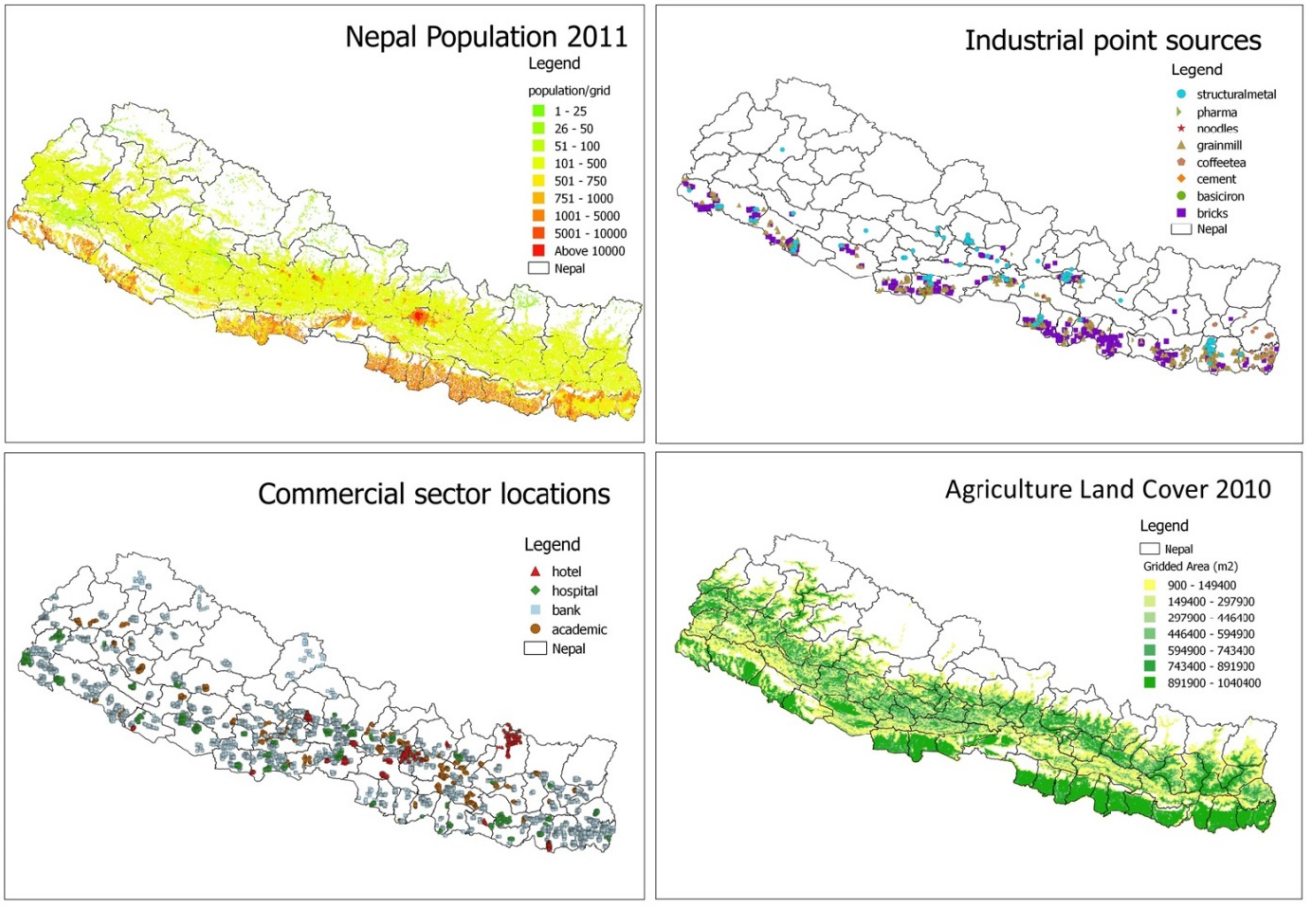

Figure S9. Proxies (a) Residential (b) Commercial (c) Industries (d) Agriculture

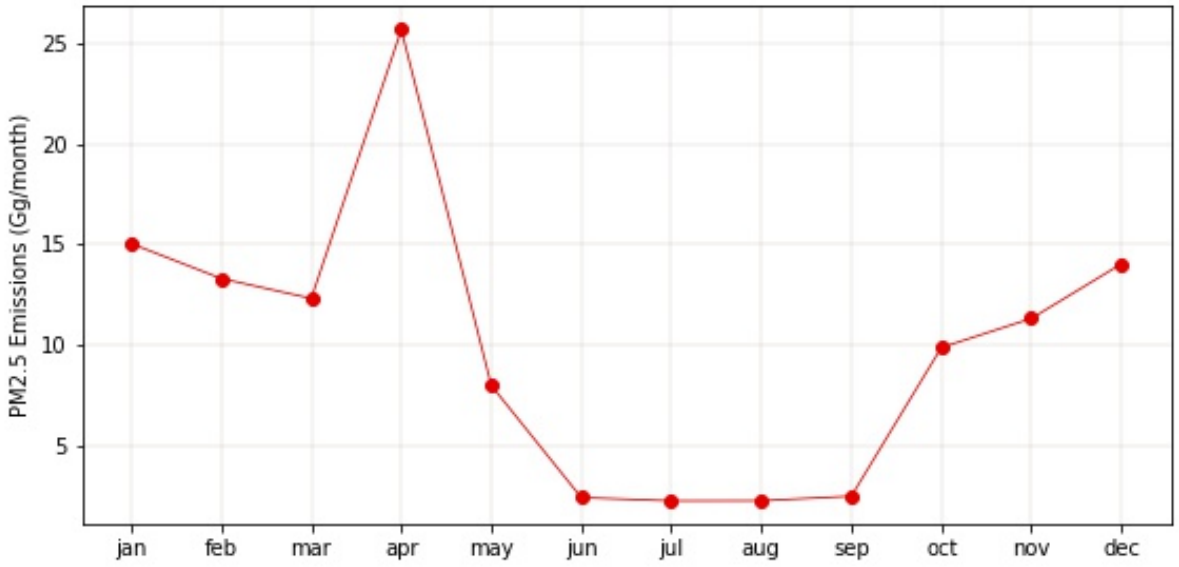

Figure S10. Seasonality in national $PM_{2.5}$ emissions

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