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Awutu Senya East LEAP modelling technical report

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Key points

- Energy consumption characteristics of all demand sectors for Awutu Senya East municipality, Ghana
- Awutu Senya East LEAP model documentation on data handling, methodology and analysis for the SAMSET project
- Future energy consumption projections for Awutu Senya East under various scenarios, with potential energy and monetary savings impact analysis

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Contents

1. Introduction

This is the technical documentation for the development, data, and methodology of the Awutu Senya East Municipality (ASEM) energy systems model, which forms part of the Supporting The SAMSET project. This is a collaboration between the Universities of Uganda Martyrs, Ghana, Cape Town, Durham, University College London, the non-profit organisation Sustainable Energy Africa, and Gamos Consulting; it is co-funded by the UK Department for International Development, the Engineering and Physical Science Research Council and the Department For Energy and Climate Change (DECC).

The model is developed on the Stockholm Environment Agency's (SEI) Long-range Energy Alternatives Planning System (LEAP) platform. LEAP is essentially an accounting-type simulation model although other uses and features have emerged as the product has developed. The rationale for the selection of LEAP as a tool for the SAMSET project has been documented in project outputs (Tait, McCall, & Stone, 2014) and the LEAP software tool itself is well documented by SEI (http://www.energycommunity.org). For the SAMSET project, LEAP is used to create a bottom-up data-driven picture of Awutu Senya's energy system on both the supply and demand sides, projecting a reference case into the future. Scenarios are then developed which project how municipal-driven interventions may alter the path of this reference case, reducing energy consumption and mitigating CO_2 emissions.

The dataset for the model was collected by the University of Ghana by means of surveys and stakeholder workshops with Awutu Senya municipal officials and local experts and is documented in another SAMSET output, the Awutu Senya State of Energy Report (Bawakyillenuo & Agbelie, 2014). In certain instances this dataset was augmented by data from the literature and online sources. The scope of energy systems models, even of a bounded municipal area, covers a broad range of activities and so it was also necessary to make assumptions in a few instances discussed below but it is hoped that if the model is kept live, as is the goal of the project, these will be refined as time goes on.

The general form of a LEAP model involves the division of the energy demand side into typical economic sectors:

- transport;
- municipal services;
- households/residential;
- industry;
- commercial; and
- agriculture.

as well as of supply sectors, under the node 'Transformation' typically but not exclusively, as follows:

- transmission and distribution;
- electricity production;
- oil refining; and
- charcoal production.

In order to build a model, data must be collected for the demand-side sectors that captures the levels of output and energy intensity of producing that output by technology and/or energy carrier for each of the typical services required in that sector, for instance lighting, heating, passenger transport or production of steel. An example is given in Figure 1.

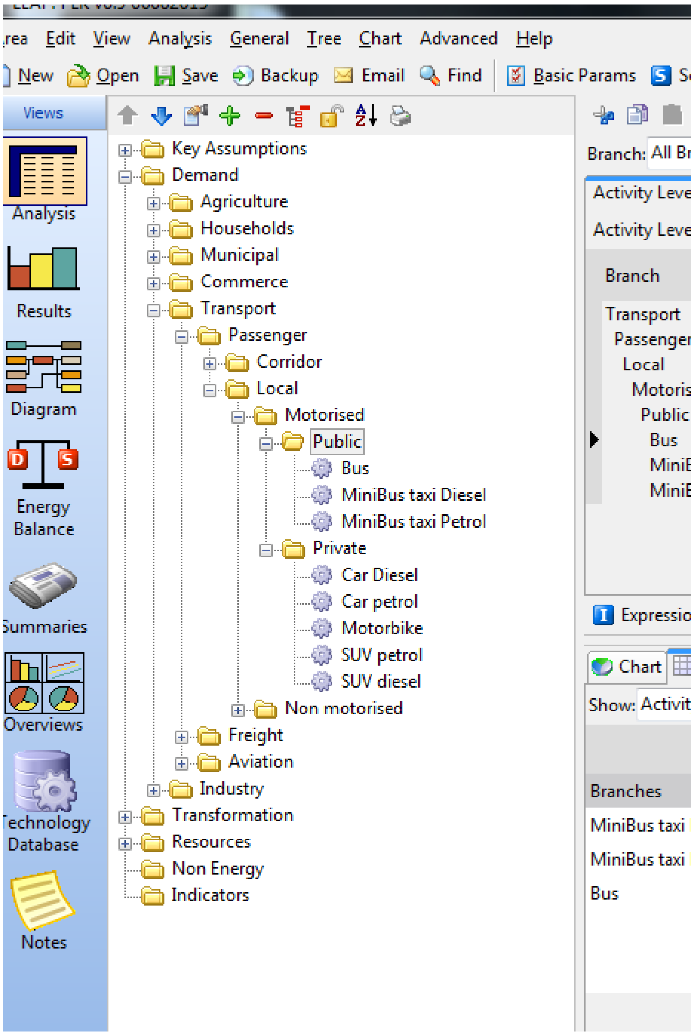


Figure 1: Example of the tree structure in LEAP which aids in categorising the sectors and subsectors of a model down to individual technologies. Here the level goes down to the share of private cars which are diesel or petrol and so on.

It is important to understand clearly that an energy service like heating may be supplied by many technologies, which may use different energy carriers (fuels) such as coal, diesel or electricity. A combination of a technology and an energy carrier will have distinct energy efficiency and emissions, which has important implications for sustainability. An important feature of a useful energy systems model is therefore that, while we want to capture the actual technologies and energy carriers used to supply services today, which we define as the base year, we want to be able to simulate switching to other technologies and energy carriers in the future to evaluate the impact on sustainability.

The general mathematical form by which the energy consumption of the services in a sector is calculated is a simple accounting formula outlined in a general but not overly mathematically formal way below for the sake of communicating across disciplines. For simplicity's sake we will assume that a technology may be either a different means of doing the same thing (for example travelling by bus or by car) but also using a different energy carrier / fuel (for example travelling using a petrol-fuelled car or electric car).

For a given year in the time horizon of the model:

Energy consumption of a sector = The sum of all the energy consumptions of services required by the sector

Where:

E_S = The energy consumed by a service in a given year

θ_i = Share of service supplied by technology i

η_i = The energy intensity (equivalent to efficiency) of technology I in units of energy required per units output for example MJ/[passenger km] or GJ/[ton steel]

O_S = The output of a service required in a given year in physical units for example, passenger km of passenger transport, tons of steel or GJ of heating

$$E_S = \sum (\theta_i \times \eta_i \times O_S)$$

This simple structure offers considerable advantages in developing scenarios of shifts to new technologies because the modeller can easily change the relative shares θ_I of technologies that supply a service at a given future output O_S and the impact on emissions and energy consumption can be quickly assessed. Technologies that have no share of service provision in the base year, say electric cars, can be readily assigned a growing share in a scenario of the future. The given future output is readily projected in LEAP which provide a spreadsheet like formula builder for generating time series of parameters such that an output O_S such as residential heating or tons of steel can be linked to a driver such as population or gross domestic product (GDP). GDP itself can be set up as a global assumption accessible to all sectors in the tree structure of the model and defined as a geometric progression relative to time such that it grows at a fixed percentage of say 2% per annum for the time horizon of the model. More elaborate representations, including step changes and linear interpolation between defined points are equally possible using the formula builder, giving the modeller considerable flexibility in implementing the views of stakeholders or other forms of data. An example of this flexibility is demonstrated in Figure 2, where the shares of an individual technology is set easily by the user and LEAP instantly shows the graphic representation of this change.

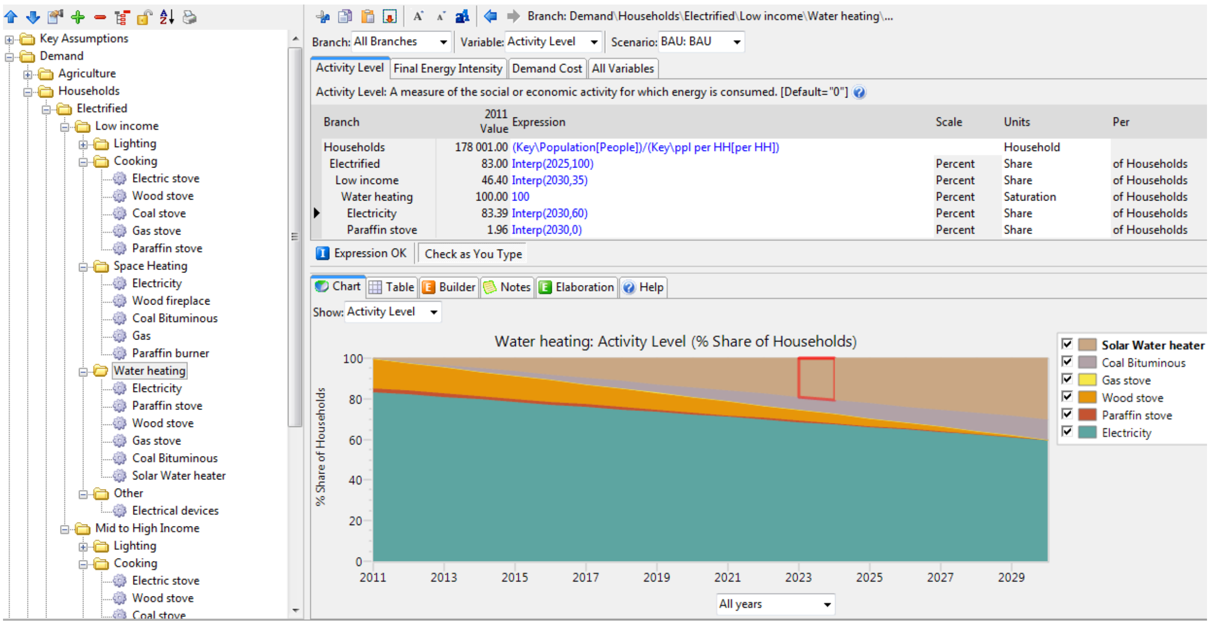


Figure 2: A screen shot of the LEAP interface showing the change in water-heating technologies for low-income households through to 2030

LEAP has a financial framework, and if the costs of technologies are known, the impact on net present value of supplying that service can also be quickly assessed. The disadvantage of this simplistic representation is that the share of a technology may be changed faster than is practical in the real world, given the technical life and age distribution of exiting devices. LEAP does allow for devices to be vintaged and technical change to be managed by a stock model, but this is much more data-intensive and not suitable for most cases where sectors have been represented in the SAMSET project, given the scope of the surveys. Some attention therefore needs to be paid to keeping rates of change within a conservatively realistic window.

For a bottom-up model to be reliable, the assumed activity levels and energy intensities used in services need to be calibrated so that the total energy consumed in the model in the base year, which we define as an historical year, say 2010, agrees with the total energy known to have been supplied to the system in that year. This total energy data typically comes from recorded total electricity sales and petroleum fuel sales obtained from the major utilities. Acquiring this data and validating it is therefore an important first step in the modelling process.

In the model developed for Awutu Senya Municipality (ASEM) all fuels sold within the municipality, with the exception of transport fuels, are assumed to be consumed within the boundary and thus count toward the city's emissions levels. The representation of transport in a spatially bounded scope such as a municipality is inherently problematic. Given commuting behaviour in central Accra and traffic passing through, it is reasonable to assume that a significant portion of petrol and diesel that is sold within ASEM transits the boundary, while fuel from elsewhere enters the municipality daily. In this framework we attempt to represent intra-boundary trips, transboundary trips either generated in or attracted to ASEM, and corridor trips, of which ASEM is neither the origin nor destination but which refuel there. LEAP's tree structure allows the user to include or discard these sub-nodes in reporting results depending on the scope of interest.

The LEAP model was created to represent all major sectors of ASEM as a bottom-up simulation model, and this was calibrated with known fuel sales (mainly liquid fuels and electricity) within the municipal boundary. The main drivers for this model are population, and economic growth (one local, and one regional).

2. General background and key drivers

Data collection is primarily based on surveys and interviews undertaken by the University of Ghana as part of the SAMSET project. This includes the following:

- surveys of 593 households, 435 commercial businesses and 33 industrial businesses in the municipal area;
- focus groups discussions with stakeholders;
- interviews with municipal staff; and
- municipal records.

The base year for the model is 2013, as the survey data is for this year.

2.1 Population

The population given by the national statistics for the municipality was 108 422 in 2010, with an annual growth rate of 3% (Communication with Ghanaian SAMSET team, S. Bawakyillenuo and Agbelie 2014, Ghana Statistical Service, 2014b). Assuming this growth rate and extrapolating this to 2013 the population would then be 118 474. The number of households in ASEM in 2013 was estimated at 43 795 (Bawakyillenuo & Agbelie, 2014), with 83% of households being electrified (see Table 1). Household classifications are based on standard Ghanaian land-use classifications, which are in turn based on degree of access to service delivery and other factors. The ASEM growth rate is higher than the national population growth rate, estimated to be 2% per annum (Ghana Statistical Service, 2010).

Table 1: Household estimate, 2013

Household classification	*Number*	*Percentage*
HH1	10 161	23
HH2	15 057	34
HH3	18 577	42
Total	**43 795**	**100**

Source: SoE report – Bawakyillenuo S, Agbelie I (2014)

The rate of urbanisation driving Awutu Senya's population growth is likely to be high, given its location on the periphery of Greater Accra – and spatially this is the area experiencing highest concentration of urban population and urban growth (Owusu, 2011), associated with rapid peri-urban growth around these central urban areas. Population growth rates going forward are based on extrapolated urbanisation trends.

2.2 Economy

The economic output[1] or 'GDP' for ASEM is inferred from the average GDP per capita for the country. Due to the proximity of ASEM to the economic hub of Ghana (Accra), this value could be an under-estimate but was assumed sufficient for the present work. The population for Ghana in 2013 was 26.4 million (Ghana Statistical Service, 2012) and the national non-oil GDP for 2013, as given by the national statistics services was, GHC71 627 million (Ghana Statistical Service, 2014a). Thus, ASEM's GDP using the population for 2013 was estimated as GHC321.1 million (current).

3. Municipal sector

This section describes the energy consumption of the municipality authority for its operations and services, including the energy consumption of its municipal buildings and vehicle fleet.

3.1 Data

|The data was obtained by the municipality for building energy consumption and for the vehicle fleet is presented in the tables below.

Table 2: Municipal transportation data for 2013

Diesel – litres	337 500
Annual km travelled per vehicle	23 400
Vehicle count	10

Table 3: The electricity consumption of the municipal buildings of ASEM

	Lighting	*VAC*	*Refrigeration*	*Office machines*
Electricity consumption (kWh)	121 662	17 844	5 677	72 997

The data provided also indicated that the total floor area for all the municipal buildings combined is 7375m^2.

[1] This is normally referred to as GVA (gross value added) in the case of a city or area within a country.

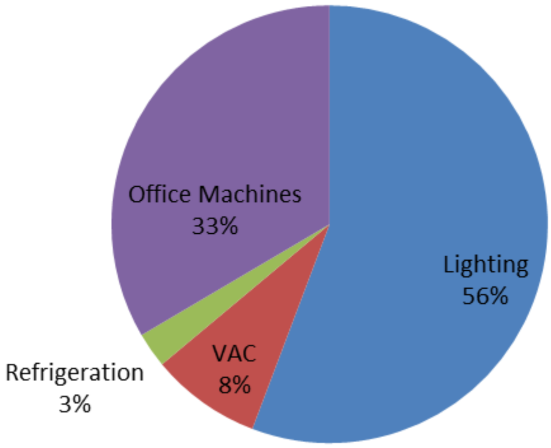


Figure 3: ASEM municipal building electricity consumption split by end use

3.2 Methodology

Transportation

The total transportation activity for the municipality is calculated as the total vehicle km travelled by all the vehicles (this is 10 vehicles × 23 400 km/vehicle), and the fuel intensity used is the total fuel consumed (337 500 litres) divided by the total vehicle km travelled which is about 1.4 L per vehicle-km. This would be about 140L/100 km, which may appear high, but garbage removal trucks are known to have poor fuel efficiency of this order of magnitude or even higher (although it is unknown at this time as to whether this is the reason for the high fuel consumption) (Nguyen, 2010)

Municipal buildings

The total intensity values for the municipal buildings are given in Table 4, using the total energy consumption divided by the total floor area.

Table 4: Municipal building electricity intensity by end use

	Lighting	*Ventilation and cooling*	*Refrigeration*	*Office machines*
Electricity intensity (kWh/m^2)	16.5	2.4	0.8	9.9

4. Household sector

4.1 Data

The data for the household sector is based on the SAMSET survey data of households in the municipality. This data was augmented by bottom-up calculations of energy consumption based on appliance ratings and consumption patterns from the literature (see Tables, 9, 10 and 11 for details). The survey data collected data for households in three categories based on Ghanaian land use classifications – designated as Household class 1 (HH1) to Household class 3 (HH3).[2] These classifications have been used as a proxy for income, in the absence of other data. The electrification rate for the municipality was assumed constant across household categories to provide a breakdown of six household categories.

2 See the ASEM SoE report (Bawakyillenuo, Agbelie, 2014) for more information about the survey.

Table 5: Number of households by HH category

Household classification	*Sample size*	*Total households*
HH1 – electrified	113	8 448
HH1 – unelectrified	24	1 713
HH2 – electrified	170	12 518
HH2 – unelectrified	33	2 539
HH3 – electrified	210	15 444
HH3 – unelectrified	43	3 133
Total	**593**	**43 795**

The average size of a household is estimated to be 2.7 people, based on the data provided in the SoE report. This is based on the average household size for the Central region from the 2010 Census (Ghana Statistical Service, 2012).

Table 6: Estimated annual average consumption per household

	Wood (kg)	*Electricity (kWh)*	*Kerosene (l)*	*Charcoal (kg)*	*LPG (kg)*	*Dry cell battery (no. of singles)*
Electrified						
HH1	390	2 212	10	295	140	60
HH2	404	1 677	14	284	114	68
HH3	643	1 501	13	277	131	57
Unelectrified						
HH1	420	-	8	326	147	133
HH2	514	-	12	405	121	91
HH3	390	-	-	338	100	120
Note: Based on household survey data						

Table 7: Household percentage shares of fuels for enduses

	Electrified (%)			*Unelectrified (%)*		
	HH1	*HH2*	*HH3*	*HH1*	*HH2*	*HH3*
Lighting	**100**	**100**	**100**	**83**	**76**	**77**
Electricity	100	100	100			
Solar	3	0	1	4	0	0
Batteries	43	36	49	79	67	77
Kerosene	0	2	3	0	9	0
Cooking & water heating	**100**	**100**	**100**	**100**	**100**	**100**
Electricity	43	27	19			
Wood	7	7	17	29	33	37
Charcoal	82	89	88	83	88	95
LPG	75	76	60	54	45	30
Kerosene	12	17	22	4	3	0
Refrigeration	**68**	**61**	**58**			
Electricity	100	100	100			
Entertainment	**98**	**98**	**100**	**50**	**21**	**37**
Electricity	100	100	100			
Dry cell batteries	8	5	9	50	21	37
Space cooling	**95**	**80**	**79**			
Electricity	100	100	100			
Other energy services	**85**	**71**	**54**			
Electricity	100	100	100			
Notes: Bolded lines refer to percentage of all households; fuel categories refer to the percentage of households that use that energy service.						

The household surveys investigated the extent of ownership and usage of efficient appliances. All electrified households use CFL lightbulbs. The Ghanaian government instituted a widescale National Efficiency Lighting Project in 2006/07 aimed at conserving electricity in response to an electricity power crisis. In 2008, the government legislated against the manufacture and sale of incandescent lamps. It has also instituted minimum energy-efficiency standards for refrigeration appliances as well as a refrigeration rebate scheme whereby households can swap old and inefficient appliances for newer, more efficient ones. Take-up of this scheme among sampled households was low, however: only one of the surveyed households reported using the Energy Commission's refrigerator rebate programme. Table 8 indicates that ownership of efficient refrigeration appliances is higher in the higher-income category. Despite the widespread usage of charcoal and wood, efficient products using these fuels have not reached significant market penetration rates. None of the sampled households recorded using efficient woodstoves. There was some usage of efficient charcoal stoves, such as the Gyapa. Usage is higher amongst poorer and un-electrified households.

Table 8: Efficient appliance usage
Source: SAMSET household survey

	Electrified (%)			*Unelectrified (%)*		
	HH1	*HH2*	*HH3*	*HH1*	*HH2*	*HH3*
CFL lightbulbs	100	100	100	-	-	-
Refrigeration	30	20	17	-	-	-
Charcoal stoves	1	4	2	10	10	12
Wood stoves	0	0	0	0	0	0

4.2 Methodology

Consumption profiles are based on the survey data collected, and the energy intensities of end-uses were calculated based on bottom-up calculations of typical energy profiles of households.

Total consumption for each fuel by energy service is calculated as:

> ***Number of households in sub-category*** *(e.g. HH1 electrified) X*
>
> ***Percentage of households that use energy service*** *(based on survey data) X*
>
> ***Percentage of households that use fuel*** *(e.g. electricity)* ***for energy service*** *(e.g. cooking) (based on survey data) X*
>
> ***Energy intensity per energy service*** *(based on bottom up calculations of appliance ratings and hours of usage, and calibrated to meet total sample consumption estimate from survey data).*

Table 9: Electricity consumption estimates for 'HH1 electrified'

Energy service	*Households using energy service*	*Households using electricity for energy service*	*Average daily consumption (kWh)*	*Days per year used*	*Average household energy intensity kWh/yr*	*Total consumption estimate for municipality*
Cooking and water heating	100%	43%	2.182	320	698	2 557 708
Lighting	100%	100%	0.432	365	158	1 332 003
fridge	68%	100%	2.835	365	1035	5 956 442
Entertainment	98%	100%	0.576	320	184	1 529 487
Space cooling	95%	100%	1.028	350	360	2 878 029
Other	85%	100%	1.798	350	629	4 516 263
Total						**18 769 932**

Table 10: Electricity consumption estimates for 'HH2 electrified'

Energy service	*Households using energy service*	*Households using electricity for energy service*	*Average daily consumption (kWh)*	*Days per year used*	*Average household energy intensity kWh/yr*	*Total consumption estimate for municipality*
Cooking and water heating	100%	27%	1.792	320	573	1 942 350
Lighting	100%	100%	0.432	365	158	1 973 819
fridge	61%	100%	2.351	365	858	6 507 036
Entertainment	98%	100%	0.736	320	236	2 878 841
Space cooling	80%	100%	0.89	350	312	3 119 455
Other	71%	100%	1.478	350	517	4 570 940
Total						**20 992 440**

Table 11: Electricity consumption estimates for 'HH3 electrified'

Energy service	*Households using energy service*	*Households using electricity for energy service*	*Average daily consumption (kWh)*	*Days per year used*	*Average household energy intensity kWh/yr*	*Total consumption estimate for municipality*
Cooking and water heating	100%	19%	2.012	320	644	1 846 678
Lighting	100%	100%	0.432	365	158	2 435 255
fridge	58%	100%	2.242	365	818	7 282 196
Entertainment	93%	92%	0.666	320	213	2 837 992
Space cooling	79%	100%	0.950	350	333	4 034 819
Other	54%	100%	1.613	350	565	4 733 210
Total						**23 170 150**

Table 12: Household wood consumption estimates

Household category	*Households that use wood for cooking*	*Appliance type*	*Percentage that use appliance type*	*Average estimated annual consumption*	*Total estimated consumption for population*
		Electrified			
HH1	7%				233 241
		Efficient stove	0%		-
		Inefficient stove	100%	390	233 241
HH2	7%				209 903
		Efficient stove	0%		-
		Inefficient stove	100%	420	209 903
HH3	17%				435 036
		Efficient stove	0%		-
		Inefficient stove	100%	514	435 036
		Unelectrified			
HH1	29%				209 903
		Efficient stove	0%		-
		Inefficient stove	100%	420	209 903
HH2	33%				435 036
		Efficient stove	0%		-
		Inefficient stove	100%	514	435 036
HH3	37%				454 404
		Efficient stove	6%		14 658
		Inefficient stove	94%	402	439 746

Table 13: Charcoal consumption estimates

Household category	*Households that use charcoal for cooking*	*Appliance type*	*Percentage that use appliance type*	*Average estimated annual kg/HH*	*Total estimated consumption for all households (Kg)*
		Electrified			
HH1	82%				2 042 884
		Efficient stove	1%	148	10 266
		Inefficient stove	99%	296	2 032 619
HH2	89%				3 164 937
		Efficient stove	4%	145	64 591
		Inefficient stove	96%	290	3 100 346
HH3	94%				4 035 784
		Efficient stove	2%	140	40 765
		Inefficient stove	98%	281	3 995 019
		Unelectrified			
HH1	83%				463 423
		Efficient stove	10%	172	24 391
		Inefficient stove	90%	343	439 032
HH2	88%				905 547
		Efficient stove	10%	213	47 660
		Inefficient stove	90%	427	857 886
HH3	95%				1 007 105
		Efficient stove	12%	180	64 283
		Inefficient stove	88%	360	942 822

The aggregated survey data for household generator usage in ASEM is presented below, along with the scaled-up estimate for the entire household population usage of generators. Equations 8 and 11, discussed below in Section 6.2.2, were used to convert annual fuel use and generator rating into electricity generated, assuming an average load factor of 0.75. There were 20 households in the ASEM survey which had generators, 10 in the HH1 category, 6 in the HH2 category, and 4 in the HH3 category. Of these, 3 of the HH1 household's with generators were not electrified and 1 in the HH3 category.

Table 14: ASEM HH1 generator use survey data and estimated population usage

Group	*Grid status*	*Own generated electricity (kWh)*	*Grid electricity (kWh)*	*Total Electricity (kWh)*	*Share of own gen. elec. (%)*	*Petrol used (litres)*	*Diesel used (litres)*	*Estimated average utilisation (hours/day)*
Sample (with gensets)	Electrified	3 227	24 907	28 134	11%	1 714	330	0.6
	Unelectrified	2 139	0	2 139	100%	1 560	-	0.7
Population (estimate)	Electrified	241 291*	18 519 798[#]	18 761 089	1.3%	128 155	24 671	
	Unlectrified	152 647	0	152 647	100.0%	111 345	-	

** Scaled from genset-owning sample only*
 # Scaled from entire sample

Table 15: ASEM HH2 generator use survey data and estimated population usage

Group	*Grid status*	*Own generated electricity (kWh)*	*Grid electricity (kWh)*	*Total Electricity (kWh)*	*Share of own gen. elec. (%)*	*Petrol used (litres)*	*Estimated average utilisation (hours/day)*
Sample (with gensets)	Electrified	1 706	20 362	22 067	8%	1 133	0.2
	Unelectrified						
Population (estimate)	Electrified	125 610*	20 990 945#	21 116 556	0.6%	83 414	
	Unelectrified						

** Scaled from genset-owning sample only*
 # Scaled from entire sample

Table 16: ASEM HH3 generator use survey data and estimated population usage

Group	*Grid Status*	*Own generated electricity (kWh)*	*Grid electricity (kWh)*	*Total electricity (kWh)*	*Share of own gen. elec. (%)*	*Petrol used (litres)*	*Diesel used (litres)*	*Estimated average utilisation (hours/day)*
Sample (with gensets)	Electrified	695	4 909	5 603	12%	540		0.6
	Unelectrified	764		764	100%		560	0.6
Population (estimate)	Electrified	51 083*	23 175 628#	23 226 711	0.2%	39 713		
	Unelectrified	55 659		55 659	100%		40 801	

** Scaled from genset-owning sample only*
 # Scaled from entire sample

The data indicate that, while only just over 3% of the sample of households own generators, accounting for about 1% of total household electricity supply, those households that own them make quite significant use of them, particularly considering that the price of petrol and diesel is likely to discourage regular use. The share of own-generation was less than the sample observed in Ga East (20%) but a share of around 10% was observed across all three household classes in contrast to Ga East where only HH1 households owned generators. Quality of supply may be better in ASEM accounting for lower own-generation shares. Substantial suppressed demand is still however indicated.

5. Industry

This section describes the energy consumption characteristics for the industries active in ASEM that were surveyed during the data collection process by the Ghanaian SAMSET team.

5.1 Data

This sector is split up into subsectors based on survey data (Bawakyillenuo & Agbelie, 2014): construction, mining and quarrying, and manufacturing. From the SAMSET survey of 26 construction, six manufacturing, and one mining and quarrying businesses which is thought to compromise the entire industrial activity of ASEM, the total industrial output for ASEM is about 1 million tonnes:

Table 17: ASEM industrial activity in 2013, data from SAMSET survey

Count of businesses in survey	*ASEM industry*	*Tonnes output*	*Electricity consumption – kWh*
26	Construction	37 950	27 778
6	Manufacturing	115 677	46 666
1	Mining & quarrying	850 000	888 889

As part of the survey, the use of energy in the industries within ASEM was also profiled. The electricity consumption for various end uses is presented in Table 18.

Table 18: Electricity consumption by end use for industries in ASEM (kWh)

	Machinery	*Lighting*	*Cooling systems*	*Other machine drive*	*Other*	*Total*
Construction	17 304	9 249	370	936	247	28 106
Manufacturing	30 352	13 286	2 411	306	306	46 662
Mining and quarrying	211 640	423 280	84 656	0	169 312	888 889
Share	26.91%	46.26%	9.07%	0.13%	17.6%	100%

The majority of the energy consumption is in lighting and machinery. Lighting makes up a large proportion of the mining and quarrying industry of ASEM, and thus distorts it's share overall – it accounts for less than 30% for construction and manufacturing where machinery take up more than 60% of electricity consumption.

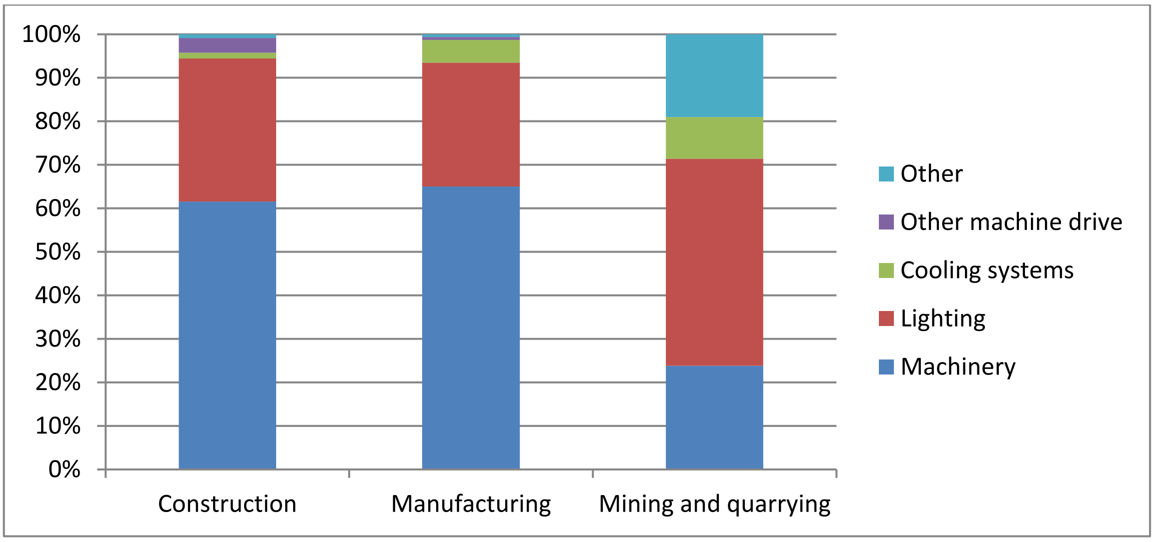


Figure 4: The electricity usage share for industries in ASEM

The industry sector makes extensive use of diesel or petrol generators, most likely as a result of unreliable electricity supply from the grid, or no grid connection.

Table 19: Industry diesel and petrol generators data for ASEM in 2013 from the survey

Subsector	*Total capacity – kW*		*Litres consumed in 2013*		*kWh output*		*Electricity share of own generation*
	Diesel	*Petrol*	*Diesel*	*Petrol*	*Diesel*	*Petrol*	
Manufacturing#	111	6	628	160	1 966	319	41%
Construction	2	-	240	-	752	-	12%
Mining and quarrying*	30	-	60 000	-	187 970	-	99.8%

** 1 enterprise (ID 17).*
 # Three of the six enterprises in the sample owned generators.

The survey indicated that the industry also uses diesel for 'machinery' – presumably earth moving equipment and road work equipment as well. Table 20 summarises the diesel consumption in industry.

Table 20: The breakdown of industry diesel consumption in ASEM for 2013 (litres/year)

	Generator	*Machinery*	*Other machine drive*	*Process heating*	*Total*
Construction	240	18 060	261	180	18 501
Manufacturing	628	1 499	0	0	1 499
Mining and quarrying	60 000	30 000	30 000	0	60 000

5.2 Methodology

End use

The industry sector is represented in the model by each subsector, and for each subsector the energy consumption of industry was split into the following categories:

- lighting,
- machinery,
- cooling,
- process heating,
- other machinery, and
- ‘other’.

Using the data provided for the total energy consumption for each end use and the total tonnes output for each subsector, the energy intensity for each subsector was calculated:

Table 21: Industry end use energy intensity values for electricity and diesel fuels

	Machinery		*Lighting*	*Cooling*	*Other machine drive*		*Other*	*Process heating*
	kWh/tonne	*L/tonne*	*kWh/tonne*	*kWh/tonne*	*kWh/tonne*	*L/tonne*	*kWh/tonne*	*L/tonne*
Construction	0.456	0.476	0.244	0.010	0.025	0.007	0.007	0.005
Manufacturing	0.262	0.040	0.115	0.021	0.003		0.003	
Mining and quarrying	0.249	0.791	0.498	0.100		0.791	0.199	

Generators

The diesel and petrol generators that are used in the industry sector are grouped into the supply side of the model for ASEM as indicated and are assumed to run at the same level as their base year capacity factor for the time horizon of the model in the reference case:

Generator type	*Capacity kW*	*Capacity factor %*
Diesel	143.2	15
Petrol	5.5	0.6

6. Commercial sector

This section describes the commercial sector of ASEM, which includes offices, shops, restaurants and other non-industrial and non-residential activities surveyed (Bawakyillenuo & Agbelie, 2014).

6.1 Data

Data for the commercial sector is based on survey data collected by the University of Ghana for the SAMSET project. The surveys collected data on energy carriers used, end-uses, own generation with petrol and diesel generators, total floorspace occupied, and the costs of energy consumption. A total of 435 businesses were surveyed, including 86 formal and 349 informal. The total number of commercial businesses is estimated to be 1854 (Bawakyillenuo & Agbelie, 2014), based on a business registration list. The types of businesses classified as commercial, based on University of Ghana classifications, include the following:

Formal:

- offices (e.g. IT, finances, consultancy, etc),
- hotels & guest houses,
- schools,
- non-banks financial services,
- hospitals,
- banks.

Informal:

- aluminium fabricator,
- carpentry/welding shops,
- cold store,
- corn mill,
- drinking bar, restaurant, catering services,
- electronic repair shops,
- fitting/mechanic,
- laundry,
- other,
- petty trading,
- retail,
- tailoring/seamstress.

In this methodology, the energy consumption for the sector is driven by total floorspace in the municipality. Assuming the sample is representative, the total floorspace surveyed was scaled up proportionally to estimate the energy demand from all businesses in the municipality. The total floor-space of the sample was dominated by the formal sector, as shown in Table 22, even though these only accounted for about 11% of the premises surveyed.

Table 22: Floorspace of sample and total businesses

	Number of businesses sampled	*Floorspace of sample*	*Total estimated number of businesses*	*Total estimated floorspace of all businesses*
Formal	86	73 868	367	314 829
Informal	349	22 163	1487	94 462
Total	435	96 031	1845	409 290

As shown below, schools and to a lesser degree hospitals, hotels and guesthouses account for a disproportionate share of floorspace in the formal sub-sector and the sample as a whole. The informal sub-sector shows a more even spread of area by activity. This raises a few issues as regards the use of the data as follows:

- About a fifth of the commercial sector was sampled, so the energy baseline of the sample was scaled-up for input to the model. If schools, which are area outliers, are a higher share of the sample than they are of the population they will have a disproportionate contribution to the population.
- The methodology of determining floor-space area and the need for clear metadata for this data set is discussed in the Data issues section. Floor area, from which future energy demand is calculated, assuming a fixed energy intensity, is projected geometrically in the model. In spite of the issue raised above, it is therefore likely that because the area contributions of the activities are scaled up proportionally, distortions caused by outliers like schools will have a

relatively small effect on energy demand projections. The dataset, particularly when averaged, should, however, be compared to other data and to energy-efficiency benchmarks with great caution, and future modelling should be cautious around defining and measuring commercial building floorspace.

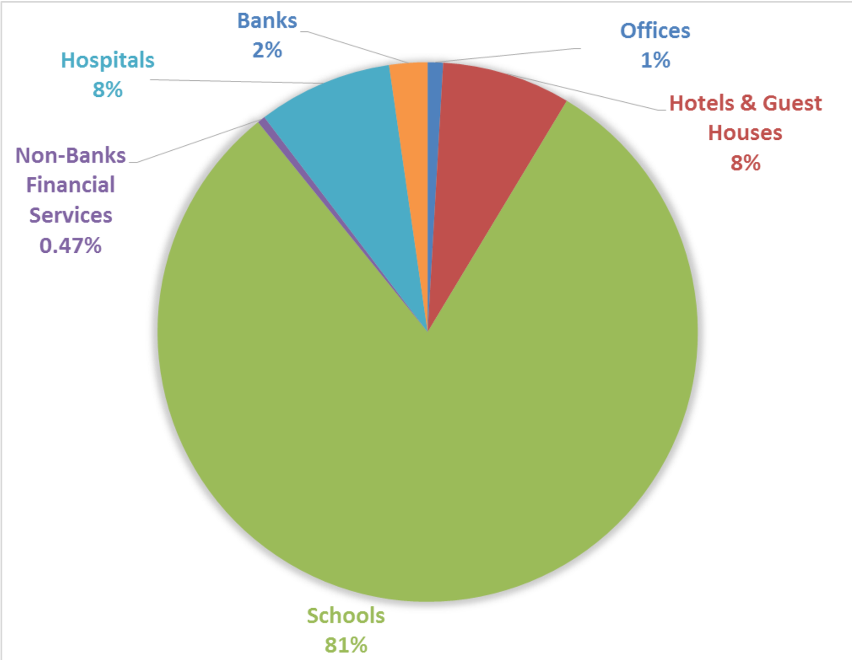


Figure 5: Share of formal commercial floorspace by activity type

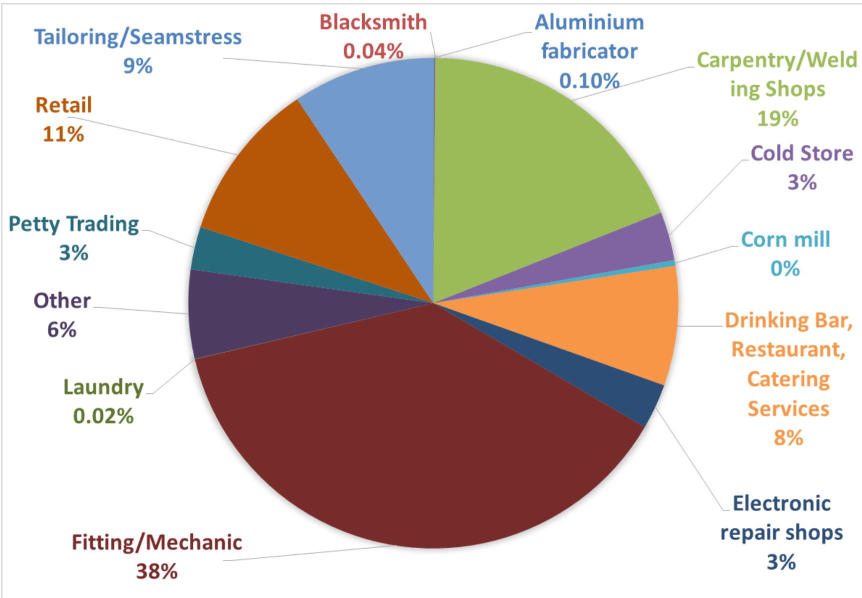


Figure 6: Share of informal commercial floorspace by activity type

The survey data of the businesses shows the energy consumption characteristics for informal and formal commercial businesses as in Table 23.

Table 23: Formal sector – Survey results of annual consumption by fuel and end-use for sample

	HVAC	*Cooking/ water heating*	*Lighting*	*Refriger-ation*	*Machine operation*	*Entertain-ment*	*Other*	*Total*
Electricity (kWh)	267 132	31 419	183 398	56 566	234 172	79 037	52 305	904 030
LPG (kg)	-	11 868	120	-	180	-	300	12 468
Charcoal (kg)	-	53 496	-	-	-	-	-	53 496
Wood (kg)	-	2 835	-	-	-	-	-	2 835
Kerosene (L)	-	14	-	-	-	-	-	14

Table 24: Informal sector – Survey results of annual consumption by fuel and end-use for sample

	HVAC	*Cooking/ water heating*	*Lighting*	*Refriger-ation*	*Machine operation*	*Entertain-ment*	*Other*	*Total*
Electricity (kWh)	33 156	5 635	169 385	1438 44	168 876	59 843	12 070	592 809
LPG (kg)	-	7 540	-	-	1318	-	41 177	50 034
Charcoal (kg)	-	32 906	-	-	-	-	18 287	51 193
Wood (kg)	-	5 325	-	-	-	-	-	5 325
Kerosene (L)	-	9	0	-	-	-	9	18

The survey included questionnaires on the use of generators in the commercial sector, and this data is presented in Table 25.

Table 25: Generator usage data from survey for the commercial sector

	Com. subsector	*Capacity (kW)*	*Litres used*	*Electricity generated (kWh)*	*Capacity factor*	*Sample count*
Petrol	Formal	346	15 333	34 617	1.1%	23
	Informal	131	8 502	14 345	1.2%	41
Diesel	Formal	375	24 338	76 245	2.3%	11
	Informal	33	14 578	45 671	15.8%	3

6.2 Methodology

6.2.1 End-use energy intensities

The survey of businesses was assumed to be representative and the values for the sample were scaled up proportionally to estimate the demand from the population (Bawakyillenuo & Agbelie, 2014). The consumption of energy for a fuel =

The floor area occupied by sub-sector k ***X***

The share of floor area of businesses in a sub/sector that need an energy service like heating of the floor area of all business in a sub/sector ***X***

The share of floor area of businesses that use this fuel/technology for this energy service of the floor area of businesses that use this energy service ***X***

The energy intensity (GJ/m2; kg charcoal/m2; litres diesel/m2 etc.) of this energy service for these businesses using this fuel / technology (calibrated)

For the formal sector, the inputs to this methodology as determined from the survey data is presented in the following tables.

Table 26: Formal businesses percentage of floorspace with end-uses

% of total floorspace with end uses	*HVAC*	*Cooking/ water heating*	*Lightin g*	*Refriger-ation*	*Machine operation*	*Entertain-ment*	*Other*
Formal	100	56	100	60	48	73	45

Table 27: Formal sector percentage of floorspace end-use by fuel type

	HVAC	*Cooking/ water heating*	*Lighting*	*Refriger-ation*	*Machine operation*	*Entertain-ment*	*Other*
Electricity	100	21	99	100	100	96	100
LPG	0	18	0	0	1	0	1
Charcoal	0	45	0	0	0	0	0
Wood	0	44	0	0	0	0	0
Kerosene	0	0	0	0	0	0	0

Using the total fuel consumed for each end-use and the total floorspace which has that end-use (and fuel), the final energy intensities for each end use by each fuel are calculated in Table 28.

Table 28: Formal sector – the average annual energy intensity by fuel and end-use

	HVAC	*Cooking/ water heating*	*Lighting*	*Refriger-ation*	*Machine operation*	*Entertain -ment*	*Other*
Electricity (kWh/m^2)	3.62	3.57	2.52	1.27	6.67	1.53	1.58
LPG (kg/m^2)		1.58			0.79		0.83
Charcoal (kg/m^2)		2.87					
Wood (kg/m^2)		0.15					
Kerosene (L/m^2)		2.00					

Similarly, processing the survey data for the informal sector yielded the profile for end-uses and fuels shown in Tables 29 and 30.[3]

Table 29: Informal sector percentage of floorspace with end-uses

% of total floorspace with end-uses	*HVAC*	*Cooking/ water heating*	*Lighting*	*Refriger-ation*	*Machine operation*	*Entertain-ment*	*Other*
Informal	15%	9%	96%	22%	70%	36%	7%

Table 30: Total floorspace of fuel used for end-use/total floorspace with end-use

	HVAC	*Cooking/ water heating*	*Lighting*	*Refriger-ation*	*Machine operation*	*Entertain-ment*	*Other*
Electricity	96%	44%	99%	99%	99%	99%	91%
LPG	-	30.%	-	-	0.33%	-	48%
Charcoal	-	43%	-	-	-	-	7.1%
Wood	-	3.2%	-	-	-	-	-
Kerosene	-	2.0%	-	-	-	-	0.84%

3 It should be noted that for commerce it was not clear how the data on energy consumption disaggregated by energy service was estimated, whether by independent measurement, by the surveyor, or by the participant in the survey, and whether the estimates reflect bottom-up calculations or judgement. As noted in the data issues section, more detailed metadata for the survey results would make for a more powerful dataset.

The final energy-intensity values for the informal sector by end-use and by fuel-type based on survey data:

Table 31: Informal sector – average annual energy intensity by fuel and end-use

	HVAC	*Cooking/ water heating*	*Lighting*	*Refriger-ation*	*Machine operation*	*Entertain-ment*	*Other*
Electricity[3] (kWh/m^2)	10.065	6.497	8.036	29.59	11.00	7.54	9.12
LPG (kg/m^2)		12.651			26.01		59.11
Charcoal (kg/m$_2$)		38.821					177.25*
Wood (kg/m^2)		84.110					
Kerosene (L/m^2)		0.209	0.025				0.74
*The very high energy intensity for charcoal in the 'other' category refers to pot makers.							

6.2.2 Own-generation data

The survey data indicated that there was about 477kW of petrol generators in the sample of the commercial sector mainly in the formal sector. Diesel generator capacity was about 408kW but the vast majority lies in the formal sector, presumably because of the higher cost of diesel generators and because these machines typically also have higher capacities.

Table 32: Own generator usage for informal and formal in the surveyed sample of the commercial sector for 2013

	Capacity – kW	*kWh generated*	*Litres consumed*	*Capacity Factor*
Formal				
Petrol	346	34617	15333	1.14%
Diesel	375	76245	24338	2.30%
Informal				
Petrol	131	1435	8502	1.25%
Diesel	33	45671	14578	15.8%

The methodology described below was followed in cleaning the own-generator data and converting the corrected volumes of fuel consumed to an estimate of kWh generated. The Ga East and Awutu Senya East survey generator data was processed together and this methodology refers to both samples and models. Both monthly and annual volumes of diesel and petrol consumed were recorded and the agreement between these was checked. Only ID 742 had a monthly volume that, when scaled-up to an annual volume, deviated by more than 20% from the recorded annual volume. In this case the monthly and annual fuel costs agreed well so these were assumed a better indication. The monthly and annual expenditure on petrol and diesel were also recorded. In a few cases there was expenditure data but no volume data and vice versa. Volumes were divided into expenditure to yield an implied price which was the same for most observations but with a distribution of errors either side of this, as shown for petrol in Figure 7.

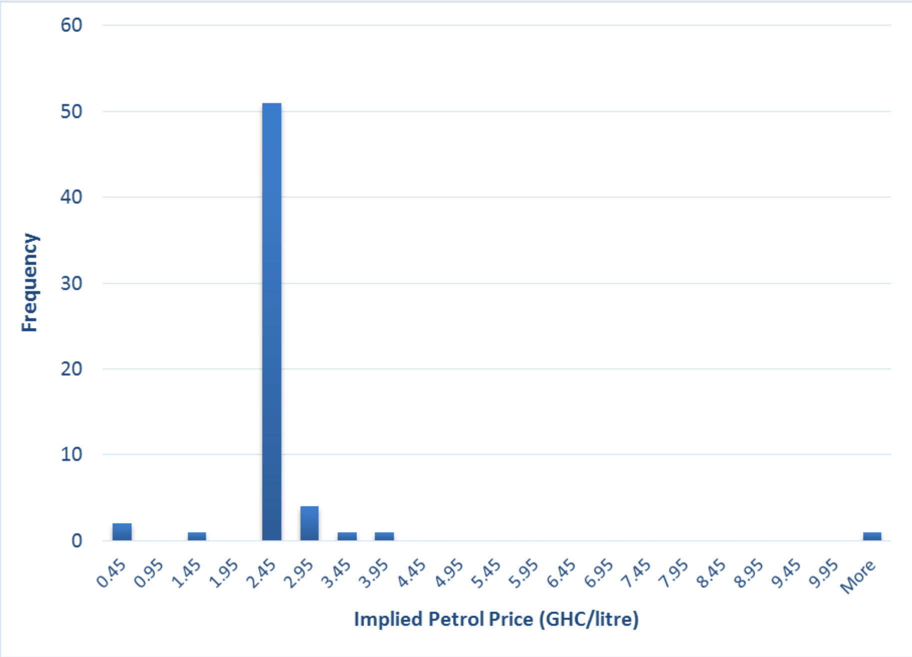


Figure 7: Histogram of implied prices obtained by dividing petrol volume data into petrol expenditure data

A ‘corrected’ volume of petrol and diesel was estimated as follows:

It was assumed that expenditure data was likely to be more accurate than volume data on average. Therefore, in cases where expenditure was available this was converted to volume using the median implied price of the respective petrol and diesel samples otherwise the indicated annual volumes were used. Two observations (ID 128 and 320) had neither volume nor cost data although an onsite generator was indicated and these data were discarded.

The survey queried whether premises had a petrol or diesel generator on site and its capacity presumed to be in most cases the kVA rating. A corrected generator capacity was obtained as follows: The generator capacities were listed in order of magnitude and compared to standard sizes of generator from online industry catalogues. In the case of petrol generators we would in general expect these to be small (< 10 kVa). A common size in the sample was 6.5 kVa. It was therefore assumed that values such as 650,000 (ID 302) and 6500 (IDs 304, 305, 310 and 313) were 6.5 kVa generators. Listed petrol generator sizes of 2700 (ID 423) and 1500 (ID 309) were assumed to be 2.7 kVA and 1.5 kVA respectively.

The formal sector had 4 large petrol generators listed between 64 and 94. These correlated with quite large volumes and were therefore assumed to be correct kVA ratings and are perhaps older machines. Two other large values for petrol generator ratings of 250 (ID 425) and 240 (ID 724) were, however, replaced with the informal sample average (3 kVA) and formal sample average (11 kVA) respectively.

In the case of diesel generators we would generally expect larger capacities (> 10 KVa) although smaller machines are commercially available. Exactly half the diesel generator sample had capacities between 10 and 90 kVA and 42% of the sample were indicated as being small machines (1.2–10 kVA). In cases where the annual volume consumed was less than 1000 litres these were left unchanged but for cases with high annual consumption (IDs 43, 741 and 743) the indicated capacity was assumed to be an error and the diesel total sample average (25 kVA) was assumed.

Any instances where generator consumption volumes were indicated but capacity ratings were not recorded were replaced either with the petrol informal sample average (3 kVA), petrol formal sample average (11 kVA) or diesel total sample average (25 kVA). The corrected capacities and volumes were then converted into kWh of electricity produced by assuming a fixed linear relationship between volumetric consumption and electrical output from a brief survey of online industrial sources as follows:

$FC_P = 0.398\ R_P + 0.566$ (1)[4]

$FC_D = 0.3192\ R_D$ (2)[5]

$E_P = V_P / (FC_P/R_P)$ (3)

$E_D = V_D / (FC_D/R_D)$ (4)

Where:

- FC = volumetric consumption (litres/hour)
- R = generator rating (kW)
- V = annual fuel consumed
- E = annual electrical energy produced (kWh)
- P denotes petrol and D denotes diesel

By combining Equations 5 and 7 we can derive a constant thermal efficiency assumption of 31.4% for diesel machines. The more partial the load on a generator relative to its rated load, the lower its thermal efficiency. There is, however, no way of knowing from the sample data what average load the generators are being run at. While relatively high, this assumed efficiency for diesel machines is more conservative than some other sources and was thus assumed reasonable given other sources of error. For petrol machines, the intercept in Equation 4 results in a diminishing efficiency as the capacity of petrol machines drops, which, while true in reality for both petrol and diesel machines, is poorly captured by this model for very small machines on further reflection. For the sample, however, the error is limited by the low volume consumed by small machines such that the weighted average thermal efficiency assumed is 21%. For future work the author's propose the following equations based on a more rigorous analysis of fuel consumption published by various manufacturers (see Appendix A).

For petrol-fuelled generators of capacity < 20 kVA where a load factor has been assumed:

$\eta_P = 1.03X10^{-1}\ \text{Load Factor} + 4.04X10^{-3}\ R_P + 6.18X10^{-2}$ (5)

$FC_P = R_P / (CV_p\ X\ \eta_P)$ (6)

For petrol-fuelled generators of capacity > 20 kVA or where a load Ffactor is not assumed:

$FC_P = 5.33\ X10^{-1}\ R_P + 5.00\ X10^{-2}$ (7)

For diesel-fuelled generators of all capacities where a load factor has been assumed:

$\eta_D = 1.26E\text{-}01 * \text{Load Factor} + 5.13E\text{-}04 * R_D + 1.69E\text{-}01$ (8)

$FC_D = R_D / (CV_D\ X\ \eta_D)$ (9)

Where:

- FC = volumetric consumption (litres/hour)
- R = generator rating (kW)
- P denotes petrol and D denotes diesel
- η denotes the thermal efficiency of the generator
- Load factor is the ratio of average load to rated load in operation and is between 25% and 100%
- CV denotes the calorific value of the fuel assumed to be 8.94 kWh/litre for petrol and 9.93 kWh/litre for diesel in this study

For this iteration of the model, the data processed by the first method was assumed to be a satisfactory estimate given other sources of error. By assuming a fuel consumption rate for each generator in the sample we can estimate the average time of use of the generators per day which

4 Linear regression by authors of online data for various manufacturers.

5 http://www.hardydiesel.com/generator-fuel-consumption-calculator.html.

is distributed as shown in Figure 8. On average, formal businesses use generators for 1.2 hours a day and informal businesses 0.85 hours per day.

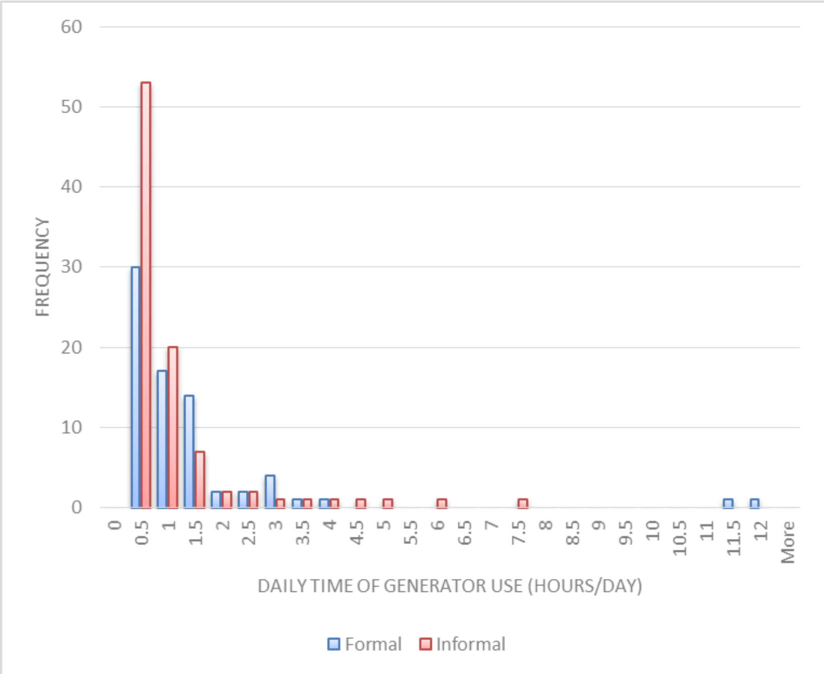


Figure 8: Distribution of calculated daily generator use for informal and formal businesses in both Ga East and Awutu Senya East

7. Agriculture sector

A survey was undertaken of agricultural activities in the municipal area, and mainly constitutes poultry farms and some 'cash-crop' farms – mainly pineapple producers. The total production of these mechanised farms was about 500 tonnes in 2013 and can fluctuate widely over the years, as shown in Table 33. The types of energy and consumption for 2013 were measured as shown in Table 34.

Table 33: Estimated output in the agriculture sector of ASEM

Year	*Output (tonnes)*
2010	268
2011	537
2012	312
2013	494

Table 34: Fuel consumption in the agriculture sector for ASEM

	*Transport**	*Processing*	*Heating*	*Drying*	*Lighting*	*Generator use*
Petrol (litres)	660					378
Diesel (litres)	2 018					
Electricity (kWh)		20 424	26290	14622	2549	
Charcoal (kg)		245	15499	192		
LPG (kg)			720	117		
Solar (kWh)					33	
* It is possible that the diesel consumption is being used for generators and not transport.						

We assume, however, that the transport requirements in agriculture are accounted for in the freight subsector of transport. Thus we do not include the transport component here; see Table 35.

Table 35: Energy intensities by end use in the agriculture sector for ASEM

	Processing	*Heating*	*Drying*	*Lighting*
Electricity (kWh/tonne output)	41.3	53.2	29.6	5.2
Charcoal (Kg/tonne output)	0.5	31.3	0.4	
LPG (Kg/tonne output)	-	1.5	0.2	-
Solar (kWh/tonne output)				0.1

8. Transport sector

This section describes the data and methodologies used for representing the transportation energy demand in ASEM. In this methodology, transport is split into passenger freight demands, each with its own driver (of demand). From the Focus Group Discussions (FGD) it was estimated that half of all households in ASEM had a vehicle, and this results in the light passenger vehicle count of 21 898.

8.1 Data

Data obtained by the SAMSET team indicated that in ASEM there were 29 245 passenger vehicles and 235 freight vehicles operating in and around the municipality (see Table 36).

Table 36: Vehicle population count for ASEM, survey 2014 data

Source: ASEM focus group discussions with transport stakeholders as part of the SAMSET project (Bawakyillenuo & Agbelie, 2014)

Vehicle type	*Vehicle count*	*%share*	*Petrol(%)*	*Diesel(%)*	*LPG(%)*
Heavy passenger vehicle >12	15	0.05		100	
Light passenger vehicle <12	21 898	74.21	90.4	9.6	
Mini buses	6 150	20.84	70	30	
Taxis	1 120	3.80	50.8	32.5	16.7
Motorbikes	62	0.21	100		
Tricycles	30	0.10		100	
Light trucks – Freight	70	0.24		100	
Medium trucks – Freight	45	0.15		100	
Heavy trucks – Freight	120	0.41		100	

The total fuel sold in the ASEM municipality was obtained from focus group discussions with fuel service stakeholders and representatives from the municipality and the municipal assembly that was part of the SAMSET survey in ASEM that included the direct surveys undertaken in the residential, commercial and industrial sectors. The data input to the transport model did not therefore derive from direct survey as was the case for other sectors.

The total fuel sales from fuel service stations in ASEM for 2013 as estimated by the focus group discussions is 17.4 million litres for diesel and 17.1 million litres for petrol (see table 37):

Table 37**: Annual fuel sold in ASEM stations in 2013**
Source: Stakeholder engagement by Ghanaian team for SAMSET project

No. of fuel stations	37
No. of LPG stations	9
Avg. volume petrol sold	450 000 litres/station
Avg. volume diesel sold	459 000 litres/station
Avg. volume LPG sold	4 468 720 kg/station

A liquid fuels energy balance for ASEM was compiled using the supply information (above) and the total demand for each liquid fuel indicated by the surveys for the other sectors (residential, commercial, etc). The balance of fuels is shown in Table 38, and indicates that transport (excluding municipal use) accounts for about 95% of petrol and 96% of diesel consumption in the municipality.

Table 38: The petroleum fuels energy balance for ASEM in 2013

			Diesel (L)	*Petrol (L)*	*LPG (kg)*
Supply	Supply from ASEM fuel stations:		17 442 000	17 100 000	40 218 480
Demand	Sector	Use			
	Industry	Machinery	49559		
		Other machine drive	30261		
		Process heating	180		
		Generators	60868	160	
	Residential	Cooking			3558961
		Generators	268652	911206	
	Commercial	Cooking			19431
		Machine operations			1498
		Other			41486
		Generators	24853	23319	
	Local Government	Vehicles	337500		
		Generators	0		
Demand subtotal			771873	934684	3621376
Balance to transport			16 670 127	16 165 316	36 597 104
Implied transport use % share of supply			95.6%	94.5%	91.7%

Some estimates on vehicle activity for passengers and freight were obtained by the SAMSET FGD's and help to inform assumptions and input on the passenger and freight activity as shown in Table 39.

Table 39: The average use of each vehicle type in the ASEM

Vehicle type	*Occupancy (people per vehicle)*	*Vehicle return trips per day*	*Days of use per week*	*Total people/week or tonnes/day*
Heavy passenger vehicle >12	60	4	6	43 200
Light passenger vehicle <12	1.5	2	6	394 164
Mini buses	20	10	6	7 380 000
Taxi	5	10	6	336 000
Motorbikes	2	8	6	5 952
Tricycle				450
Light trucks				2 100
Medium trucks				2 025
Heavy trucks				5 400

8.2 Methodology

ASEM is located approximately 30km west of Accra, and the Cape Coast road, which is a major route in and out of Accra, runs through ASEM. Households in ASEM are thus within a practical, though quite long, commuting distance to Accra and presumably can refuel there or within the municipality, while vehicles passing through on the Cape Coast road may choose to refuel in ASEM.

The general approach to the LEAP model of Awutu Senya for other sectors was to employ a calibrated supply and demand modelling methodology – the consumption of fuels in the model was calibrated so as to sum to the total supply of fuel to the municipality. This is a common energy modelling methodology and hinges on the premise that the municipality can usually only influence planning decisions within the municipality boundary. Clearly, a bounded area like a municipality is a generator and attractor of trips in the case of the transport sector, and therefore the municipality may be able to exert policy influence on the mode and other characteristics of these trips. Against this, an unbounded model of a bounded area cannot be calibrated against supply statistics and may be highly uncertain without a great deal of detailed measurements. Furthermore, such a model may not be consistent with that of another area, given overlapping trips and this can make reconciling models of different spatial scopes difficult. The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC Protocol), a collaborative effort to develop practical methodologies for local scale GHG emission inventories, has developed a standardised approach to deal with these issues (WRI 2014). This protocol recommends that data and models be organised in different scopes which tackle the spatial problem in different ways as follows:

Scope 1: Only trips that originate and end within the boundary are included. Upstream emissions embedded in energy carriers like petrol diesel and electricity are excluded.

Scope 2: Upstream emissions from electricity supply are added.

Scope 3: Transboundary trips originating and ending within the bounded area are included in Scope 3. A few methods may be considered but ideally the method of induced activity is preferred whereby 50% of the total trip length that occurs outside the boundary is accounted for as shown in Figure 9. Trips that pass through the bounded area are excluded completely in this methodology. It is, however, recognised that in general sophisticated traffic models for a city are required to track transboundary trips to this level of detail.

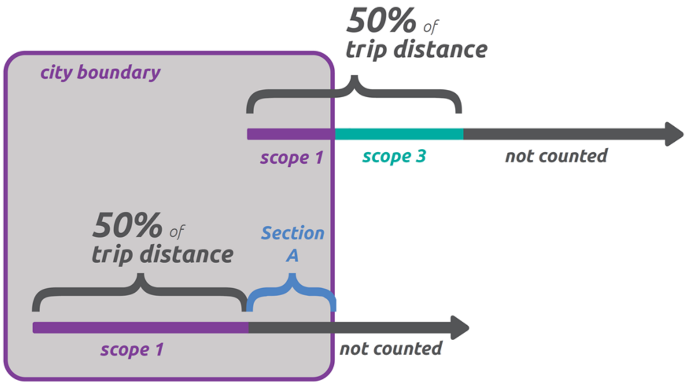


Figure 9: Induced activity method for accounting for transboundary trips in GHG inventories

The GPC protocol (WRI 2014) advocate the following methodologies that can be used in a GHG inventory of a city:

Fuel sales approach: GHG emissions are based only on the fuel sold within the boundary.

Induced activity approach: GHG emissions from intraboundary trips; 50% of transboundary trips are estimated from traffic models and surveys.

Geographic or territorial approach: Only GHG emissions from activity within the city's boundaries is included. Only some European traffic models, usually used for local air pollutant model make these estimates (WRI, 2014)

Resident activity approach: Only GHG emissions from activity by city residents is included. This requires a survey of resident behaviour and vehicle registration records but is limited by excluding the possibly substantial contribution of non-residents.

It was decided, given the data to hand and because the transboundary component of travel was of interest to stakeholders, to follow a hybrid methodology of the fuel sales and induced activity approach. Currently the level of detail in the available data is not sufficient for a rigorous implementation of the induced activity approach. so it was important to ground the approach in the fuel sales approach which was used to define 'Scope 1' energy demand and emissions but taking the following stipulation of the GPC Protocol into account:

> All fuel sales from in-boundary fuel dispensaries should be accounted for in scope 1, even though fuel purchases may be for transboundary trips. Maintaining all fuel sales emissions in scope 1 also enables more effective multi-city aggregation. However, cities may conduct surveys or use other methods to allocate total fuel sales into scope 1 and scope 3 emissions.

For this model, given the absence of surveys, Scope 1 balanced fuel sales in the area but included some portion of transboundary trips.

In the case of Awutu Senya East, there is some activity data from focus groups but no direct measurement can be confirmed, so to completely meet the stipulations of all three scopes of GPC would not be possible. We can make certain assumptions, however, based on this initial data and furthermore assume, as a starting point, that work-commuting trips are dominated by journeys to Central Accra of a similar distance. On review therefore the following principles were adopted:

- Unless service stations are not permitted within a municipal area, the quantity of fuel sold/supplied therein is likely to be broadly indicative of transport activity consisting of trips confined within the municipal area (intraboundary trips – Scope 1) and trips both originating and ending within the boundary of the municipal area (interboundary trips – Scope 2).
- The further away the strong attractors and generators of trips are from the municipal area, the greater will be the portion of fuel not accounted for by local sales.
- Counter to this, the proximity of a major arterial on which filling stations within the municipal area have been built for the clear purpose of servicing this traffic, as indicated by large volumes, implies that internal sales of fuel may over-represent in scope transport activity.

- It is important to calibrate energy models where possible, and it was therefore decided to develop a framework that allows a ‘partial’ calibration whereby the modeller can adjust the assumed or observed ratio of fuel fill-ups within the municipality relative to those without. While this ratio may be conjectural without direct measurement, it has the effect of keeping the total fuel used by vehicles registered or used for public transport in the municipality within reasonable bounds. In the case of Ga East, if we assume a large proportion of trips are made to central Accra, we can adjust this refuelling ratio and the trip length till a reasonable compromise is reached between the supply and demand side data from the focus groups, spatial considerations and typical norms like vehicle fuel economies and trip frequencies.
- If calculated transport energy demand, given reasonable, representative or observed activity levels for the vehicle population assumed to operate within the municipal boundary is less than the supply-side total in the petroleum fuels energy balance (see Table 38) then the remainder can be assigned to ‘corridor’ traffic refuelling in the municipality which is modelled as a separate demand to transport service demand within the municipality. This is to be considered in the case where the municipality is located on a major route such as a highway and the fuel stations are reasonably proximate to that route, such that commuters passing through might refuel there. If results were to be reported according to Scope 3 of the GPC, then the energy demand and emissions from these trips would be excluded, but it is included in the model as a demand node to be included or excluded as required.
- Clearly, in so-called ‘dormitory’ municipalities an important energy and emissions scenario may be to reduce the travel demand of commuting to a neighbouring big city by developing public transport options. It is, however, proposed that, in the case that this is of interest, this travel demand is also modelled as a separate transport demand in the model and furthermore that data be collected on the frequency, distance and vehicle occupancy of this type of commuting to make a reasonably representative model possible. This demand node, consisting of transboundary trips, would be equivalent to Scope 3 of the GPC methodology discussed above. For formal GPC-compliant reporting purposes this demand can be halved to be consistent with the 50% transboundary trip requirement, given the current simple activity assumptions of a fixed mileage per vehicle at an assumed representative fuel economy. For the purpose of assessing the energy system of the municipality in isolation, however, it is more useful to report the estimated entire trip energy demand arising from the focus group’s assessment of general vehicle behaviour in GEM.

For the ASEM model, assumptions were developed for local and commuting passenger demand, applying the data collected where possible. These are explained in more detail below. Essentially this results in petrol supply being more or less balanced by local travel demand and commuting to outside the municipality by residents with little allocation to corridor, while diesel allocation to corridor is far greater, to balance supply. It must be stressed that these assumptions should ideally be improved by future data collection on both commuting behaviour and rates of refuelling of vehicles passing through the municipality.

The remaining fuel balance from Table 38 is used to calibrate the transport model for ASEM in conjunction with the data on vehicle count and estimated vehicle occupancies and trip frequencies – this is outlined next.

Model set up

The overall approach to handling the data and setting up the transport energy model was to first set up the model with the given data and review the results against known common indicators/data such as the annual distance travelled by each vehicle as well as total fuel supplied to the transport sector.

The model is set up with the following elements:

1. Vehicle count (from data)
    a. For each vehicle type (minibus, bus, car, etc).
2. Vehicle split by fuel type (from data)
    a. Diesel, petrol, or LPG (only in taxis).

3. Vehicle occupancy per trip (from data).
4. Fuel economy (L/100km).
5. Vehicle trips per week (from data).
6. Trip split for each vehicle between 'local' and 'Accra' (an assumption).
7. Assumption on frequency of fill-ups for each vehicle that occurs in ASEM (assumption).

For the ASEM model, assumptions were developed for local and commuting passenger demand applying the data collected where possible, and these are explained in more detail below. Essentially this results in petrol supply being more or less balanced by local travel demand and commuting to outside the municipality by residents with little allocation to corridor, while diesel allocation to corridor is far greater to balance supply. It must be stressed that these assumptions should ideally be improved by future data collection on both commuting behaviour and rates of refuelling of vehicles passing on the Cape Coast Corridor.

Model detail

The vehicle count for ASEM was adjusted down somewhat mainly in order to help calibrate fuel consumption in ASEM, but this could be justified by the fact that older vehicles may no longer operate or operate very little in practice. The vehicle counts are also not from a registration database and are estimates from stakeholder engagement and therefore is was deemed acceptable to make slight adjustments if this assisted calibration. Table 40 shows the adjustments to the vehicle count in ASEM.

Table 40: Vehicle count adjustments for ASEM

Vehicle type	*Original data on vehicle count*	*Adjustment*	*New vehicle count*	*Comment on adjustment*
Bus	15	100%	15	
Car	21 898	90%	19 708	Adjusted down assuming some do not operate in ASEM, this also aides in balancing fuel consumption
Mini buses	6 150	90%	5 535	As above
Taxi	1 120	90%	1 008	As above
Motorbikes	62	100%	62	Did not modify since this vehicle count is very low.

The passenger transport model requires assumptions on travel activity and fuel economy for each vehicle type in order to gauge how far each vehicle travels per year and thus how much fuel they consume. With an occupancy number this can be converted into passenger-km demand for ASEM.

Model set up

The overall approach to handling the data and setting up the transport energy model was to first set up the model with the given data and review the results against known or common indicators/data such as annual distance travelled by each vehicle as well as total fuel supplied to the transport sector.

The model requires the following key inputs:

8. Vehicle count (from data)
    a. For each vehicle type (minibus, bus, cars etc).
9. Vehicle split by fuel type (from data)
    a. Diesel, petrol, or LPG (only in taxis).
10. Vehicle occupancy per trip (from data).
11. Fuel economy (L/100km).

12. Vehicle trips per week (from data).
13. Trip split and length for each vehicle between 'local' and 'Accra' (assumed commuting demand).
14. Assumption on frequency of fill-ups for each vehicle that occurs in ASEM (assumption).

Since there is a large portion of people living in ASEM and working in Accra (Communication with Ghanaian SAMSET team), the trips to and from Accra needed to be accounted for. This aspect also adds to the complexity of fuel balancing since the boundary of the city is now 'porous' when it comes to fuel utilisation as described above. Thus the total pass-km demand for this model is set up to account for local and 'Accra' trips that a vehicle may take during the year, and how much ASEM would effectively be responsible for fuelling is based on data provided and various assumptions where necessary. This is given in the equations below.

The total effective passenger-km demand as seen by ASEM fuelling stations:

$$Total\ pass.km\ demand = \sum_v EAM_v \times Veh\ count_v \times Avg.Occupancy_v \quad (13)$$

where EAM is the Effective Annual Mileage[6] (in km per year) of each vehicle type (v):

$$EAM_v = \sum_t R_{t,v} \times (\%\ Trips\ Serviced\ by\ ASEM)_{t,v} \quad (14)$$

where, $R_{t,v}$ is the total return trip km for each trip type (t is either 'Accra' or 'Local') and for each vehicle type (v) for a year:

$$R_{t,v} = 2 \times (1way\ trip\ distamce)_{t,v} \times (total\ Return\ trips\ per\ year)_{t,v} \times (Trip\ Split\ \%)_{t,v} \quad (15)$$

These equations are used in conjunction with assumptions on trips splits based on two different scopes adopted for study here. The first scope is a calibrated (to total fuel sold) transport model, and the second (Scope 3) is one where transboundary travel is accounted for (trips to Accra).

8.2.1 Scope 1 methodology

In this scope, only a portion of transboundary trips are accounted for, while the majority of local (intraboundary) trips are assumed to be serviced by ASEM such that the total fuel consumed by that portion of the transport sector represented in the model is calibrated to the total fuel sold in ASEM. The inputs for these equations are given in the tables below, and effectively describe the assumptions and characteristics of the transport sector model for ASEM.

Table 41: The basic assumptions for the passenger transport model for ASEM

Vehicle type (v)	*Trip split % (a)*		*1way trip distance – km (b)*		*Return trips per day (c)*	*Days of trip Use (c)*	*Total return trips/year*
	Accra	*Local*	*Accra*	*Local*	*Trips/day*	*days/year*	
Bus	25%	75%	30	6	4	312	1 248
Car	75%	25%	30	6	1*	312	312
Minibuses	10%	90%	30	6	5*	312	1 560
Taxi	10%	90%	30	6	10	312	3 120
Motorbike	0%	100%	30	6	8	312	2 496

(a)These are assumptions
(b) Local distance is an assumption. Accra distance is estimated from Google maps.
(c) Communication with Ghanaian SAMSET partners
* The original numbers from the FGD are factored down by half, without which the fuel consumption in ASEM is more than 50% of what was sold and this is mainly from light vehicles and minibuses.

6 The EAM is the effective veh-km that ASEM would be servicing with fuel. Much of the transport in and around ASEM is thought to be corridor transit – mainly to and from Accra, and thus ASEM would not supply 100% of all the fuel a vehicle consumes, and so only 'sees' the vehicle doing less or equal to the vehicle's true mileage.

Combined with Table 36 (vehicle counts) and Table 39 (vehicle occupancy) and the following fuelling assumptions and vehicle activity, the remaining inputs to the equations as well as the effective annual mileage (EAM) are presented in Table 42.

Table 42: Passenger travel between Accra and ASEM – Assumptions for Scope 1

	Total km of return trips		*True mileage (km/year)*	*Return trips/day serviced by ASEM (assumptions)*		*Veh-km serviced by ASEM*		*EAM for Scope 1 (km/year)*
	Accra	*Local*		*Accra*	*Local*	*Accra*	*Local*	*Total*
Bus	18 720	11 232	29 952	50%	100%	9 360	11 232	20 592
Car	14 040	936	14 976	25%	100%	3 510	936	4 446
Mini buses	9 360	16 848	26 208	10%	50%*	936	8 424	9 360
Taxi	18 720	33 696	52 416	25%	100%	4 680	33 696	38 376
Motorbikes	0	29 952	29 952	50%	100%	0	29 952	29 952
* Without this adjusted number (from 100%) the total fuel consumption becomes much larger than what is supplied to ASEM. This is purely an assumption to assist calibration therefore								

Notably, the result of calibrating the mileage travelled within the municipality (EAM) to balance the sales of ASEM fuel service stations results in low mileages for cars and minibuses, but as can be seen from the discussion on Scope 3 below, the true annual mileages implied by the assumptions above are somewhat closer to average typical global annual mileages (in the region of 10 000–20 000 km/year for passenger cars and double this or more for public transport vehicles). The assumed fuel economies of each vehicle type used in this model are given in Table 43.

Table 43: The fuel economy per vehicle type used in this model

	Fuel economy (litres/100 km)		
	Petrol	*Diesel*	*LPG*
Bus		30	
Car	10	8	
Mini buses	18	15	
Taxi	10	8	6.5
Motorbikes	3.5		

Applying the assumptions for distance travelled per day and vehicle occupancy yields the passenger transport demand for each mode shown in Table 44. Light passenger vehicles do not travel very far as seen by the municipality because the quantity of fuel observed to be sold is not large enough to account for the full vehicle activity. This is a result of the 'serviced by ASEM' assumption in Table 42. These assumptions imply that a lot of fuel used by vehicles does not come from within ASEM but this should ideally be verified by future surveys. The total fuel use allocated to each vehicle type is presented in Table 45.

Table 44: Resulting passenger vehicle activity for ASEM

	Effective annual mileage (vehicle km/year)	*Total demand based on mileage serviced by ASEM, vehicle count and occupancy (passenger-km/year)*
Bus	20 592	18 532 800
Car	4 446	131 433 986
Mini buses	9 360	1 036 152 000
Taxi	38 376	96 707 520
Motorbikes	29 952	3 714 048

Table 45: Total fuel consumption for the passenger transport model by vehicle type

	Fuel consumption (litres)		
	Petrol	*Diesel*	*LPG*
Bus	-	92 664	
Car	7 923 171	671 276	
Mini buses	6 527 758	2 331 342	
Taxi	1 964 384	1 005 765	420 362
Motorbikes	64 996	-	
Total	**16 480 309**	**4 101 046**	**420 362**

Freight transport

Freight transportation in ASEM is estimated based on the vehicle count data provided (see Table 36) and a set of assumptions on overall vehicle activity, shown in Tables 46 and 47.

Table 46: The assumptions used for the freight section of transport in ASEM

	Fuel split		*Capacity load (tonnes)*	*Assumed load factor*	*Annual-km*
	Petrol	*Diesel*			
Tricycle		100%	0.08	50%	30 000
Light trucks		100%	1	50%	30 000
Medium trucks		100%	8	50%	45 000
Heavy trucks		100%	20	50%	55 000

Table 47: Fuel economy assumptions for freight vehicles

	Fuel economy (litres/100 km)	
	Petrol	*Diesel*
Tricycle	4	-
Light trucks	20	18
Medium trucks	38	35
Heavy trucks	-	50

From these assumptions the following (Table 48) is used for model input relating total freight demand and fuel consumption:

Table 48: The freight transport model inputs for ASEM

Vehicle type	*Tonne-km*	*Assign to*	*MJ/tonne-km*
Heavy truck	66 000 000	Corridor	1.8
Medium	8 100 000	Corridor	3.14
Light	1 050 000	Local	12.9
Tricycle	36 000	Local	0.0
Total	75 186 000		

Fuel unaccounted for

The total fuel balance left over after deducting fuel demand estimated by the transport methodology from the fuel sales less the consumption by other sectors is then allocated to the demand from corridor traffic. Given the assumptions discussed above, this totals about 49% diesel that is unaccounted for by local demand and private commuting to Accra and surrounds as shown in Table 49.

Table 49: Balance of fuel left over after passenger and freight consumption

Fuel	*Unaccounted volume (litres)*	*Share of supply allocated to transport (%)*
Diesel	8 182 331	49
Petrol*	0	0
* From the passenger demand model set up the fuel consumed was about 1% more than supplied given the assumptions in this model, thus there is no petrol allocated to corridor.		

The large amount of diesel unaccounted for may easily be attributed to freight traffic passing through the municipality along the coastal road leading in and out of Accra.

An assumption is made about the split between freight and passenger usage along the corridor, shown in Table 50.

Table 50: Assumptions on the unaccounted fuel usage along the ASEM corridor

	Diesel
Freight	85%
Passenger	15%

It is assumed that the freight transport mode that consumes the unaccounted fuel is large trucks – most likely the type that would be passing through the municipality on long distance routes.

Table 51: Resulting corridor transport activity

	Litres consumed		*MJ tonne-km or passenger-km*		*Total activity (tonne-km or passenger-km)*	
	Diesel	*Petrol*	*Diesel*	*Petrol*	*Diesel*	*Petrol*
Freight	6 954 981		1.79		138 606 399	
Passenger	1 227 350		0.27		163 646 614	

The freight transport from the vehicle count data is combined with the fuel balancing freight component as given in Table 52 to give the corridor freight and the local freight

Table 52: Freight split by corridor and local components for vehicle type

	Applied methodology	*Assigned to*	*tonne-km*
Tricycle	Vehicle count from data	Local	36 000
LCV	Vehicle count from data	Local	1 050 000
MCV	Vehicle count from data	Corridor	8 100 000
HCV	Vehicle count from data	Corridor	66 000 000
HCV	Fuel balancing	Corridor	138 606 399

The final fuel consumption for Scope 1 methodology is given in Table 53:

Table 53: Fuel consumption and supply (in litres) for scope 1 methodology transport for ASEM

	Petrol	*Diesel*	*LPG*
Fuel consumed	16 480 309	16 670 127	369 098
Fuel supplied	16 165 316	16 670 127	68 300 260
Error	-1.95%	0.00%	99.46%

This scope 1 methodology approach results in the passenger and freight transport inputs into the model shown in Table 54.

Table 54: Passenger and freight transport inputs into the model

Locally refuelled	*Passenger-km*	*% share*	*MJ/passenger-km*
Passenger	**1 449 606 705**		
Transboundary	**390 662 824**		
Public	**286 899 151**		
Bus	8 424 000	2.9	0.179
Minibus D	194 150 911	67.7	0.269
Minibus P	72 530 640	25.3	0.289
Taxi D	3 832 945	1.3	1.146
Taxi P	5 988 976	2.1	1.284
Taxi LPG	1 971 679	0.7	0.532
Private	**103 763 673**		
Car D	9 936 645	9.6	1.909
Car P	93 827 028	90.4	2.140
Local	1 058 943 881		
Public	1 027 559 520		
Bus	10 108 800	1.0	0.179
Minibus D	279 761 040	27.2	0.269
Minibus P	652 775 760	63.5	0.289
Taxi P	43 120 627	4.2	1.284
Taxi D	27 597 201	2.7	1.146
Taxi LPG	14 196 091	1.4	0.532
Private	**31 384 361**		
Car D	2 649 772	8.4	1.909
Car P	25 020 541	79.7	2.140
Motorbike	3 714 048	11.8	0.562
Corridor	**163 066 351**		
Public	**163 066 351**		
Mini bus D	163 066 351	100.0	0.269
Mini Bus P	-	0.0	
	tonne-km	*% share*	*MJ/tonne-km*
Freight	**213 792 399**		
Local	1 086 000		
Trike	36 000	6.4	14.42
LCV	1 050 000	93.6	12.98
Corridor	212 706 399		
MCV	8 100 000	3.8	3.13
HCV	204 606 399	96.2	1.79

8.2.2 Scope 3 methodology

In this section, we present the assumptions used to set up the transport model in the Scope 3 methodology where all trips are accounted for – both local and transboundary trips. We use the same data and assumptions as Scope 1 for the trip splits and trips per year as given in Table 42, but new assumptions for the share of return trips to Central Accra are included in the scope of the model. This yields a new effective annual mileage (EAM) that reflects the assumed average annual mileage of vehicles in ASEM. Using the inputs to the model shown in Table 55, the total passenger-km demand for ASEM is determined, as in Table 56.

Table 55: Passenger travel between Accra and ASEM – Assumptions for Scope 3

	Total km of return trips		*True mileage (km/year)*	*Return trips/day accounted for (assumptions)*		*Vehicle-km included in ASEM scope*		*EAM for Scope 3 (km/year)*
	Accra	*Local*		*Accra*	*local*	*Accra*	*Local*	*total*
Bus	18720	11 232	29 952	100%	100%	18 720	11 232	29 952
Car	14040	936	14 976	100%	100%	14 040	936	14 976
Mini buses	9360	16 848	26 208	100%	100%	9 360	16 848	26 208
Taxi	18720	33 696	52 416	100%	100%	18 720	33 696	52 416
Motorbikes	0	29 952	29 952	100%	100%	0	29 952	29 952

Table 56: Total passenger-km for all vehicles in ASEM in 2013 in Scope 3 methodology

	True mileage (vehicle km/year)	*Annual mileage (vehicle km/year)*	*Total demand (passenger-km/year)*
Bus	29 952	29 952	26 956 800
Car	14 976	14 976	442 725 005
Mini buses	26 208	26 208	2 901 225 600
Taxi	52 416	52 416	132 088 320
Motorbikes	29 952	29 952	3 714 048

Freight

The freight model set-up and assumptions used in Scope 3 are the same as for Scope 1 methodology described above.

Fuel unaccounted for

The transboundary assumptions centre on the passenger mode which is dominated by demand for petrol, easily accounting for estimated supply in the municipality but the increased mileage of diesel fuelled passenger vehicles under Scope 3 also leaves less diesel remaining on the supply side after accounting for passenger and freight demand than for the Scope 1 approach as shown in Table 57. This unaccounted for diesel was designated to the corridor under the same assumptions as the Scope 1 methodology; see Table 58.

Table 57: Unaccounted for fuel in the supply demand balance: Scope 3

	Litres	*% of supply*
Diesel	1 956 956	11.7%
Petrol	-	

Table 58: Unaccounted fuel to corridor transport assumptions in Scope 3 methodology

	Assumed split		*Litres consumed*		*MJ per activity*		*Total activity (tonne-km or Pass-km)*	
	Diesel	*Petrol*	*Diesel*	*Petrol*	*Diesel*	*Petrol*	*Diesel*	*Petrol*
Freight	85%	30%	1 663 413	-	0.90	-	66 536 505	-
Passenger	15%	70%	293 543	-	0.27	-	39 139 121	-

The freight transport from the vehicle count data is combined with the fuel balancing freight component as given in Table 59 to give the corridor freight and the local freight:

Table 59: Freight tonne-km split between local and corridor for scope 3 methodology

	Applied methodology	*Assigned to*	*tonne-km*
Tricycle	Vehicle count from data	Local	36 000
LCV	Vehicle count from data	Local	1 050 000
MCV	Vehicle count from data	Corridor	8 100 000
HCV	Vehicle count from data	Corridor	66 000 000
HCV	Fuel balancing	Corridor	33 268 252

The fuel consumption in this Scope 3 methodology is given in Table 60, where diesel meets supply but petrol is almost 200% more than supply.

Table 60: Fuel consumption balance for Scope 3 methodology

	Petrol	*Diesel*	*LPG*
Fuel consumed	47 714 355	16 670 127	369 098
Fuel supplied	16 165 316	16 670 127	68 300 260
Difference	195.17%	0.00%	-99.46%

Using this methodology and assumptions about travel for transboundary passenger trips, the detail on transport shown in Table 61 was used as input for the LEAP model.

Table 61: Scope 3 methodology transport model inputs

Locally refuelled	*Passenger-km*	*% share*	*MJ/passenger-km*
Passenger	**3 545 848 893**		
Transboundary	**1 554 368 213**		
Public	**1 139 313 521**		
Bus	16 848 000	1.5%	0.179
Minibus D	349 984 721	30.7%	0.269
Minibus P	725 306 400	63.7%	0.289
Taxi D	15 331 779	1.3%	1.146
Taxi P	23 955 904	2.1%	1.284
Taxi LPG	7 886 717	0.7%	0.389
Private	**415 054 692**		
Car D	39 746 581	9.6%	1.909
Car P	375 308 111	90.4%	2.140
Local	**1 991 480 681**		
Public	**1 960 096 320**		
Bus	10 108 800	0.5%	0.179
Minibus D	559 522 080	28.5%	0.269
Minibus P	1 305 551 520	66.6%	0.289
Taxi P	43 120 627	2.2%	1.284
Taxi D	27 597 201	1.4%	1.146
Taxi LPG	14 196 091	0.7%	0.389
Private	**31 384 361**		
Car D	2 649 772	8.4%	1.909
Car P	25 020 541	79.7%	2.140

Motorbike	3 714 048	11.8%	0.562
Corridor	39 139 121		
Public	39 139 121		
Mini bus D	39 139 121	100.0%	0.269
Mini Bus P	-	0.0%	
Freight	*tonne-km*	*% share*	*MJ/tonne-km*
Total	108 454 252		
Local	1 086 000		
Trike	36 000	6.4%	14.426
LCV	1 050 000	93.6%	12.888
Corridor	107 368 252		
MCV	8 100 000	7.5%	3.13
HCV	99 268 252	92.5%	1.79

9. Predicting the future: Business-as-usual

This section outlines the basic assumptions and data used to inform the 'business as usual' scenario for ASEM that will be the baseline against which to measure interventions/scenarios.

9.1 Main Drivers and assumptions

With accounting multi-sectorial models such as this one, population and economy are generally assumed to be the main elements which drive the overall activity (and hence energy consumption) of the municipality.

GDP and economy

Figure 10 shows national annual GDP growth rates. Although the country has sustained high national growth rates for the last 15 years as a whole, the last couple of years have seen much lower growth rates as the country has experienced energy shortages, currency depreciation and rising inflation. Ghana's economic growth has largely been driven by the services sector, which accounts for approximately half of the national economy, followed by industry and agriculture sectors (Ghana Statistical Services, 2014).

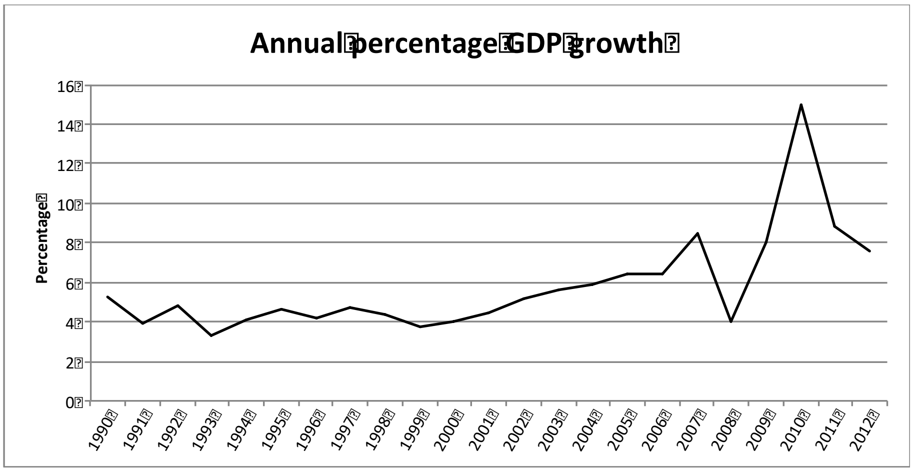


Figure 10: Ghana GDP growth rates
(www.databank.worldbank.org)

The economy of Ghana grew between 4% and 9.6% annually between 2009 and 2013 if oil related value activities are excluded as shown In Table 62.

Table 62: Recent economic growth rates for Ghana
(Ghana Statistical services 2014a)

	2009	2010	2011	2012	2013
GDP at current market prices (%)	21.3	25.8	29.9	25.3	24.7
GDP at constant 2006 prices (%)	4	8	15	8.8	7.1
Non-oil GDP at constant 2006 prices (%)	4	7.7	9.6	8.1	6.5

Ghana has achieved a relatively high economic growth rate (even when excluding oil). The average non-oil GDP growth rate between 2009 and 2013 for Ghana was 7.2%.

It is assumed that, since ASEM is in close proximity to Accra, which is a major centre for Ghana's economy, that the local economy of ASEM would closely track that of the country. The 'TradingEconomics' website[7] which compiles many indicators and statistics for countries, estimates that the growth trend for Ghana will likely remain relatively high through to 2020 at around 6.6% year on year on average. The following assumptions were made for this scenario regarding economic growth:

- Up to 2020, the economy will grow at national rates of 7.2% on average – this is the average of non-oil GDP over the last 5 years.
- From 2020 to 2030, the economy will 'slow' somewhat to a 6.5% year-on-year growth rate on average.

Population

The population growth rate assumed till 2030 is 3% per annum – this is from communication with the SAMSET Ghana team.

Fuel prices

The prices of liquid fuels in ASEM were obtained by the SAMSET Ghana team during data collection (see Table 63).

Table 63: Prices of liquid fuels in ASEM (GHC/litre)

	2012	2013
Diesel	2	2.44
Petrol	2	2.56
LPG	2.57	2.72

It is assumed that the prices of petrol, diesel and LPG will follow the trend of international crude oil prices. The projection of crude oil prices by the World Bank is given in Table 64.

Table 64: The expected cost of crude oil, as projected by the World Bank to 2025

	2013	2014	2015	2016	2017	2018	2019	2020	2025	2030*
Real 2010 USD	98.1	90.9	54.4	56.8	58.2	59.7	61.2	62.7	70.8	75.8

* The 2030 value is interpolated based on world economic outlook and the 2025 World Bank figure.

The cost of charcoal as reported by the SAMSET survey was 0.53 GHC per kg in 2013 (see Table 65).

[7] Website was accessed mid-2015 and projections were based on the data for Ghana at that time. See http://www.tradingeconomics.com/ghana/gdp-growth-annual for more information on GDP forecasts.

Table 65: Price of charcoal GHC per kg in ASEM

	2011	*2012*	*2013*
Charcoal	0.43	0.44	0.53

Assuming an exchange rate of 2.31 Cedi to a USD in 2013, the fuel prices shown in Table 66are assumed in the ASEM model.

Table 66: fuel prices in ASEM in 2013 USD

Fuel	*2013*
Petrol	1.11 litres
Diesel	1.06 litres
LPG	1.18 kg
Charcoal	0.23 kg

Electricity costs are adapted from the public utilities regulatory commission notice on electricity tariffs changes for 2013; see Table 67. These prices were mapped to households and non-residential customers in ASEM using the existing tariffs in Table 68.

Table 67: Electricity prices approved by the Ghana Public Utilities Regulatory Commission in 2013

Approved Residential End User Electricity Tariff Effective October 01, 2013

Residential Customer Class	Existing Tariff (GHp / kWh)	Approved Tariff (GHp / kWh)	Percentage Increase
0 – 50	9.5000	15.6750	65.0%
51-150	17.5785	31.4479	78.9%
151-300	17.5785	31.4479	78.9%
301-600	22.8135	40.8134	78.9%
601+	25.3483	45.3481	78.9%

Note: GHp are Ghanain Pesewas (100 Pesewas equals one Cedi).

Table 68: Electricity prices for ASEM in 2013 and 2014

	Grouping	*GHp*	*USD Existing*	*USD new approved*
ASEM users:	kWh	2013	2013	2014
HH3	0-150	13.54	0.06	0.11
HH2	151-300	20.19	0.09	0.16
HH1	Avg. 301-600 and 601+	24.08	0.10	0.19
IND	Avg. 301 – 600 and 600+	36.76	0.16	0.29
Commercial formal	601+	42.43	0.18	0.33
Commercial informal	0-300	25.27	0.11	0.20

It is assumed the electricity price will remain constant in real terms from 2015 onwards (i.e. no change after adjusting for inflation).

The summary of the key drivers in this model, economic growth and population growth, are presented in Table 69.

Table 69: BAU key drivers assumptions summary

Key parameter	*Assumption in BAU*
GDP growth rate	7.2%pa until 2020, then 6.5% pa until 2030
Population growth rate	3% pa assumed to remain constant to 2030

9.2 Commercial sector

It is assumed that the formal part of the commercial sector growth follows that of the national growth trajectories for Ghana, with an elasticity of 0.9. The informal commercial sector, however, which makes up a significant part of the economy, is assumed to follow population growth rates since by nature it is driven largely by the formal economy being unable to create new jobs – pushing people into the informal sector (Ose-Boateng and Ampratwum, 2011). This inherently comes with the assumption that there is no change in the rate at which the formal sector assimilates the informal sector – or, rather, there is no change in the economic structure of ASEM.

9.3 Transport

Freight

Freight transport projections are assumed to follow the output from industry within ASEM. It is broadly assumed that the overall truck usage within the municipality is linked to the activity of those sectors which are more likely to use freight transport.

Corridor

The freight component of the corridor is assumed to follow the growth rates of GDP since it is a reflection of economic activity, not just of ASEM, but nationally.

The passenger component of transport is assumed to follow that of the GDP per capita growth rates.

Passenger transport: Tracking future passenger-km demand:

Simulation transport models have generally employed a simple tracking of GDP per capita to estimate future passenger-km demand, as this follows the general wealth of citizens which would lead to higher mobility demand. However, a simple GDP over population formulation would mean that a scenario where population growth outstrips economic growth would result in a decrease in transport demand. Therefore we derived an alternative formulation of the GDP per capita driver for passenger transport demand – one which keeps the GDP per capita (or general wealth of the populace) as the key component to transport demand but does not allow for a net drop in transport demand with increased population (something which would not be observed in reality). This is outlined below.

Private passenger demand is directly proportional to motorisation (vehicles per thousand people), and motorisation is proportional to GDP per capita[8] and can be written as some linear function of GDP per capita:

$$M \approx k\left(\frac{GDP}{Pop}\right) \quad (16)$$

where *k* is a constant to calibrate the base year values (in the year 2011 of the model).

The number of cars (private 4 wheel cars) is then:

$$cars = M \times population \times 1000 \quad (17)$$

Again this is calibrated to the base year value for Awutu Senya (this is 29 418 vehicles of the active four-wheel private vehicles).

Then the population that is motorised (privately) is:

$$mpop = Occupancy \times cars \quad (18)$$

where *occupancy* is the assumed base year value of 1.5 people per vehicle.

8 This relationship is typically represented using a Weibull or Gompertz relation which is a logisitic ‘S-shaped curve’; however, without reliable registration data on vehicles, this Weibull relation cannot be tested or the parameters for a distribution empirically derived. With this in consideration, a linear relation is deemed sufficient until better information is available.

And thus:

$$Private\ pass.km\ demand = Occupancy \times Avg\ Mileage \times cars \qquad (19)$$

where *Avg Mileage* is the weighted average of 4 wheel private vehicles (private cars and the LCV's assumptions) from the analysis in the transport section of this report.

The population of non-private car motorisation is then:

$$NCAP = Population - mpop \qquad (20)$$

Then the passenger-km demand for public transport is assumed to be linearly linked to the non-private car populace:

$$pass.km\ public\ = x \times NCAP \qquad (21)$$

where *x* is used to calibrate to the base year values in the transport model.

With this formulation, therefore, the demand for private transport is driven by population and income growth while the demand for public transport is driven by the growth in the population without access to a car.

BRT is planned to be implemented in Accra by the end of 2015, with only a few buses starting in the initial phase from the Amasaman and Achimota areas as part of a trial phase (see Figure 11). The BRT system will be extended in time, based on the success of the initial phase, to include Kosoa (Awutu Senya) and Adenta. This second phase of the BRT which may operate within ASEM, will likely be a few years after the initial phase – provided that proves successful.

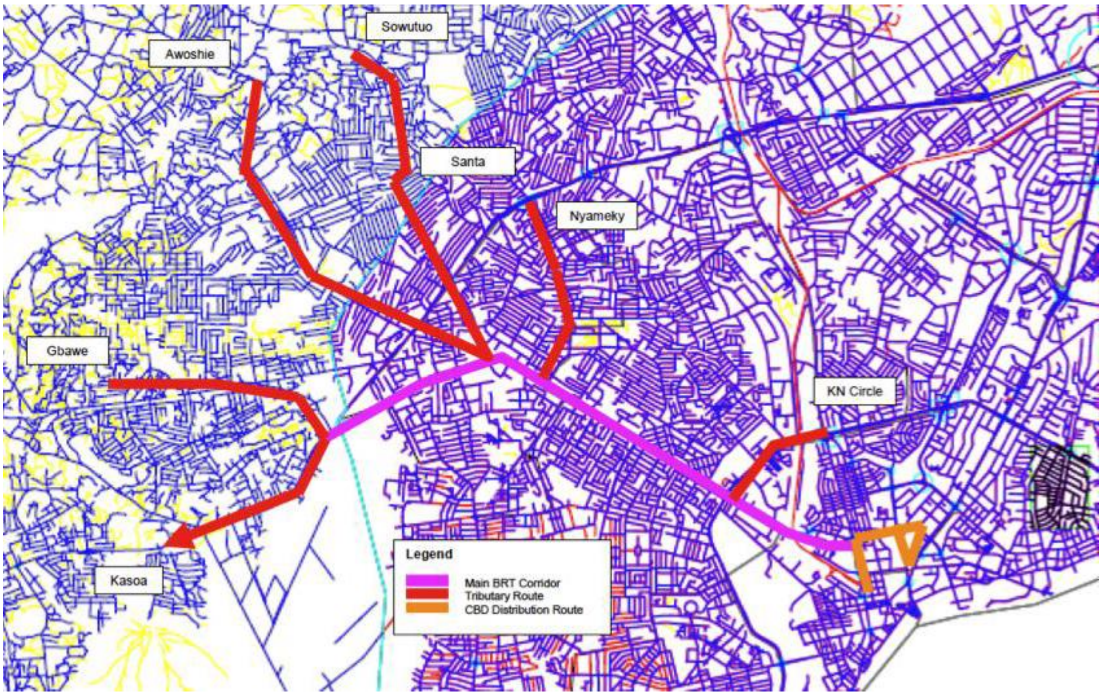


Figure 11: Map of Pilot BRT in Accra
(Okoye et al., 2010)

The transport land use research study for the BRT project (Okoye et al. 2010) expected that most of the users of the BRT system would migrate from trotro's and buses. This is assumed to be the case in this scenario, and that once BRT comes into effect within and around ASEM that most passengers on the BRT system will come from buses and trotro users.

In summary the transport sector is represented as follows in the BAU scenario:

- The demand for private transport passenger-km is driven by population and income (GDP/capita) growth while the demand for public transport passenger-km is driven the growth in the population without access to a car. Private transportation – light vehicles and motorbikes – is assumed to have the characteristics of the base year: no change in occupancy rates, and similar fuel efficiencies.

- Future public transportation is assumed to have similar characteristics to the base year, with the addition of BRT
- BRT comes into effect by 2020 – with buses departing from Kasoa to Accra.
- BRT takes up about 10% by 2020 (the start year) and 40% of bus and trotro passenger demand by 2025.
- BRT are assumed to be 10% more fuel efficient per passenger-km than the buses.
- Freight tonne-km for trucks is driven by local industry growth.
- Corridor freight demand is driven by GDP (this is a reflection of national growth).
- Corridor passenger demand is driven by GDP per capita.

9.4 Municipal sector

Buildings

The energy use of municipal buildings or offices is assumed to grow at 10% of the household growth rate. It is assumed that, in principle, municipal energy use that is not transport will track general household growth. In other words, the more houses to serve, the more 'activity' will be required from the municipality but with a lower rate of growth of municipal building floorspace and hence energy.

Transport

Transport-related energy consumption (diesel consumption) is assumed to follow household population growth as well, but with an elasticity of 0.8 – on the basis that population growth will drive the amount of refuse removal that is needed.

9.5 Household sector

Ghana's population growth rate has previously been very high, attributable to declining mortality rates and high fertility rates. The country is, however, experiencing a demographic transition as fertility rates decline, attributed to higher school enrolment and changing economic opportunities, leading to major declines in under-19 fertility (Saleh, 2012).

Urbanisation is a significant factor influencing household growth. ASE, lying on the outer periphery of Greater Accra, receives a lot of inward migration of households seeking access to opportunities afforded in the cities. Geographically, this area is experiencing one of the highest rates of urban growth (Owusu, 2011). Focus groups undertaken with municipal officials suggest that biggest influx is for lower-income households. Annual household growth to 2030 is assumed to be an average of 3% per annum until 2030. The composition of household categories is projected to change as shown in Table 70. It is assumed that there will be a shift to 2nd and 3rd class household categories.

Table 70: Changes in household composition by category

	Share in 2014 (%)	*Project share in 2030 (%)*
HH1 electrified	19	15
HH1 nelectrified	4	1
HH2 electrified	29	32
HH2 nelectrified	6	5
HH3 electrified	35	42
HH3 unelectrified	7	5
	100	100

9.6 Industry

The assumptions underlying the projection of demand from industry sub-sectors active in ASEM are as follows:

- Construction: follows local economy growth with elasticity of 0.8.
- Manufacturing: follows local economy growth with elasticity of 0.8.
- Mining and quarrying: assumed to be low at 2% pa until 2025 and 0% to 2030 assuming a limit on extraction has been reached by 2025.

For the BAU case, it is assumed there are no changes to the characteristics of the industry sector of ASEM over the modelling time horizon, and that the energy intensities remain as they are throughout the model horizon.

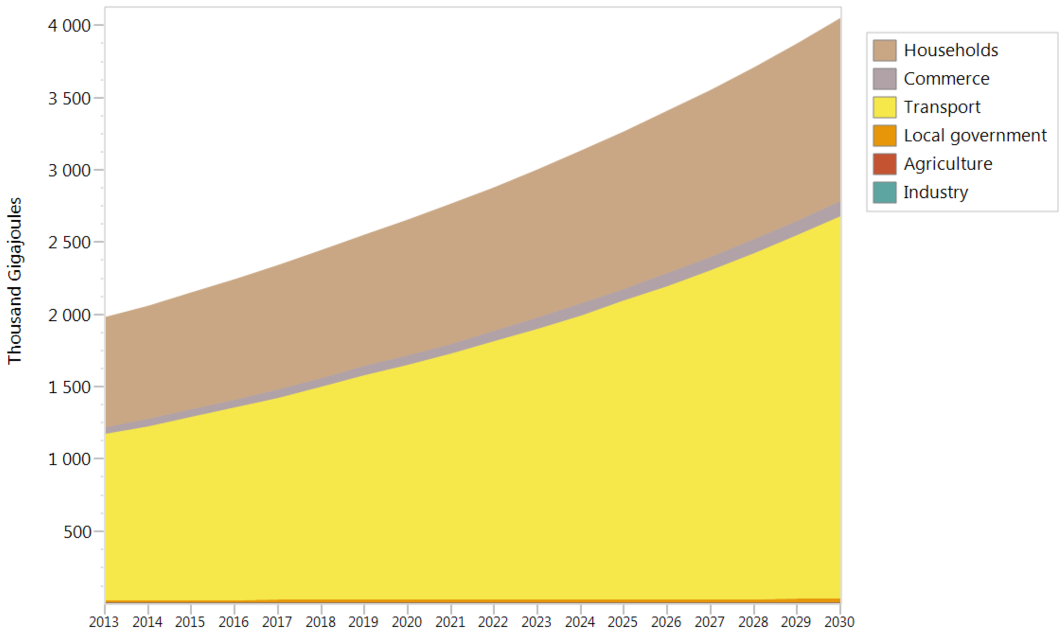
9.7 Agriculture

Discussions during the project with stakeholders at SAMSET network meetings suggested that the agriculture sector would likely disappear from ASEM within the model time horizon. In the base year, there were approximately 494 tonnes of output in 2013. It is assumed in the BAU case that the agriculture sector output remains about 500 tonnes per year until 2020, and then steadily declines until 2030 to about 30 tonnes per year.

10. Business as usual LEAP results

This section will present the results of the LEAP model projections. Scope 1 and 3 methodologies for transport in the BAU scenario will be presented in the next section below, while the other non-BAU scenarios are presented later.

10.1 ASEM scope 1 and 3 methodologies compared for the BAU



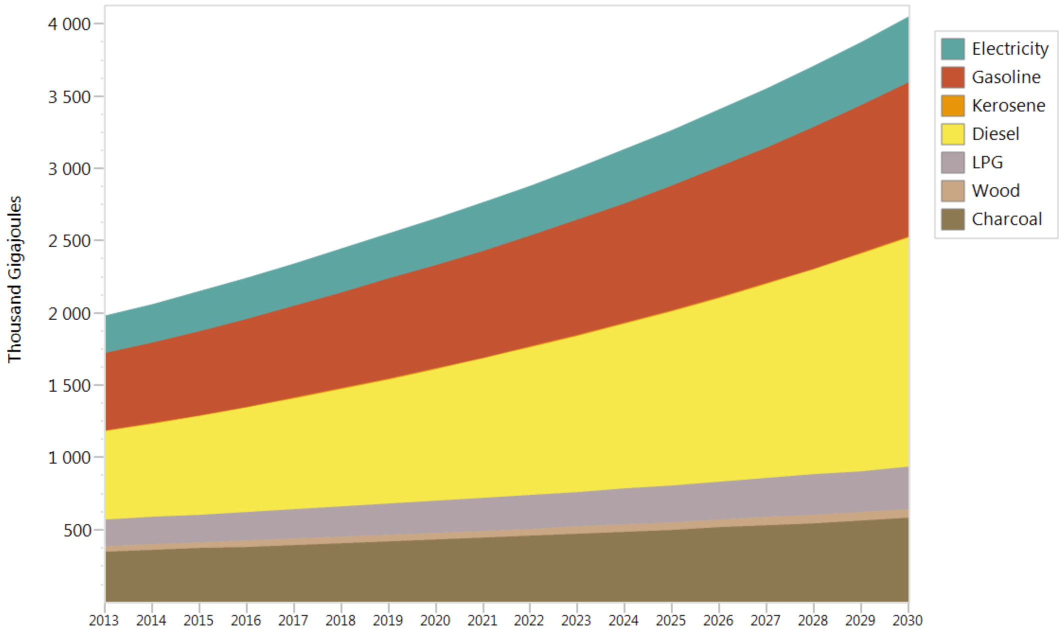


Figure 12: ASEM energy consumption by sector (above) and by fuel (below) for the BAU scenario for Scope 1 methodology

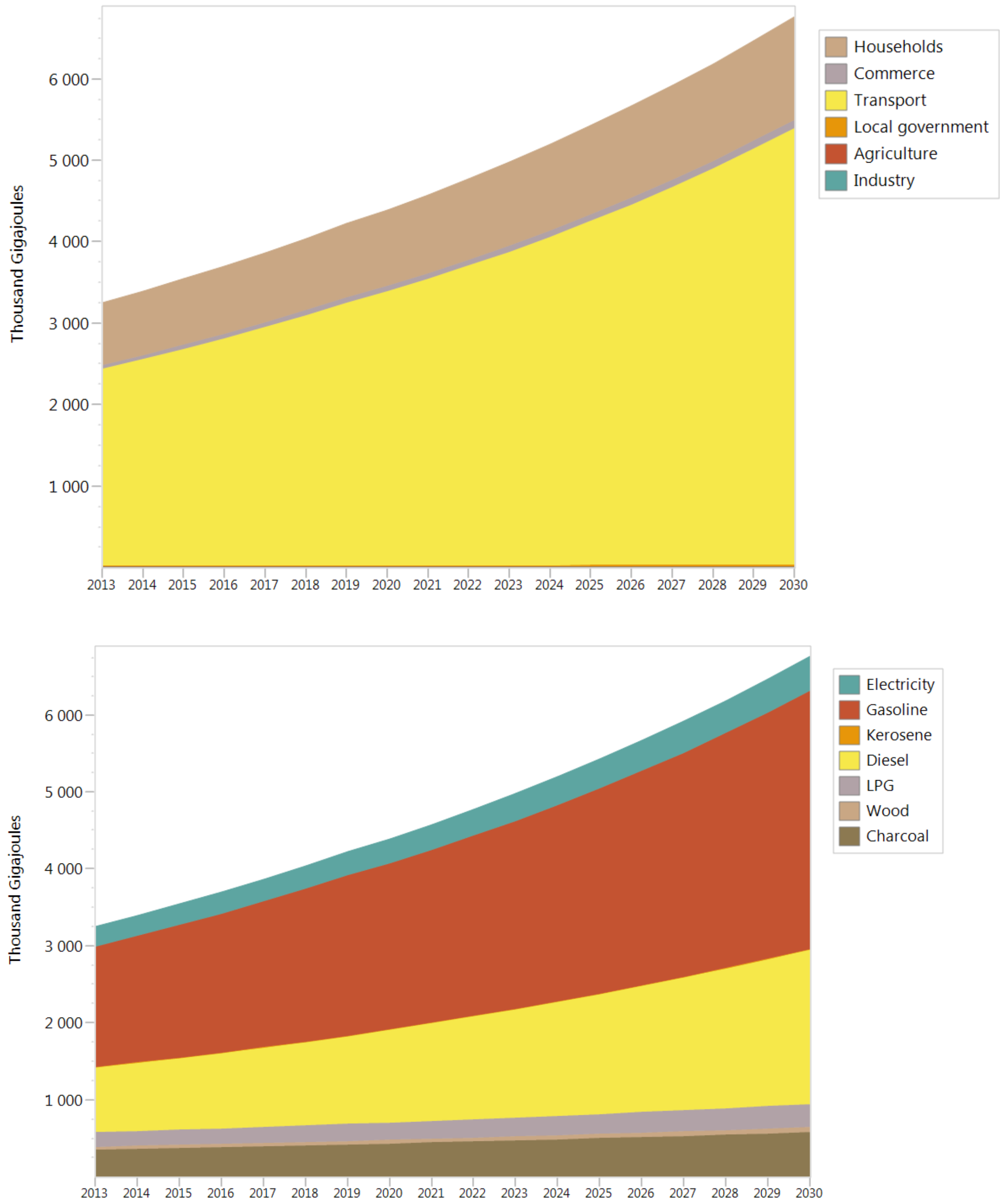


Figure 13: ASEM energy consumption by sector (above) and by fuel (below) for the BAU scenario for Scope 3 methodology

Petrol and diesel, mostly consumed in transport, dominate the Scope 1 results even without full consideration of transboundary trips. Consideration of these trips in Scope 3 results in an increase in total energy demand of about one third, with gasoline alone accounting for nearly half of total demand. This is due to the large proportion of petrol-fuelled light passenger vehicles which are assumed to commute daily to Accra.

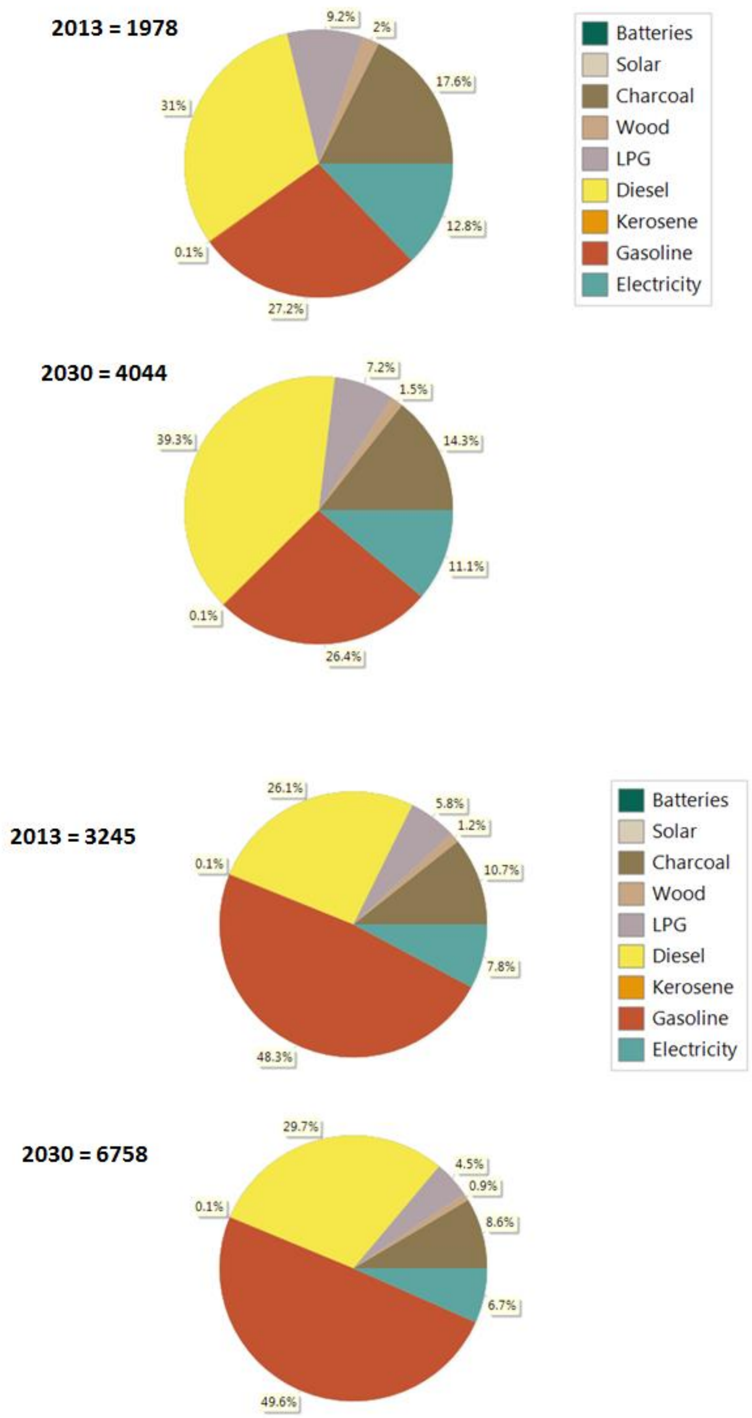


Figure 14: ASEM fuel consumption share for Scope 1 methodology (above) and Scope 3 methodology (below)

10.2 Transport sector fuel consumption

The majority of fuel consumed in the transport sector in Scope 3 methodology is in the transboundary allocation and this grows with time due to increased private car motorisation of the population, which is assumed to grow from 166 cars/1000 people in the base year to 305 vehicles/1000 people in 2030, with these cars undertaking a large proportion of their travel budget commuting to Accra

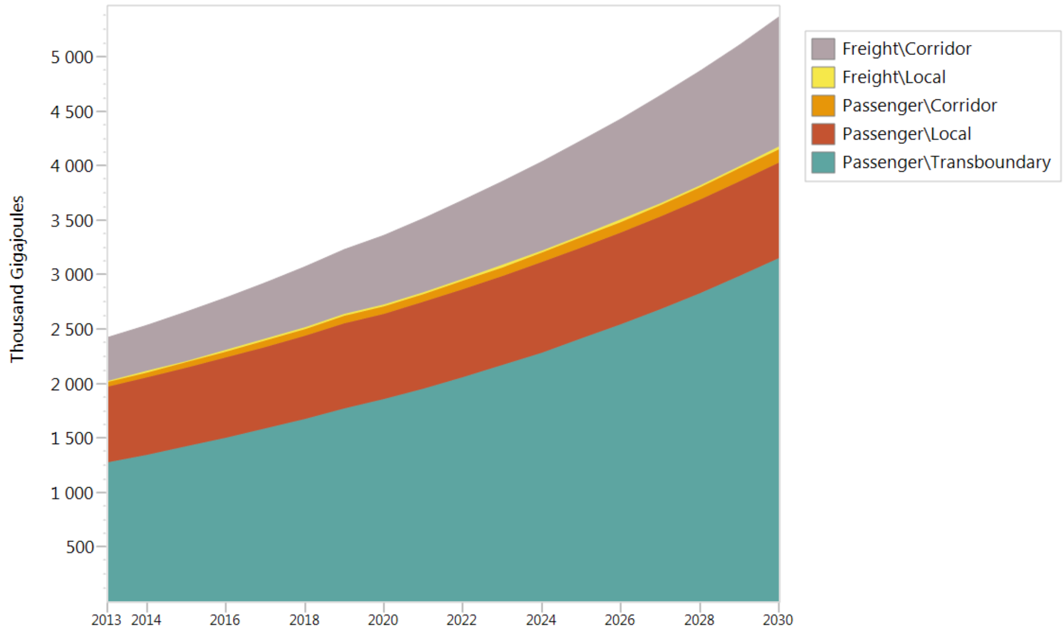


Figure 15: Transport fuel consumption by subsector for Scope 3 methodology

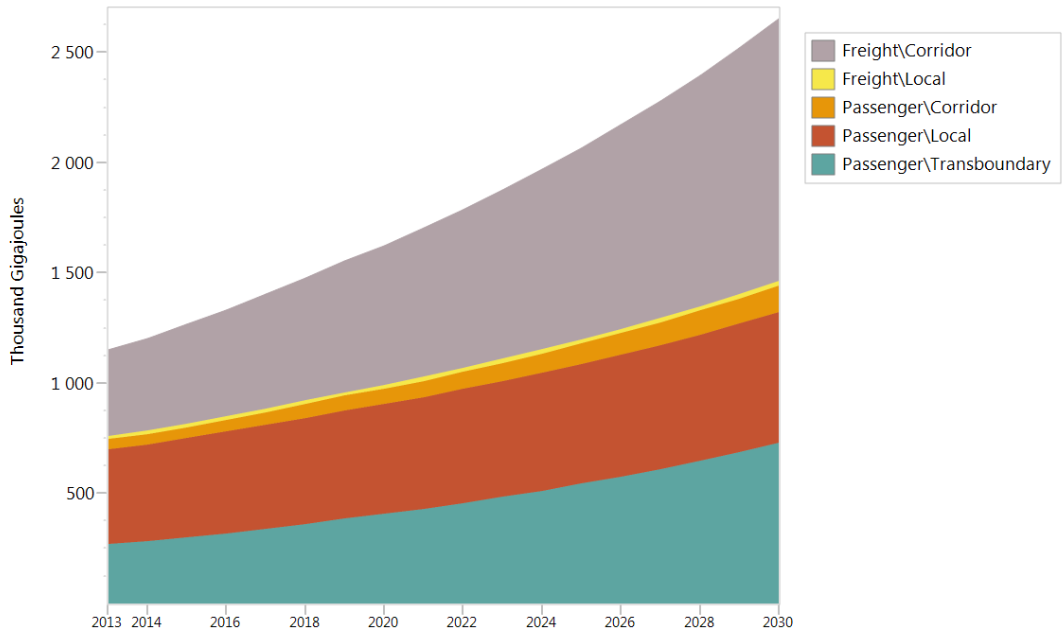


Figure 16: Transport energy demand by subsector for Scope 1 methodology

10.3 BAU general results

In this section we present results for the household sector (the next largest energy consumer) which are not impacted by the Scope 1 or Scope 3 methodologies.

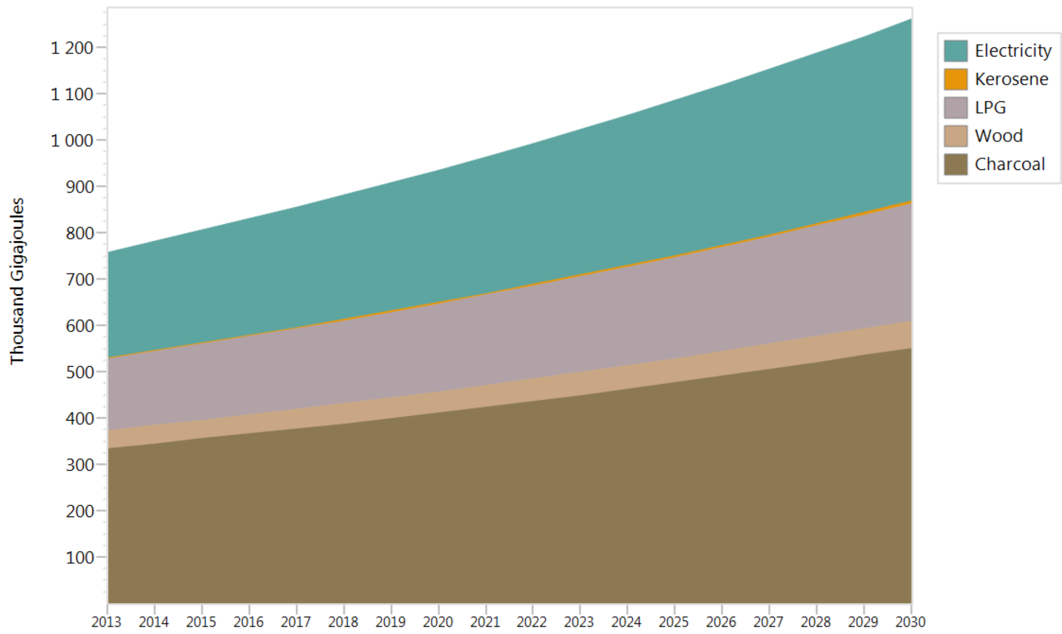


Figure 17: Household energy consumption by fuel for ASEM

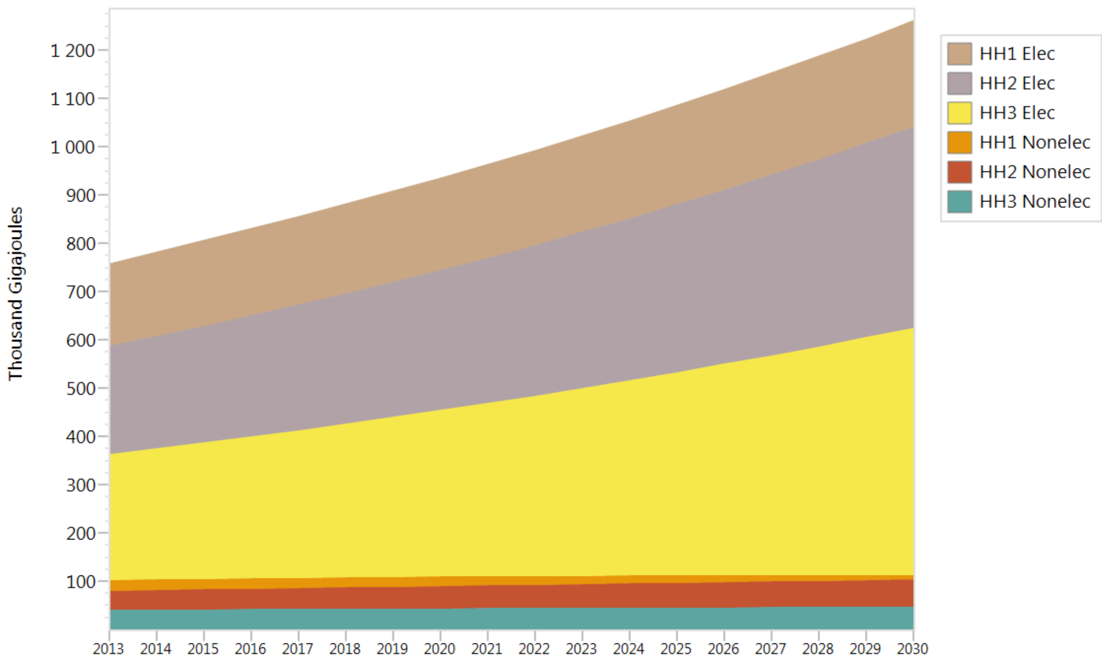


Figure 18: Household energy consumption by household category

10.4 Sensitivity scenario tests

In this section we explore the impact that an alternative view of economic growth or population growth has on the evolution of energy consumption of ASEM in the model.

Population increase (sPOP)

In this scenario, there is an increase in population growth rate from 2017 from 3% to 3.5%, and then again from 2020 from 3.5% to 4% through to 2030.

Constant and increased GDP growth increase (sGDP and sGDP2)

In this scenario, from 2017 the general economy of ASEM does not decrease in growth by 2020 as in the BAU scenario and the economic growth rate continues to grow at the same level of 7.2%. For comparison, we also include a scenario where the GDP growth rate increases to 8% pa by 2020.

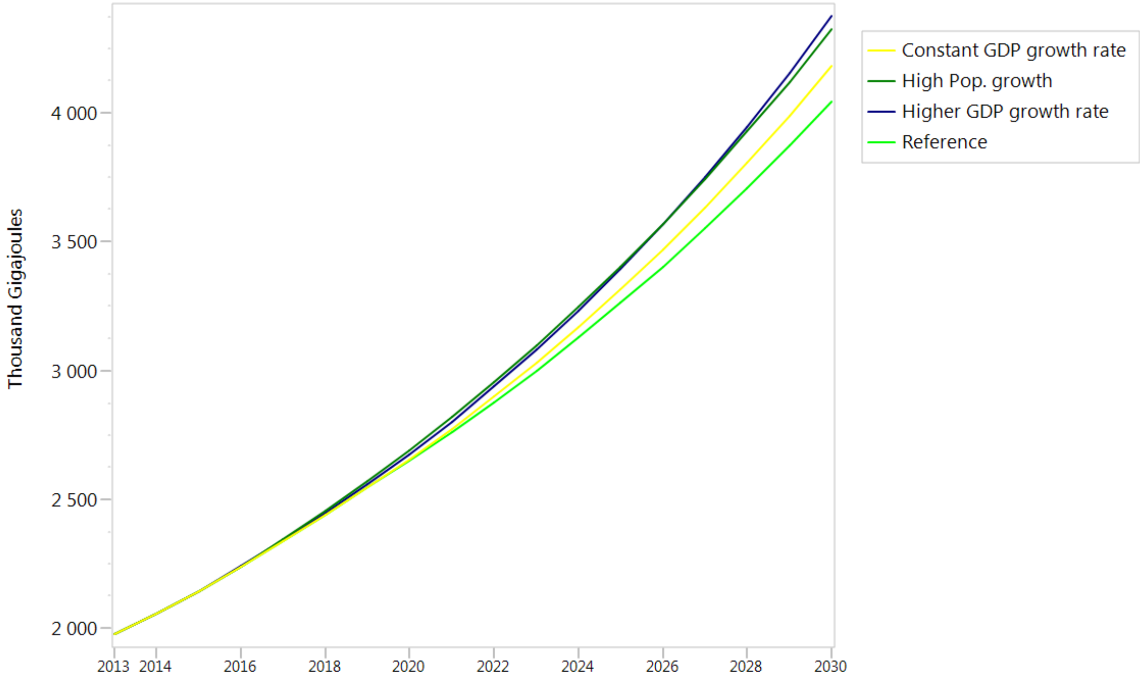


Figure 19: ASEM energy consumption comparing the two sensitivity scenarios to the reference scenario (Scope 1 methodology)

A constant economic growth rate of 7.2% has roughly half the impact that increasing the population growth rate from 3% to 4% by 2020 has on energy consumption, while increasing the GDP growth rate from 7.2% in 2013 to 8% by 2020 has a similar overall impact on energy consumption compared to the increased population growth scenario.

Much of the change in energy consumption in the municipality comes from the transport and household sectors (the largest consumers in the municipality). The results of the sensitivity scenarios for these sectors is presented next:

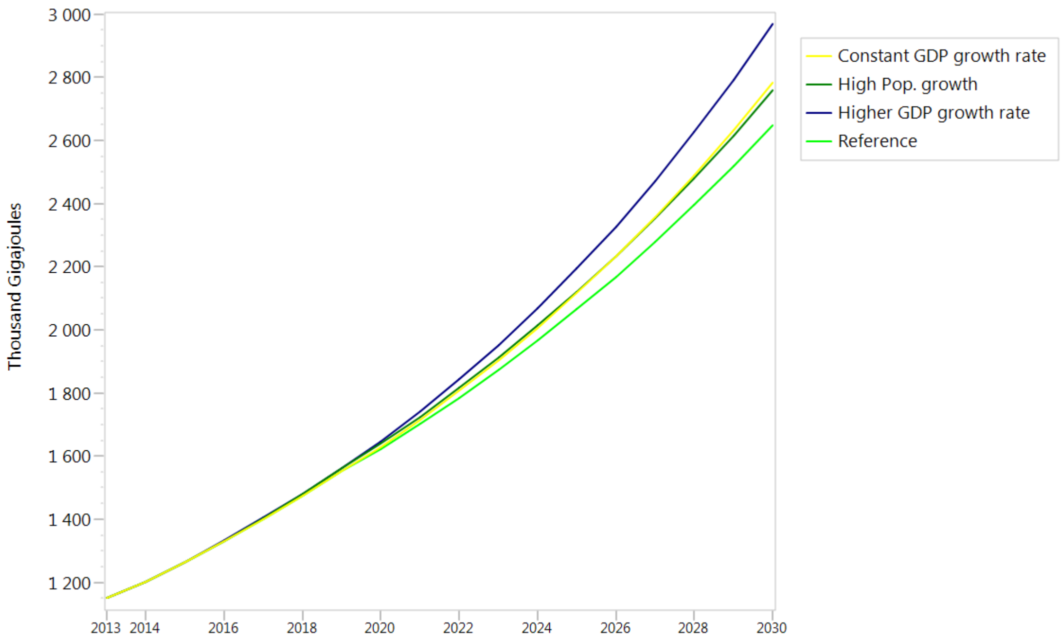


Figure 20: Transport sector fuel consumption for sensitivity scenarios (Scope 1 methodology)

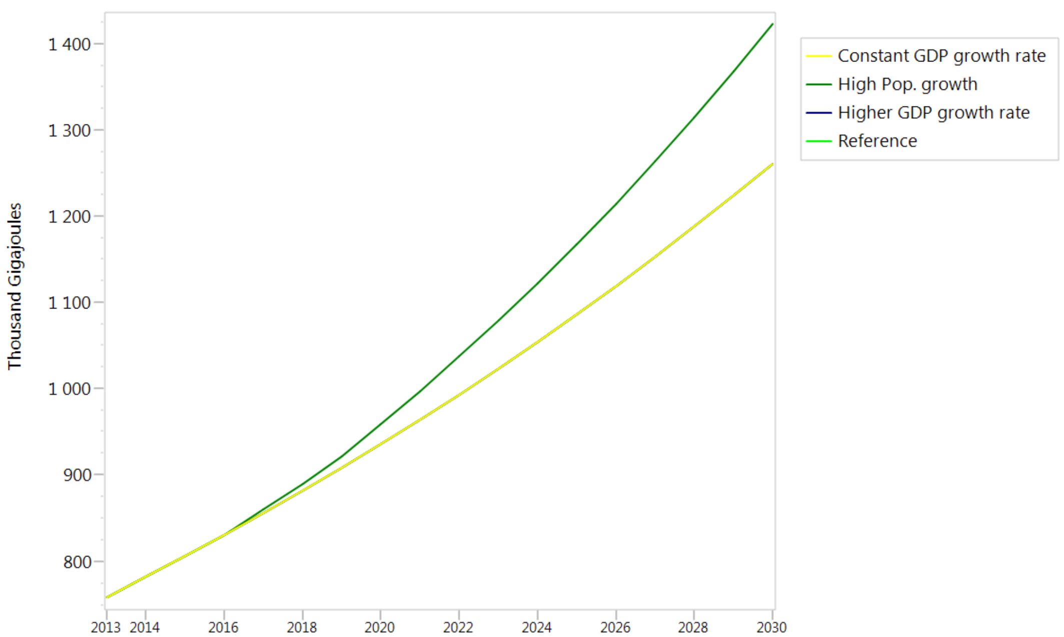


Figure 21: ASEM household energy consumption for the sensitivity scenarios

The lack of change in the household sector energy consumption with GDP growth is due to the current model structure whereby the households are not inherently linked to GDP. The shift in household class shares over time in the reference case discussed in Section 9.5 above is, for instance, a directly input assumption and is independent of GDP or income growth in the model as it is now. Clearly, in reality, average income has a significant effect on the capacity of households to purchase appliances and consume energy services. This is therefore an area of interest for future work that would greatly improve the model and the insights it can provide.

What is observed from Figure 20 is that the transport sector is more sensitive to the assumed economic growth rate than to the assumed population growth rate. Keeping the GDP growth rate constant at 7.2% year-on-year instead of reducing it to 6.5% year-on-year from 2020, which results in a 7.5% bigger economy in 2030, drives roughly the same change in fuel consumption as stepping up the population growth rate from 3% in 2013 to 4% in 2030, a 12.8% total increase in population relative to the reference case over the period. This is because of both the high intensity of private vehicle transportation (which would increase with more wealth/GDP) and the increase in the demand for freight transport (a result of a larger economy). As can be seen from the passenger demand consumption sensitivity presented in Figure **22** below, the higher GDP growth rate scenario is on par with the high population growth rate scenario, but constant GDP lags both, indicating that the freight demand increase is what pulls up the demand of the constant GDP scenario to equal the higher population growth scenario demand seen in Figure 20.

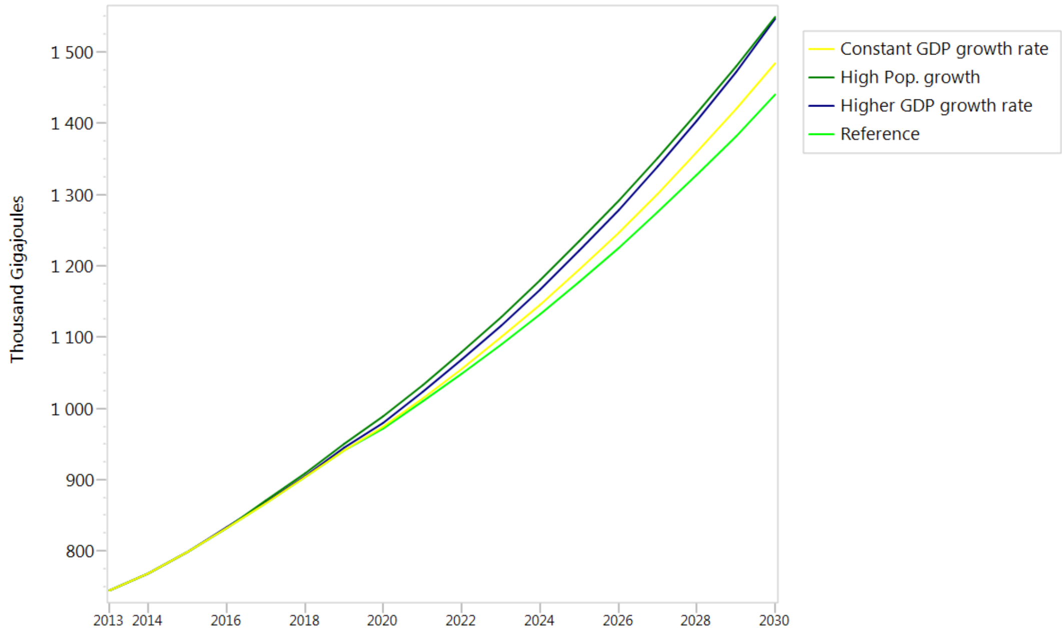


Figure 22: Transport passenger fuel consumption for ASEM in the sensitivity scenarios analysis (Scope 1 methodology)

11. Efficient cook stoves scenario (EST)

The Energy Commission of Ghana has undertaken a programme to help bring efficient cook stoves known as the 'Gyapa' to the people of Ghana, as an attempt to help reduce reliance on wood as well as improve the lives of people (SOE, 2013). The Gyapa cook stove uses less charcoal than a standard open fireplace by up to 50% as indicated on the Gyapa webpage[9]. As part of the SAMSET survey of households in ASEM, a questionnaire about the usage and awareness of the Gyapa and the programme was included. These are presented in Figure **23** below.

This scenario assesses the likely impact of a mass rollout or rebate programme for this type of stove on household energy consumption. The scenario involves a programme starting in 2016 and ending in 2021 whereby all households that indicated they wanted to use the cook stove, would obtain one. The remaining households, who did not partake in the programme by 2021, purchase a Gyapa by 2030. In this scenario:

- All households expressing a desire to have a Gyapa, from the SAMSET survey (see Figure **23**), obtain one between 2016 and 2021.
- All remaining households, which do not obtain one by 2021, do so by 2030.
- Gyapas use 50% less charcoal.
- Gyapas cost USD 10 and have a three-year lifespan.

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9 www.gyapa.com.

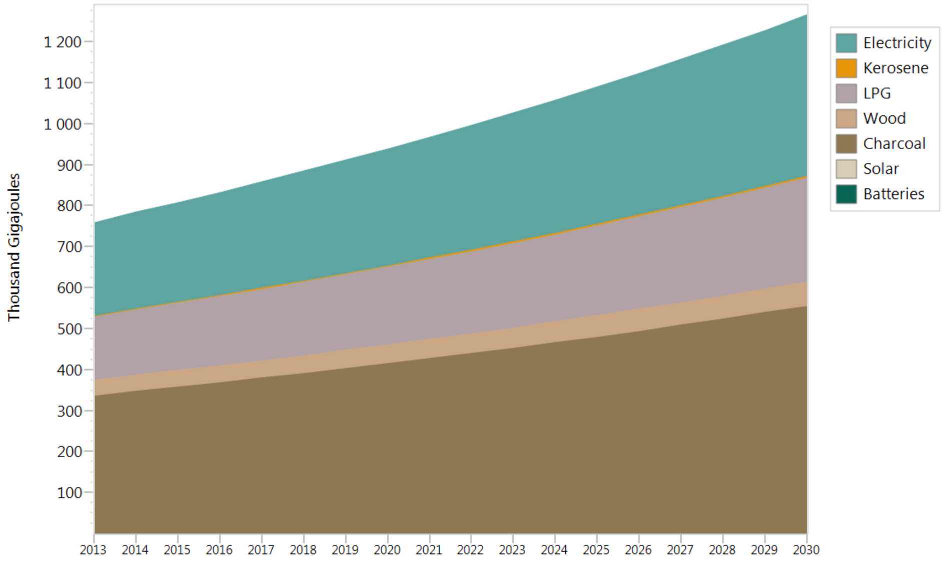
	1st Class	2nd Class	3rd Class
% who have knowledge of efficient cook stove	89.38	93.53	92.38
% who use efficient cookstove	33.66	27.67	24.74
% who wish to use efficient cook stove	73.13	80	82.19

	1st Class	2nd Class	3rd Class
% who have knowledge of efficient cook stove	75	75.76	74.42
% who use efficient cookstove	33.33	32	31.25
% who wish to use efficient cook stove	91.67	88.24	81.82

Figure 23: Awareness and use of the Gyapa cook stove in electrified households (above) and non-electrified households (below)

11.1 LEAP results for the EST scenario

The effect on the demand for household energy of the EST scenario is shown in Figure 24. Total household energy demand in 2030 is reduced by more than 20%.



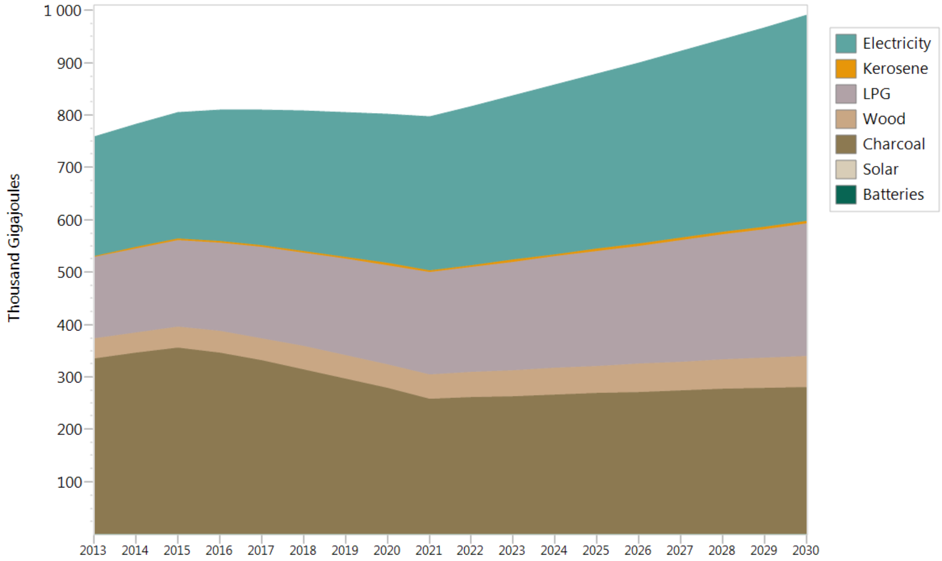


Figure 24: The household sector energy consumption by fuel in the reference scenario (above) and efficient cook stove scenario (lower)

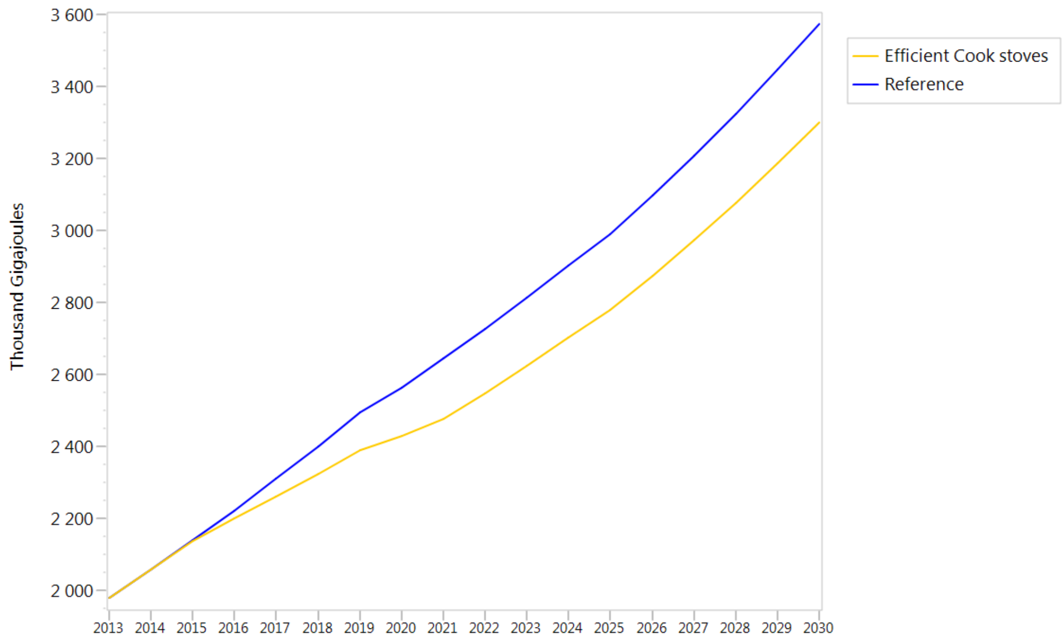


Figure 25: Awutu Senya East total energy consumption for reference and efficient cook stove scenarios

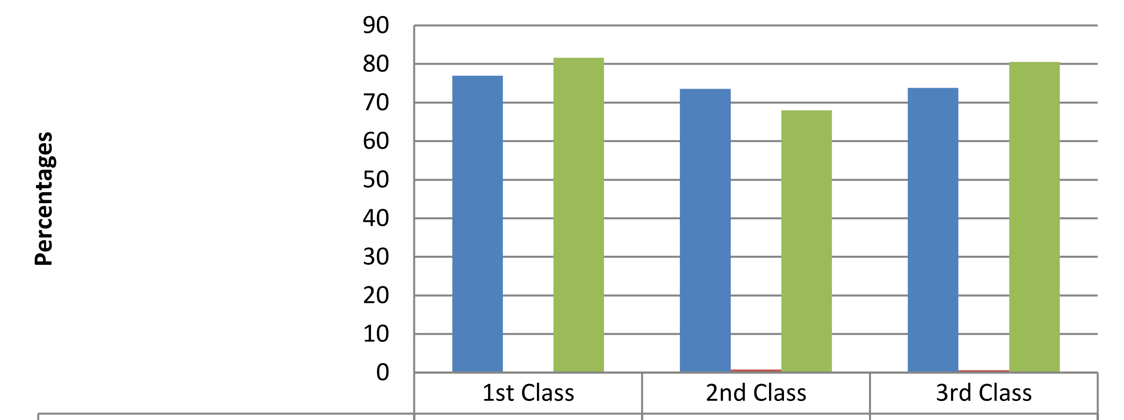
The total cumulative fuel savings and costs savings arising from that, given assumed prices, are as presented in Table 71. This can be set against the cost of a rebate or replacement programme, but it should be borne in mind that this comparison would not include the externality costs arising from indoor air pollution and contribution to climate change – another area in which this type of model can be improved.

Table 71: Cumulative fuel and cost savings for efficient cook stoves

	2016	*2020*	*2025*	*2030*
Tonnes charcoal saved	935	14 056	47 914	92 201
Million Cedi (2013)	0.3	6	21	41

12. Efficient fridges scenario (EFR)

The Energy Commission of Ghana introduced a programme in 2011 to introduce new technology-efficient fridges in an attempt to reduce energy consumption by refrigerators by half. The new fridges were expected to consume 250kWh a year as compared to the old inefficient ones, which consumed about 1200kWh a year on average. Moreover, importers and retailers of appliances such as light bulbs, air-conditioning equipment, and fridges are required by Ghanaian standards to meet minimum energy requirements (SOE, 2013). It was, however, shown by the SAMSET survey (Bawakyillenuo & Agbelie, 2014) that many households still buy second-hand and inefficient appliances. The SAMSET survey also showed that there was very little usage of the efficient fridge programme; see Figure 26.



	1st Class	2nd Class	3rd Class
% who have knowledge on EC's fridge replacement program	76.99	73.53	73.81
% who benefited from EC's fridge replacement program	0	0.8	0.65
% who wish to benefit from EC's fridge replacement program	81.61	68	80.52

Figure 26: Efficient fridge awareness and usage in ASEM
(SoE, 2013)

This scenario explores the potential impact of a new fridge rollout programme starting in 2016, where everyone who showed interest in the programme receives a fridge by 2021. All the remaining households, those that do not partake before 2021, obtain a new fridge by 2030. The cost of an efficient fridge is assumed to be on average GHS 1400 (USD 444) in 2013, and are assumed have a 15-year life span. Old or second hand fridges cost GHS 200-400 Cedi for table top or 'double door'' fridges, according to a second-hand fridge vendor[10]

Table 72: Cost of new fridges[11]

Cedi	*2013 USD*	*Fridge type*
1 800	572	280L fridge/freezer
994	316	150L fridge
1 397	444	Average above

In this scenario:

- Between 2016 and 2021, all households who expressed interest in the SAMSET survey for benefiting from the efficient fridges programme obtain a new efficient fridge by 2021.
- All those households who do not obtain a new fridge by 2021 do so by 2030.
- New fridges are 50% more efficient than second-hand fridges.
- New fridges cost USD 444 and have a 15-year lifespan.
- Second-hand fridges cost USD 173 and have a 7.5-year lifespan.

10 http://www.modernghana.com/news/442062/1/used-fridges-reduced-to-clear.html

11 This is taken from www.jumia.com.gh/frdges-freezers/

12.1 LEAP results for the EFR scenario

The effect on the demand for household energy of the EFR scenario is shown below. Total household energy demand in 2030 is reduced by around 4%.

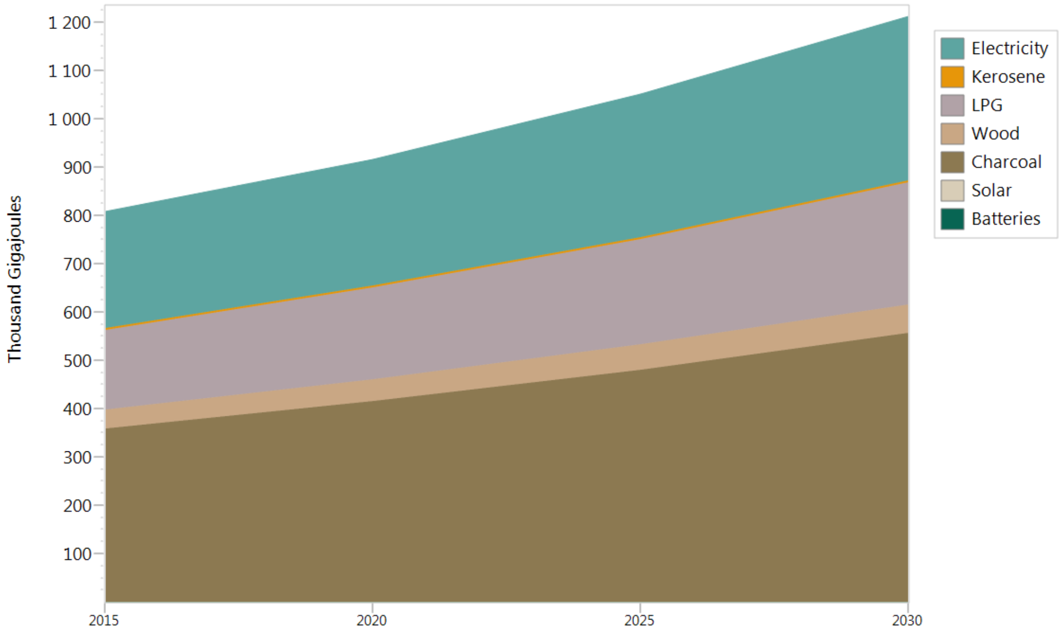


Figure 27: Household sector fuel consumption for the efficient fridges scenario

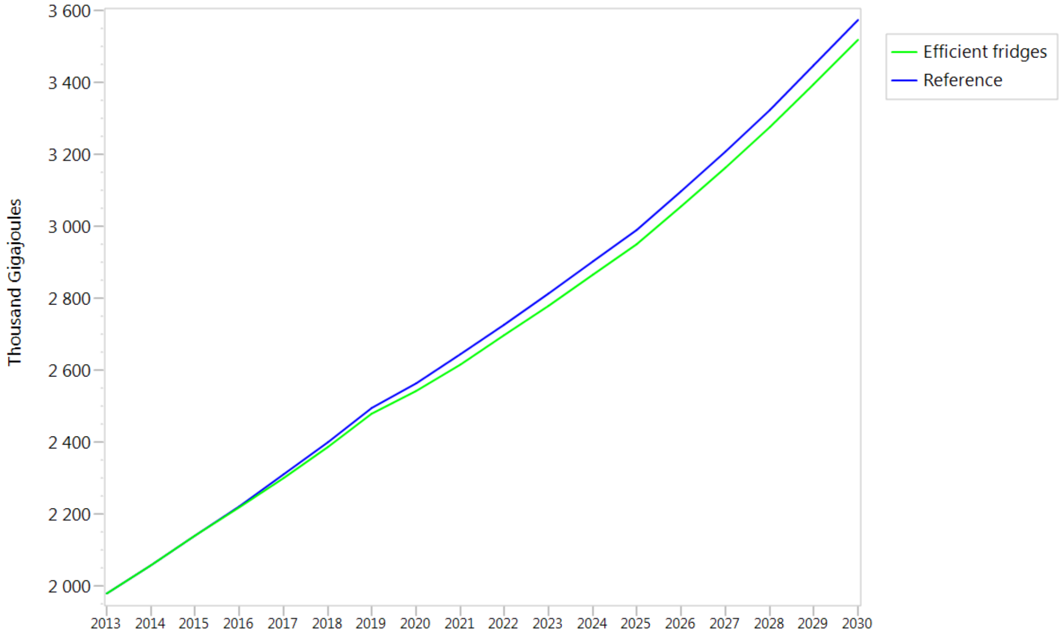


Figure 28: Total Awutu Senya Energy consumption for the reference and efficient fridges scenarios

These relatively small energy savings (see Table 73) are due to the relatively small share (< 10%) of household energy consumption in the reference case accounted for by refrigeration. By comparison, cooking accounts for over 70% of energy demand and thus interventions on this energy service have a greater effect. Comparatively therefore, the most energy savings comes from the efficient cook stoves scenario (see Figure 29). However, the cost impacts for both scenarios have similar cumulative savings of GHS 41 million and GHS 39 million (2013) by 2030 (see Table 74).

Table 73: Total cumulative savings from efficient fridges scenario

	2016	*2020*	*2025*	*2030*
Million kWh	1.12	11.30	20.63	29.20
Million Cedi	0.33	5	19	39

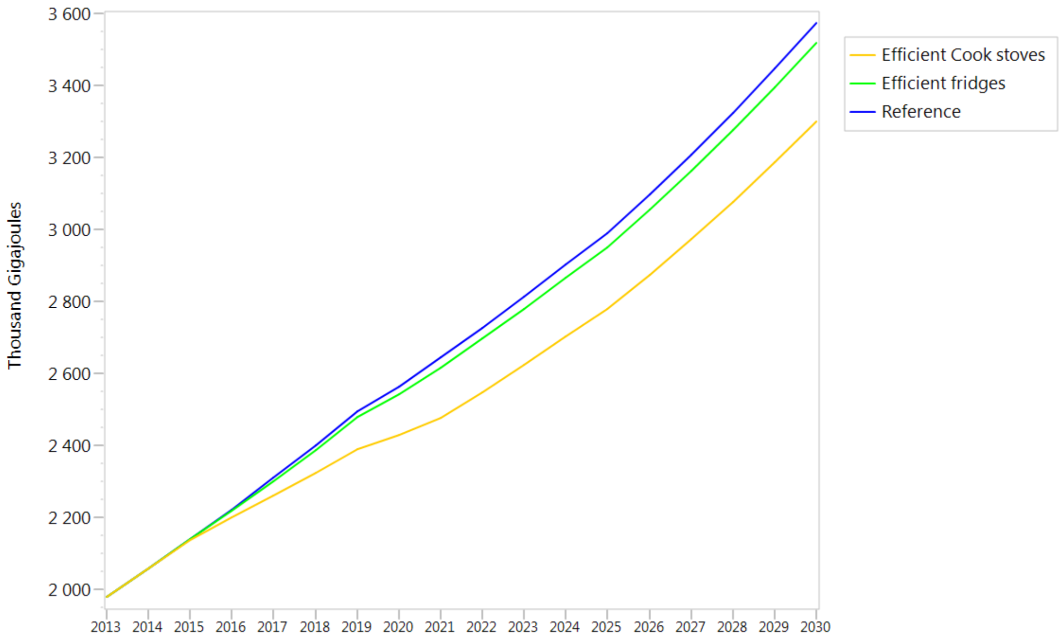


Figure 29: Total energy consumption of Awutu Senya, comparing household scenarios

Table 74: Cumulative cost savings (million 2013 Cedi) comparison for household scenarios

	2016	*2020*	*2025*	*2030*
Efficient fridges	0.33	5.41	19.05	38.59
Efficient cook stoves	0.33	6.18	21.45	41.44

13. Household access to modern energy (ACC)

In this scenario, we explore the impact on fuel consumption in the household sector of an increase in access and utilisation of modern energy fuels for cooking – mainly LPG and electricity. The number of households using clean fuels increases in this scenario starting in 2020 through to 2030. We assume that most households would prefer to cook on gas (LPG) than electricity as there are a number of households already using LPG for cooking while the use of electricity for cooking is virtually non-existent. The uptake in the number of households using these fuels is presented in Table 75.

Table 75: Shares for households using fuels for cooking in the Access to clean fuels for cooking scenario

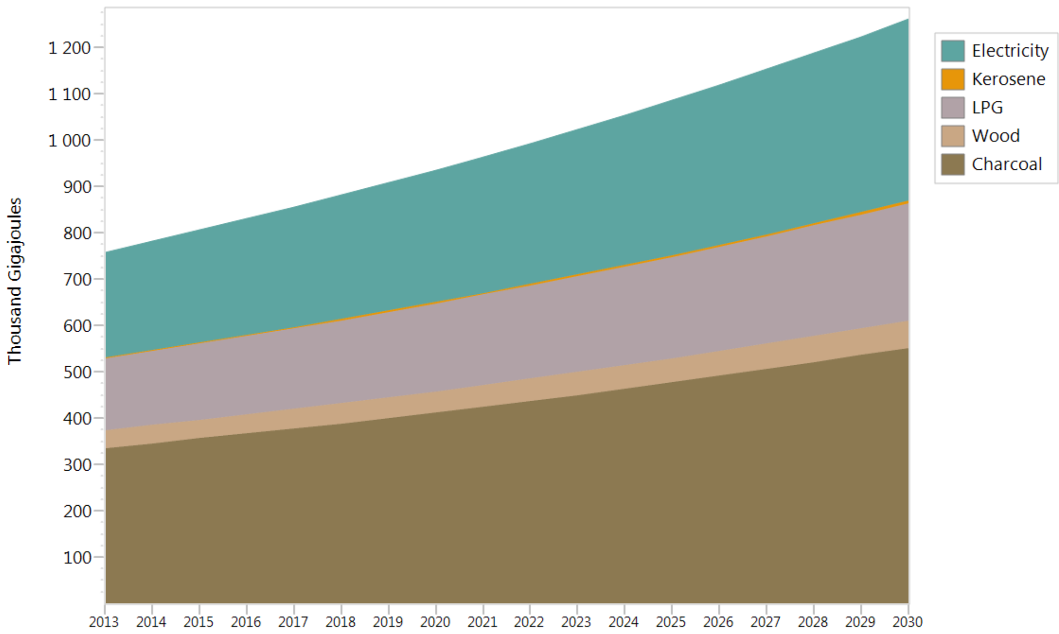
	Household class	*End use*	*Shares* in % for 2030 (2013)*		
			Electricity	*LPG*	*Charcoal*
Electrified	HH1	Cooking	25 (0)	95 (75.2)	30 (82.3)
		Other appliance use	70 (43.4)		
	HH2	Cooking	20 (0)	90 (75.9)	40 (89.4)
		Other appliance use	55 (27)		
	HH3	Cooking	5 (0)	87 (60)	50 (87.9)
		Other appliance use	40 (19)		
Non-electrified	HH1	Cooking		85 (54.2)	50 (83.3)
		Other appliance use			
	HH2	Cooking		70 (45.5)	58 (87.9)
		Other appliance use			
	HH3	Cooking		65 (30.2)	60 (95.3)
		Other appliance use			
* Note that the shares do not need to sum to 100% as most households use multiple fuels					

While households start the uptake of more frequent use of clean fuels, the use of charcoal is assumed to decrease – thus the average intensity for the clean fuels increases while the average intensity for charcoal (the majority of non-clean fuel-use) will decrease. The numbers for electricity and LPG intensities in Table 76 come from the study by Cowan (2008), while the charcoal intensities change is an assumption that the average intensity usage will drop by 75%, as most cooking is done on LPG (and electricity for some households) while some still use charcoal for traditional cooking.

Table 76: The average energy intensity for each fuel type for cooking in the ACC scenario

	Household class	*End use*	*Intensity value GJ/HH for 2030 (2013)*		
			Electricity	*LPG*	*Charcoal*
Electrified	HH1	Cooking	2 (1.5)	8 (5)	1 (8.5)
		Other appliance use	3.5 (2.5)		
	HH2	Cooking	2 (1.5)	7 (4.1)	1.2 (8.2)
		Other appliance use	3 (2.1)		
	HH3	Cooking	2 (1.5)	6 (2.8)	1.3 (8)
		Other appliance use	3 (2.3)		
Non-electrified	HH1	Cooking		5.5 (3.8)	1.4 (9.4)
		Other appliance use			
	HH2	Cooking		4 (2.6)	1.6 (11.7)
		Other appliance use			
	HH3	Cooking		3.5 (1.4)	1.5 (9.8)
		Other appliance use			

The results from the model for the household sector energy consumption in with these shares and energy intensities in the ACC scenario are presented in the figures below.



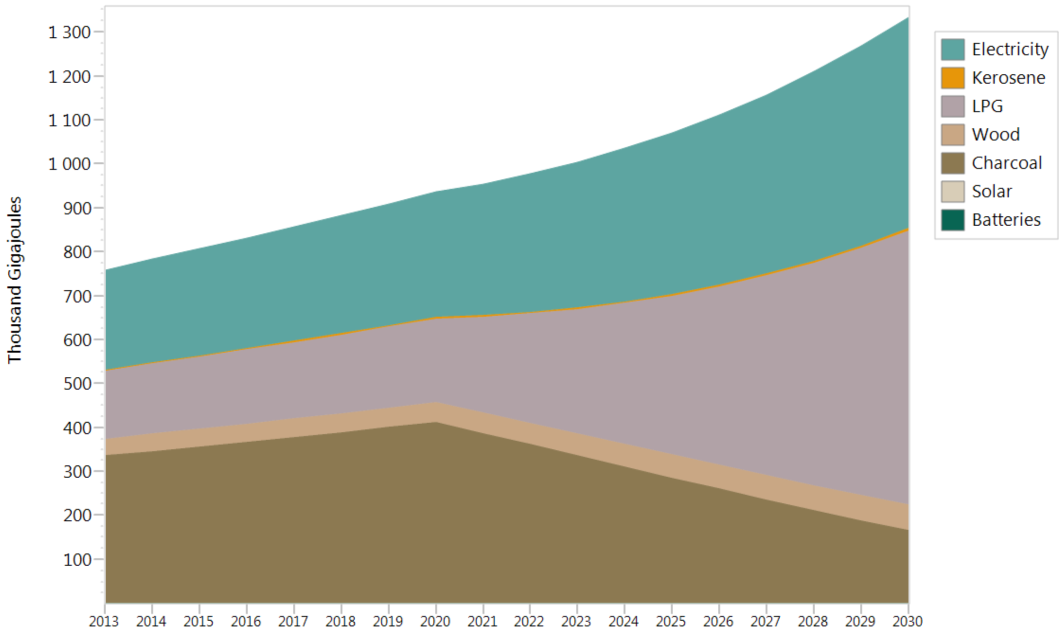


Figure 30: The household energy consumption by fuel for the reference scenario (above) and the ACC scenario (below)

Overall the fuel consumption increases in the household sector as indicated in the chart below. This increase is a result of the large uptake in LPG consumption by about 146% in 2030 relative to the reference scenario, electricity consumption only increases by 22% while charcoal consumption decreases by about 70%. The net result is an increase in fuel consumption of 71GJ in the year 2030

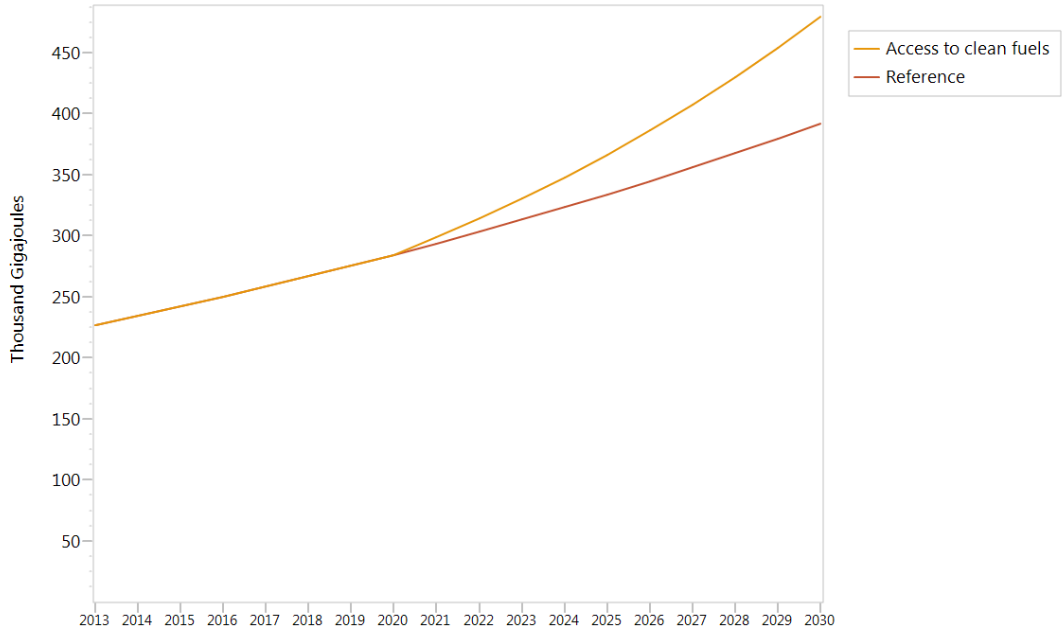


Figure 31: Comparing household energy consumption for the ACC scenario for ASEM relative to the reference scenario

The fuel consumption impact is presented in Table 77, showing a large increase in consumption of LPG (about 37 000 tonnes).

Table 77: The cumulative energy impact for the ACC scenario for ASEM

	2021	*2025*	*2030*
Electricity (MWh)	1 412	25 132	113 166
LPG (tonnes)	487	8 457	37 148
Charcoal (tonnes)	-1 306	-19 841	-73 390

Using the fuel cost assumptions as given in section 9.1 the total cost impact on fuel consumption is given in the Table 78.

Table 78: Cumulative fuel consumption cost impact for the ACC scenario

	GHC (const. 2013)		
	2021	*2025*	*2030*
Electricity	273 237	1 754 368	4 675 748
LPG	1 323 499	23 003 322	101 041 379
Charcoal	-692 056	-10 511 747	-38 882 247
Sum of costs	**904 680**	**14 245 943**	**66 834 880**

14. Conclusions

The University of Ghana has developed a unique and detailed energy dataset for the municipality of Awutu Senya, a growing municipality located about 30 km from central Accra in Ghana. The dataset was developed using detailed surveys and focus groups with stakeholders and municipal officials. This dataset includes rich detail on household, commercial and industrial energy service demand and fuel preference and an emerging picture of the transport sector. This dataset has been used to develop an energy systems model that projects long term scenarios of energy use and the impact of interventions to make energy use more sustainable.

The results show that the household and transport sectors dominate energy use in Awutu Senya, with biomass (mostly charcoal) still accounting for just under half of household sector consumption in the 'Business as usual' case. The fuel shares of the household sector observed in the ASEM survey were very similar to those observed in the Ga East (GEM) survey. Per capita energy consumption was however reported as 51% higher.

Table 79: Comparison of energy carrier shares and per capita energy consumption for ASEM and GEM municipalities

Energy carrier	*GEM*	*ASEM*
Electricity	29%	30%
Kerosene	0.1%	0.4%
LPG	22%	20%
Wood	8%	5%
Charcoal	41%	44%
Per capita (GJ/pp.a)	***4.2***	***6.4***

The transport sector's share of energy demand depends strongly on whether trips that originate inside or outside the municipality but include a portion of the trip outside its boundaries (transboundary trips) are included or excluded. The results have been presented in two scopes based on the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) to accommodate this. Scope 1 is calibrated to local fuel sales and includes only a portion of these transboundary trips, and the alternative Scope 3 includes the estimated energy demand of commuting trips to Accra by private and public transport. The inclusion of transboundary trips increases transport's share of demand from 58% for Scope 1 to just under 75% for Scope 3 and this share increases with time to nearly 80% in the Business as usual case.

Significant suppressed demand for electricity was indicated by the industry, commercial and household data. While a minority of commercial businesses and households owned generators, they accounted for around 10% of the electricity consumption of household generator owners and over 10% for generator owners in both the formal and informal commercial sector and over 40% for generator owners in the manufacturing sector in spite of the high price of petrol and diesel. The distribution of own-generation share (see **Error! Reference source not found.**) shows that a significant minority of the commercial sector generator-owning sample use generators for up to half of their electricity needs. Furthermore there was a very large span in commercial sector-specific electricity consumption (kWh/m^2) within activity types for instance offices, banks or catering (Table 8080). The issue of consistency in footprint area definition aside, this suggests that many commercial buildings may not enjoy the same complement of services that others do, particularly HVAC, and that increasing incomes and reduced constraints on supply could see significant increases in commercial building energy intensity. While informal commercial activity appears highly electricity-efficient (or electricity-poor) total energy intensity for these buildings increases dramatically when biomass use is included (see Appendix B).

Generator use in the formal commercial sector was widespread, as well as for certain activities in the informal commercial sector. The own-generated share of electricity consumption varied widely but averaged around 14% for the formal sector and 12% for the informal sector (see Appendix B). While this is a minority share, it increases the final energy intensity of floorspace by nearly an order of magnitude for both formal and informal sectors due to the relative inefficiency of home generators, particularly the small petrol generators common in the informal sector. Assuming energy costs of GHS 0.29 /kWh for petrol, GHS 0.25 /kWh for diesel and GHS 0.2–0.4 /kWh for electricity depending on the consumption band, this means that commerce bears a very high burden of cost, roughly a tenfold premium, to supplement their electricity supply.

A limited number of scenarios were investigated to illustrate the likely impacts of possible energy-saving interventions in the municipality including an efficient fridges programme, an efficient charcoal stoves programme and access to modern energy (households switching to electricity and LPG). All indicated significant savings but access to modern energy showed by far the largest impact.

The validated, reviewed and finalised datasets and models would be very useful to researchers and planners and should be published into the public domain in an easily accessible way as part of the SAMSET project.

Some data issues were identified **-** particularly the very large discrepancy observed between LPG supply and demand which was an issue in the surveys for both municipalities.

15. Data issues and future data requirements

The University of Ghana undertook extensive survey work and investigation using facilitated workshops with stakeholders at a level of detail that brings new clarity to the understanding of energy use in the region. In the process of using this data for model development, validation of the data has raised some questions on aspects of the data as can be expected. These are dealt with below and it is hoped that this contributes to an ongoing process of refinement and improvement of that dataset and methodologies.

General

- The number of households is about 43 000 according to the ASEM SoE report (Bawakyillenuo & Agbelie, 2014). However, a district report indicated that the number was about 25 000 in 2010 (Ghana Statistical Services, 2014b). This discrepancy may come down to the boundaries and or methodologies employed by the SAMSET team and the National Statistics Services but an explanation of the discrepancy is definitely warranted somewhere in the SAMSET documentation to assist future users of the research.
- A passenger transport survey is needed to get hard data on transport by mode (car, minibus, walking, etc) and how far (or how long in hours). This will greatly add to the model and understanding of the largest energy consuming sector in the municipality.
- The total consumption of LPG from the surveys of all sectors does not calibrate to the total sold within the municipality. There is a large shortfall in consumption of LPG relative to supply, and because of the magnitude it is not possible to allocate the balance in proportion to each sector in order to calibrate the model without throwing out each sectors’ energy consumption patterns severely.
- In general, the inclusion of more detailed metadata would make this interesting dataset more useful to the research community at large, for example:
    - The methodology adopted for determining floorspace area – did respondents disclose the enclosed area of buildings on the site or sometimes the site area?
    - The method of determining the energy service share of electricity.

Commercial sector energy intensities

The energy intensities calculated from the survey data for a number of observations, particularly in the formal commercial sub-sector categories of hotels and schools, are very low relative to other values in their categories. This suggests that this may be a result of total footprint of the premises being assumed as floorspace in these instances and not just the total area enclosed by the walls of buildings. As can be seen from Figure **5** above the share of area of these activities is very large and furthermore as indicated by Table 80Table 80, the spread of intensities within activity types is very large, which may either indicate a great diversity in construction and building services practices and suppressed demand or the need to validate some of the area data as discussed further below.

Table 80: Spread of electricity intensity for selected commercial activities in Awutu Senya

Indicator	*Hospitals*	*Schools*	*Hotels*	*Banks*	*Non-banks financial services*	*Offices*
Observations	*3*	*38*	*5*	*11*	*12*	*17*
	Specific electricity consumption (Includes own generation) *(kWh/m²yr)*					
Minimum	3	0	4	52	26	13
Median	3	2	4	262	84	159
Average	5	3	20	248	89	248
Maximum	8	70	68	1882	288	2594

The discrepancies are such that the average electricity intensity of the formal sector is reduced considerably by the outliers, resulting in a lower average electricity intensity than the informal sector, even excluding schools, as shown in Appendix B. This raises questions about the aggregate data and some clarification is warranted before the datasets are finalised. This data is a particularly interesting subset of the results and it would be useful for the purposes of benchmarking and informing other studies, to review the survey results and assess outliers such that a set of energy intensities can be published. Unlike the survey for Ga East, the commercial survey in Awutu Senya was estimated to cover about a fifth of commercial premises, requiring the sample to be scaled-up for the model. The distorting effects of area outliers, particularly if they are over-represented, may therefore have affected the internal consistency of the model. On the other hand, the very detailed assessment of informal businesses added a great deal to developing a realistic baseline.

As shown below in plots of specific electricity consumption per unit area floorspace versus floorspace area, outliers in the dataset tend to cluster along both axes, with observations having large areas tending to have very low electricity-intensity and vice versa. This may indicate the necessity of data checks for both extremes. To some extent, as alluded to in the conclusions, the spread of data may indicate significant suppressed demand in the commercial sector in that many sites currently lack services, particularly HVAC. The low electricity intensity of 'Hospitals' seems counter-intuitive as does the allocation of 'cold stores', to the informal sector where they are electricity-intensity outliers. The hospitals may, of course, be basic clinics with low demand for energy services which speaks to the issue of metadata.

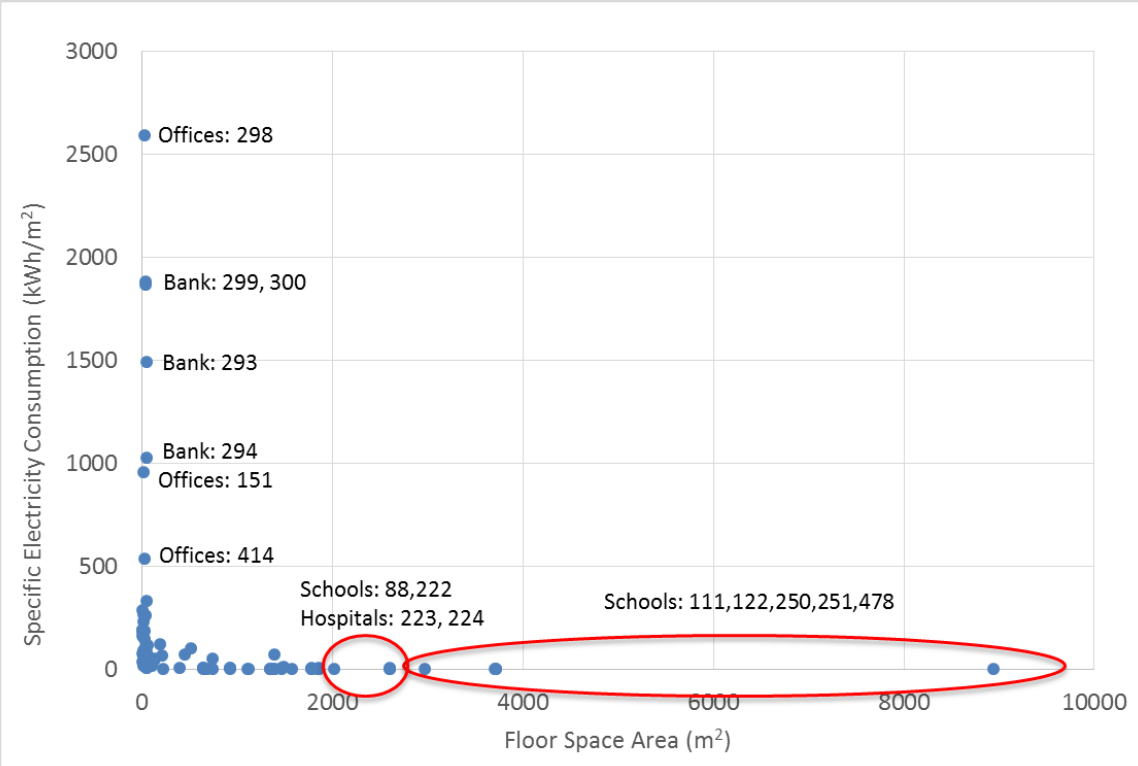


Figure 32: Ga East formal commercial sector – specific electricity consumption vs floorspace (data lables indicate activity and survey ID)

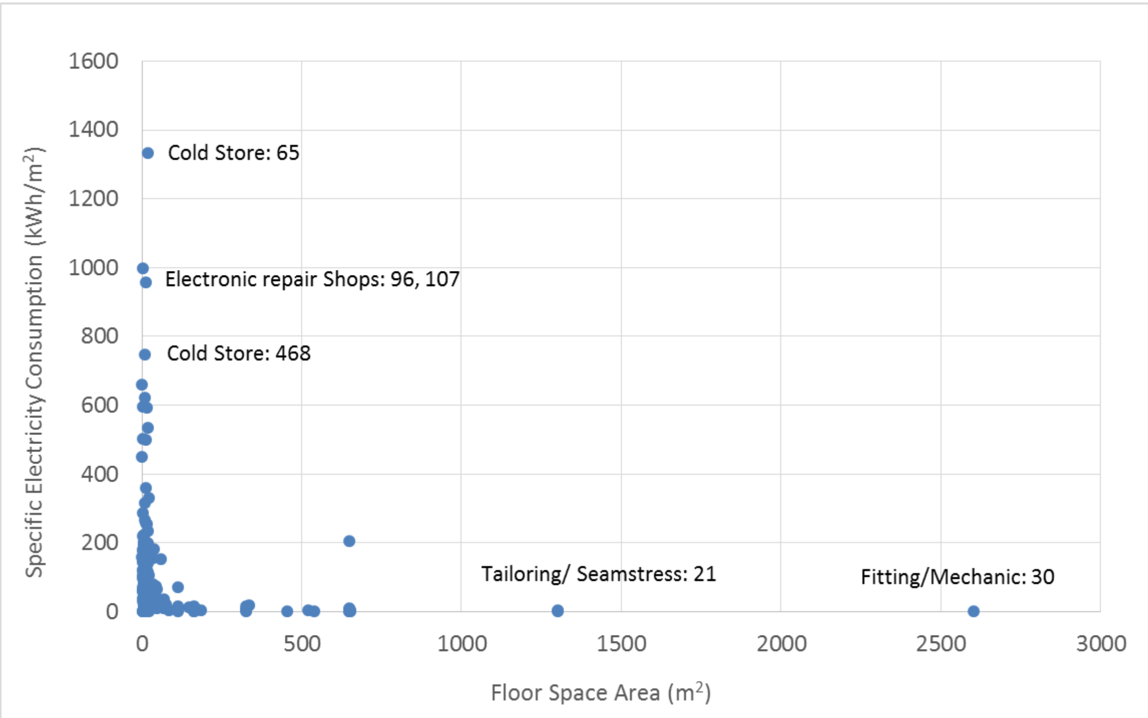


Figure 33: Ga East informal commercial sector – specific electricity consumption vs floorspace (data lables indicate activity and survey ID)

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Appendix A. Own-generation efficiency model

In order to convert the own-generation data from the survey, which consisted of generator ratings and annual fuel consumption, into electricity consumption, models for gasoline (petrol) and diesel were developed based on published data as follows. Equation 8 was determined from linear regression of the following data. The square of the Pearson correlation co-efficient of the correlation (R^2) was 62%.

Table 81: Gasoline generator data used to derive a model of generator fuel consumption and efficiency as a function of rating and load factor

Sources: www.centralmainediesel.com; www.globalspec.com; www.buffalotools.com; *gens.lccdn.com; powerequipment.honda.com; www.homedepot.com; www.northerntool.com*

Model	*Rating (kVA/kW)*	*Load factor*	*Consumption (litres/hour)*	*Efficiency (%)*
AlphaGen™ ACX2000i	1.9	1	1.77	12
AlphaGen™ ACX2000i	1.9	0.25	0.71	8
Champion 80 cc	1.2	0.5	0.55	12
GEN154	1.2	0.5	0.62	11
Generac 15,000	15	0.5	6.06	14
Generac 6500E	6.5	0.5	2.37	15
Generac GP15000E	15	0.5	6.06	14
Generac GP17500E	17.5	0.5	6.06	16
Generac iQ2000	1.6	0.25	0.52	9
Generac XD 5000	5	0.5	1.40	20
Honda GX 390	7	1	3.37	23
Honda GX 390	7	0.75	2.73	22
Honda GX 390	7	0.5	2.37	17
Honda GX 630	11.7	1	6.44	20
Honda GX 630	11.7	0.75	5.30	19
Honda GX 630	11.7	0.5	4.16	16
Honda GX 630	14	1	6.44	24
Honda GX 630	14	0.75	5.30	22
Honda GX 630	14	0.5	4.16	19
Honda GXH50 OHV	0.9	1	0.60	17
Honda GXH50 OHV	0.9	0.25	0.27	9
NorthStar 15,000	13.5	0.5	5.20	14
Robin R650	0.55	1	0.47	13
Unknown	2.7	1	1.71	18
Unknown	5.5	1	3.52	17
Unknown	6.8	0.5	2.52	15

Equation 11 was determined from linear regression of the following data. The square of the Pearson correlation co-efficient of the correlation (R^2) was 66%.

Table 82**: Diesel generator data used to derive a model of generator fuel consumption and efficiency as a function of rating and load factor**
Sources: **www.centralmainediesel.com*;* *w*ww.dieselserviceandsupply.com/Diesel_Fuel_Consumption. aspx*;* www.kohlerpower.com/onlinecatalog/pdf/g5412.pdf*;*** *https://powersuite.cummins.com/PS5/ PS5Content/SiteContent/en/Binary_Asset/pdf/Commercial/Diesel/d-3372.pd*

Model	*Rating*	*Load factor*	*Consumption (Litres/hour)*	*Efficiency (%)*
Unknown	20	0.25	2.3	22
Unknown	30	0.25	4.9	15
Unknown	40	0.25	6.1	17
Unknown	60	0.25	6.8	22
Unknown	75	0.25	9.1	21
Unknown	100	0.25	9.8	26
Unknown	20	1	6.1	33
Unknown	30	1	11.0	28
Unknown	40	1	15.1	27
Unknown	60	1	18.2	33
Unknown	75	1	23.1	33
Unknown	100	1	28.0	36
Unknown	20	0.75	4.9	31
Unknown	30	0.75	9.1	25
Unknown	40	0.75	12.1	25
Unknown	60	0.75	14.4	31
Unknown	75	0.75	17.4	33
Unknown	100	0.75	22.0	34
Kohler Diesel 6,500 Watt Diesel Generator	6.5	0.5	1.3	25
Kohler Diesel 6,500 Watt Diesel Generator	6.5	0.75	1.7	29
Kohler Diesel 6,500 Watt Diesel Generator	6.5	1	2.2	30
Kohler 35REOZT4	30	1	10.5	29
Kohler 35REOZT4	30	0.75	7.8	29
Kohler 35REOZT4	30	0.5	5.4	28
Kohler 35REOZT4	30	0.25	3.1	24
Kohler 35REOZT4	28	1	9.8	29
Kohler 35REOZT4	28	0.75	7.3	29
Kohler 35REOZT4	28	0.5	5.0	28
Kohler 35REOZT4	28	0.25	2.9	24
Cummins DSKAB	15	0.25	1.3	29
Cummins DSKAB	15	0.5	2.6	29
Cummins DSKAB	15	0.75	3.9	29
Cummins DSKAB	15	1	5.2	29
Cummins DSKAB	13.6	0.25	1.2	29
Cummins DSKAB	13.6	0.5	2.3	29
Cummins DSKAB	13.6	0.75	3.5	29
Cummins DSKAB	13.6	1	4.7	29

Appendix B. Commercial sector energy intensity by activity type

Table 83: Average breakdown of electricity and energy intensity by type of Use in the Awutu Senya commercial sector

Type and activity of use	*Floor-space (m^2)*	*Average specific electricity consumption (kWh/m^2yr)**	*Average specific electricity consumption (inc. gen fuel) ($kWh/m^2.yr$)#*	*Average specific energy consumption ($kWh/m^2.yr$)+*	*Average share of own-generation ($kWh/m^2.yr$)[1]*
Formal	**73868**	**12**	**81**	**155**	**13%**
Formal (excl. schools & Hospitals)	**8404**	**88**	**641**	**688**	**14%**
Offices (e.g. ICT, Consultancy, etc.)	679	211	728	785	5%
Hotels & guest houses	5 689	20	173	235	17%
Schools	59 516	2	5	90	2%
Non-banks financial services	349	59	686	686	16%
Hospitals	5 948	4	54	54	29%
Banks	1 688	272	2 175	2 175	16%
Informal	**22 163**	**23**	**158**	**681**	**12%**
Aluminium fabricator	23	341	2 679	2 679	9%
Blacksmith	9	12	12	12	0%
Carpentry/welding shops	4 175	12	71	495	7%
Cold store[2]	709	205	2 863	2 863	30%
Corn mill[2]	85	137	137	137	0%
Drinking bar, restaurant, catering services	1 745	34	118	4 179	3%
Electronic repair shops	664	51	158	195	3%
Fitting/mechanic	8 397	4	21	26	7%
Laundry[2]	4	597	597	597	0%
Other	1 298	39	179	1 725	4%
Petty trading	625	16	217	907	22%
Retail	2 350	28	63	77	2%
Tailoring/seamstress	2 077	21	44	145	2%

Notes:

* Includes own generated electricity

Grid electricity and petrol and diesel energy consumed by own generated electricity

+ Includes all fuels used on site including charcoal and wood

1 Share of own generation of all electricity consumed

2 Not clear if the allocation of these to ‘Informal’ is in error

Appendix C. Distribution of commercial own-generation electricity share in the GEM and ASEM surveys

The distribution of own-generation shares in the commercial sectors of both the GEM) and ASEM surveys compared favourably, as show below, and indicate that while a minority of formal and informal enterprises own generators (18% in ASEM and 28% in GEM), those that do own them use them extensively, with a significant minority generating half their own electricity consumption.

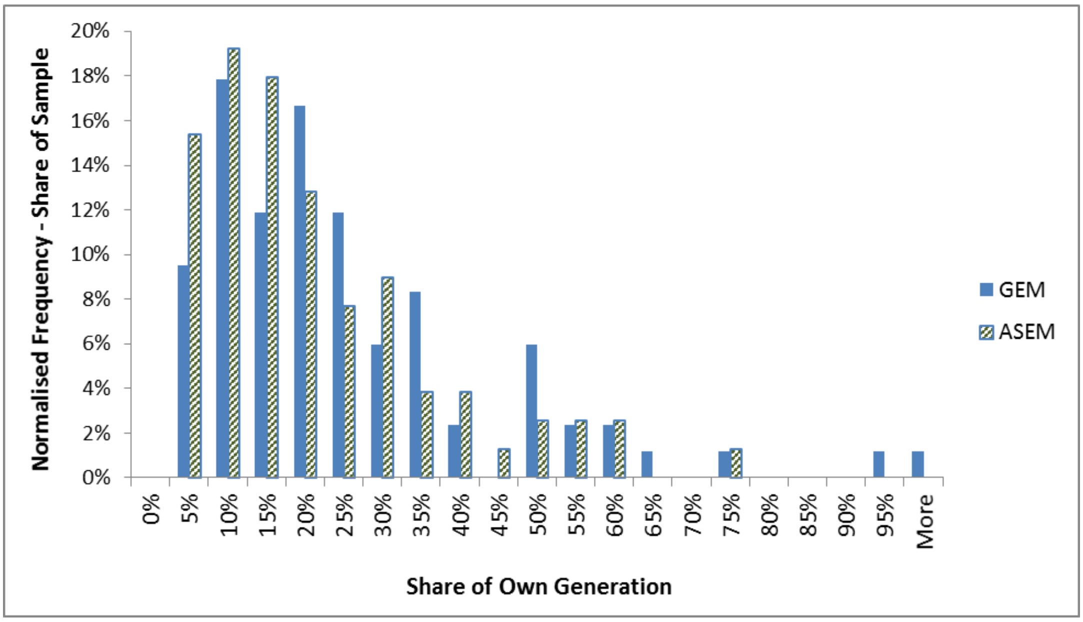

Figure 34: Comparison of share of own generation distributions for ASEM and GEM commercial sector generator owners

The outliers in the sample are instances where there was a discrepancy in the data between expenditure recorded as spent on generator fuel and volumes used as generator fuel. The methodology adopted assumed expenditure to be more reliable however on review in these instances it is likely volumes were more accurate.

Informal enterprises that owned generators showed a similar distribution to the formal sector for the Awutu Senya sample with a significant share showing high generator usage rates as shown below. The more ragged distribution may, however, indicate less accurate reporting for informal enterprises.

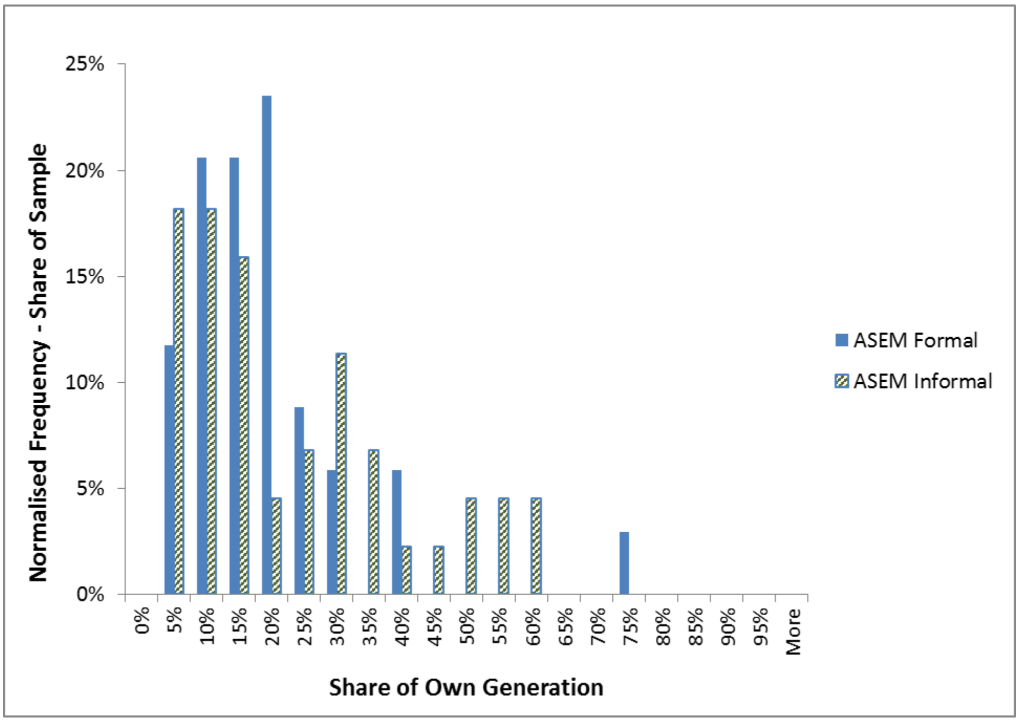

Figure 35: Comparison of share of own generation distributions for formal and informal commercial sector generator owners in Ga East Municipality sample