ENERGY RESEARCH CENTRE
University of Cape Town

RESEARCH REPORT SERIES

Ga East LEAP energy modelling technical report

BRYCE MCCALL, LOUISE TAIT AND ADRIAN STONE

May 2016

Key points

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

Suggested citation for this paper:

McCall, B, Tait, L and Stone, A. 2016. Ga East LEAP energy modelling technical report. Energy Research Centre, University of Cape Town, Cape Town.

Energy Research Centre
University of Cape Town
Private Bag X3
Rondebosch 7701
South Africa

Tel: +27 (0)21 650 2521
Fax: +27 (0)21 650 2830
Email: erc@erc.uct.ac.za
Website: www.erc.uct.ac.za

Contents

1. Introduction **1**

2. General background **4**

2.1 Households and population 4

2.2 Economy 5

3. Municipal sector **5**

3.1 Data 5

3.2 Methodology 6

4. Household sector **7**

4.1 Data 7

4.2 Methodology 9

5. Industry **12**

5.1 Data 12

5.2 Methodology 14

6. Commercial sector **14**

6.1 Data 15

6.2 Methodology 17

6.2.1 Estimating energy intensities by end-use and fuel 17

6.2.2 Formal sector calculations 17

6.2.3 Informal sector 18

6.2.4 Own-generation 19

7. Transport sector **22**

7.1 Data 22

7.2 Methodology 23

7.2.1 Scope 1 methodology 27

7.2.2 Scope 3 Methodology 30

7.2.3 Discussion on fuel sold in GEM 33

8. Business as usual (BAU) **33**

8.1 Main drivers and assumptions 34

8.2 Transport 36

8.3 Household sector 38

8.4 Municipal sector 39

8.5 Commercial sector 39

8.6 Industry 39

9. BAU LEAP results **39**

9.1 GEM scope 1 and 3 methodologies compared for BAU 40

9.2 Transport sector energy consumption 43

9.3 BAU general results 44

9.4 Sensitivity scenario tests 45

10. Efficient charcoal stoves scenario 47

Household access to modern fuels for cooking 49

11. 49

12. Conclusions 53

13. Data issues 54

14. Efficient Fridges scenario (EFR) 57

References 61

Appendix A. Own-generation efficiency model 62

Appendix B. Commercial sector energy intensity by activity type 64

Appendix C. Distribution of commercial own generation electricity share in the GEM and ASEM surveys 65

1. Introduction

This is the technical documentation for the development, data, and methodology of the Ga East Municipality (GEM) energy systems model which forms part of the Supporting Sub Saharan African Municipalities with Sustainable Energy Transitions (SAMSET) project. The project is a collaboration between the Universities of Uganda Martyrs, Ghana, Cape Town, Durham and University College London, the non-profit organisation Sustainable Energy Africa and Gamos Consulting. It is co-funded by UK aid from the UK Department for International Development, the Engineering and Physical Science Research Council and the Department for Energy and Climate Change.

The model is developed on the Long range Energy Alternatives Planning System (LEAP) platform of the Stockholm Environment Agency (SEI). 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 another project output (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 Ga East's energy system on the supply and demand side, 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 GEM officials and local experts and is documented in another SAMSET output, the Ga East 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 very 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;

and 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 categorised 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 the figure below.

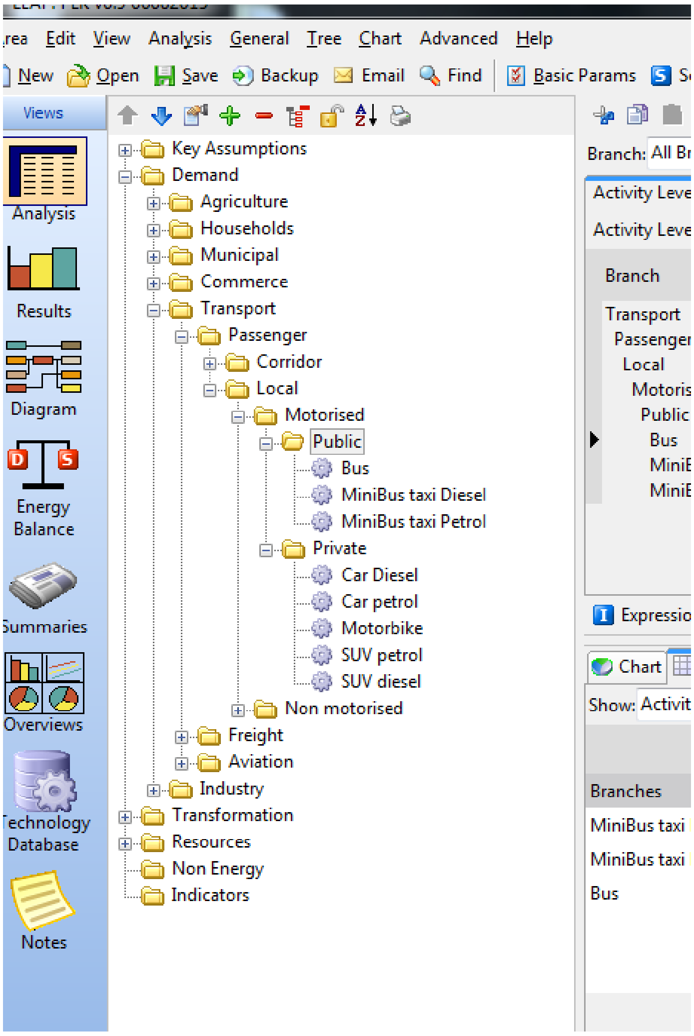


Figure 1: Example of the tree structure in LEAP which aids in categorising the sectors and subsectors of a model down to individual technologies. Here the level goes down to the share of private cars which are diesel or petrol and so on.

It's important to understand clearly that an energy service, heating for instance, 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 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

$$E_S = \sum (\theta_i \mathrm{X} \eta_i \mathrm{X} O_S) \qquad \text{Equation 1}$$

if:

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

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 provides a spreadsheet-like formula builder for generating time series of parameters such that an output $O_{S,}$ for instance 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 below where the shares of individual technologies is set easily by the user and LEAP instantly shows the graphic representation of this change.

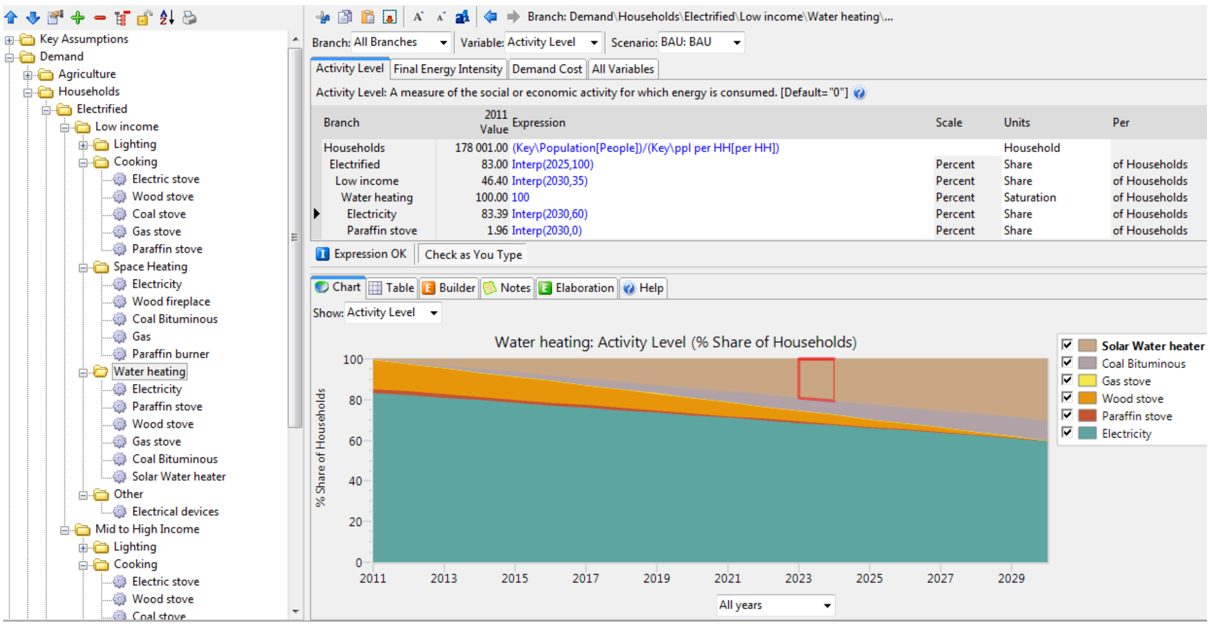


Figure 2: A screen shot of the LEAP interface showing the change in water heating technologies for low-income households through to 2030

LEAP has a financial framework and, if the costs of technologies are known, the impact on net present value of supplying that service can 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 needs to be paid, therefore, 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 Ga East 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 to Accra and traffic passing through, it is reasonable to assume that a significant portion of petrol and diesel that is sold within Ga East transits the boundary while fuel from elsewhere enters the municipality daily. In this framework we attempt to represent intra-boundary trips, inter-boundary trips either generated in or attracted to Ga East and corridor trips, of which Ga East 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 Ga East 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

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

- surveys of 590 households, 310 commercial businesses and 50 industrial businesses in the municipal area;
- focus groups;
- interviews with municipal staff; and
- municipal records.

Much of the detail of these surveys is presented in the State of Energy report by the Ghanaian team members of the SAMSET project – see Bawakyillenuo and Agbelie (2014).

The Base year for this model is 2013 since the survey was carried out in 2013.

Ga East is located in the Greater Accra region, and is an outlying part of Accra.

2.1 Households and population

The household population of Ga East in 2010 was estimated, through the 2010 national census to be 33 949 households, and 75% of households were electrified (Bawakyillenuo & Agbelie, 2014). Household classifications are based on standard Ghanaian land-use classifications, which are based on degree of access to service delivery and other factors[1].

[1] See Bawakyillenuo et. al (2014) for more details on household classification.

Table 1: Household estimate, 2010

Household classification	*Number*	*Percentage*
Household 1	28 743	85
Household 2	1 870	5
Household 3	3 336	9
Total	**33 949**	**100**

The population of Ga East was estimated to be 147 742 in 2010 according to the Ghana National Statistics (Ghana Statistical Service, 2014b). Extrapolating this estimate to 2013 with an annual 3% growth rate, equates to 161 441 people living in 37 096 households (assuming household density does not change).

2.2 Economy

The gross value added (GVA) – the 'GDP' for GEM is inferred based on the average GDP per capita for the country. Due to the proximity of GEM to the economic hub of Ghana, Accra, this value could be an underestimate.

The population for Ghana in 2013 was 26.4 million (Ghana Statistical Service, 2012) and the national non-oil GDP for 2013 was GHC71 627 million (Ghana Statistical Service, 2014a).

Thus, with the population of GEM and the GDP per capita, the inferred GDP for the municipality would be 437.5 Million GHC in 2013.

3. Municipal sector

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

3.1 Data

The SAMSET partners in Ghana provided data on the municipality's own energy consumption and how the energy is used within the municipal buildings and for municipal services. Much of this data is taken from the State of Energy report by Bawakyillenuo and Agbelie (2014). The total floorspace of all municipal buildings in 2013 was estimated to be 8860m^2. The energy consumption for the municipality buildings and their vehicle fleet is presented in the tables below.

Table 2: The GEM own energy consumption by end use for 2013

	Unit	*Lighting*	*Ventilation and air-conditioning*	*Refrigeration*	*Transport*	*Office machines*
Electricity	kWh	174 468	1 239 840	606 216	0	527 316
Diesel	Litres	360	600	240	56 250	303

Table 3: The electricity consumption of GEM's water system

2010	*2011*	*2012*	*2013*
51 667 kWh	51 667 kWh	23 333 kWh	12 963 kWh

Table 4: The GEM municipality's data on own generators use in 2013

Diesel generator	120 kW	1 503 L/year

The municipality had eight vehicles in operation in 2013 consuming about 56 250L of diesel a year.

Table 5: Municipality vehicle fleet details and fuel consumption

Vehicle count	8
Average use	520 km/month
km/year	6 240 km
Total diesel	56 250 L/year

The electricity consumption share by end use for the municipality is presented below and highlights ventilation and air-conditioning as the main energy consumer in municipal buildings.

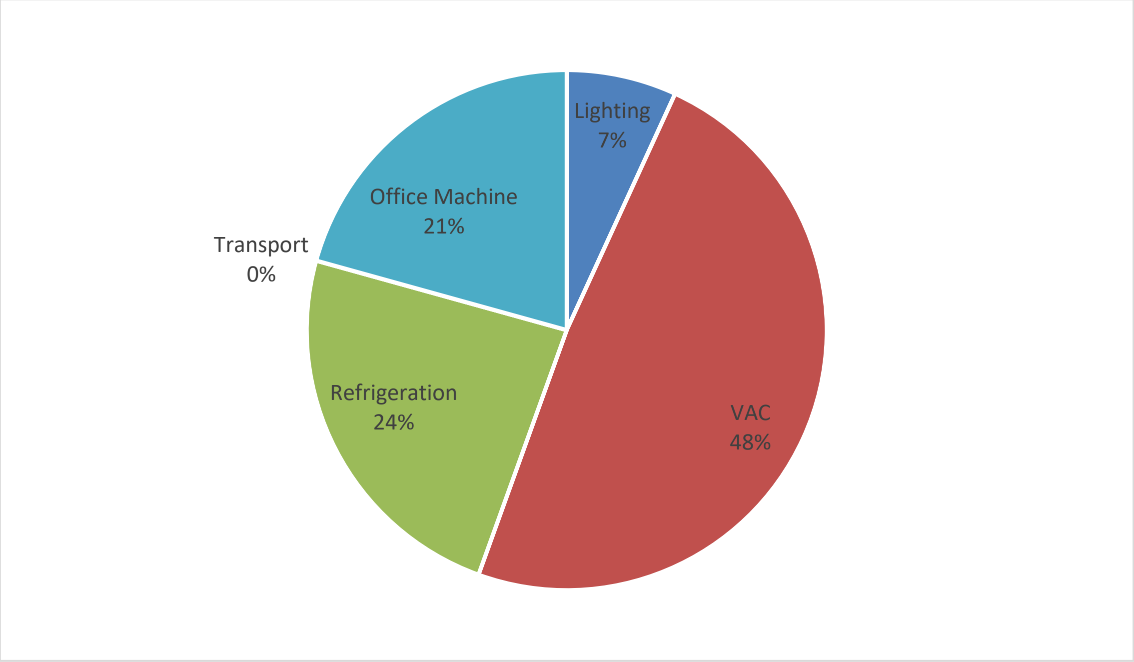


Figure 3: Electricity consumption in municipal buildings

3.2 Methodology

Municipal buildings

Using the electricity consumption data and the total floor space data the energy intensity values for each end use for the municipality is given below.

Table 6: GEM building end use energy intensity values for 2013

	Lighting	*VAC*	*Refrigeration*	*Office Machines*
kWh/m^2	19.7	139.9	68.4	59.5

Transportation

Using the data for the GEM vehicle fleet, the following vehicle km and fuel economy were used for model input:

Table 7: GEM vehicle fleet activity and energy consumption

Total all vehicles	4 160	km/month
Annual km	49 920	All vehicles
Fuel consumption	7 031	L/veh per year
Fuel economy:	113	L/100km*
* This fuel efficiency is rather poor, but large garbage trucks are known to have very poor fuel efficiency on the order of 100's of L/100km (See www.cert.ucr.edu/events/pems2014/liveagenda/25sandhu.pdf).		

4. Household sector

4.1 Data

The data for the household sector is based on survey data of a statistically representative sample of households undertaken in the municipality. This data was augmented by bottom-up calculations of energy consumption based on appliance ratings and consumption patterns from the literature. The survey data collected data for households was disaggregated in three categories based on Ghanaian land-use classifications. These classifications have been used as a loose proxy for income, in the absence of any other data. The electrification rate for the municipality was assumed constant across household categories which yields a breakdown of six household categories as follows (due to the small sample sizes of Household 2 electrified and Household 3 electrified these households values were grouped together and the average value is used).

Table 8: Number of households in 2013 survey

Household classification	*Sample size*	*Total Households*
Household 1 - electrified	390	21 534
Household 1 - unelectrified	134	7 209
Household 2 - electrified	25	1 401
Household 2 - unelectrified	7	469
Household 3 - electrified	45	2 499
Household 3 - unelectrified	13	837
Total	**614**	**33 949**

The sample survey (adjusted where necessary based on typical appliance ratings and hours of use) shows the following average annual consumption per energy carrier.

Table 9: Annual average consumption per household

	Wood (kg)	*Electricity (kWh)*	*Kerosene (L)*	*Charcoal (kg)*	*LPG (kg)*	*Dry cell batteries (no. of singles)*
Electrified						
Household 1	527	2 083	20	265	131	83
Household 2	989*	1 374	67	264	97	72
Household 3	989*	1 595	9	265	126	97
Unelectrified						
Household 1	721	-	37	424	113	146
Household 2	1200	-	6	273	72	6
Household 3	1200	-	6	273	72	117
* Survey data revised for wood consumption						

The household survey data for wood consumption varied quite significantly, with Household 3 Electrified reportedly using almost 370% of the amount that Household 2 Electrified households reported using. A degree of information error in survey data is likely due to issues like memory bias as well as the fact that people are unlikely to consistently weigh their wood. To resolve this inconsistency and provide a more reasonable estimate, an average of the two sample estimates was used for both categories of 989 kg per annum.

Table 10: The proportion (%) of the household sample using end-uses (bold) and energy carriers (*italic*)

	Electrified			*Unelectrified*		
	Household 1	*Household 2*	*Household 3*	*Household 1*	*Household 2*	*Household 3*
Lighting	**100**	**100**	**100**	**76**	**90**	**66**
Electricity	*100*	*100*	*100*	-	-	-
Solar	*2*	*8*	*4*	*1*	*0*	*0*
Batteries	*41*	*48*	*22*	*75*	*86*	*62*
Kerosene	*1*	*6*	*6*	*1*	*4*	*4*
Cooking and water heating	**100**	**100**	**100**	**100**	**100**	**100**
Electricity	*50*	*40*	*22*	**-**	**-**	**-**
Wood	*8*	*16*	*13*	*24*	*35*	*35*
Charcoal	*81*	*92*	*100*	*94*	*96*	*96*
LPG	*82*	*76*	*64*	*40*	*15*	*15*
Kerosene	*3*	*4*	*4*	*2*	*1*	*1*
Refrigeration	**80**	**80**	**67**	**-**	**-**	**-**
Electricity	*100*	*100*	*100*	-	-	-
Entertainment	**100**	**100**	**100**	**37**	**41**	**41**
Electricity	*100*	*100*	*100*	**-**	**-**	**-**
Dry cell batteries	*5*	*0*	*4*	*37*	*41*	*4154*
Space cooling	**86**	**96**	**82**	**-**	**-**	**-**
Electricity	*100*	*100*	*100*	-	-	-
Other energy services	**80**	**92**	**62**	**-**	**-**	**-**
Electricity	*100*	*100*	*100*	-	-	-

Source: Household survey

Note: A household may use more than one energy carrier for an energy service, for instance electricity and wood for cooking so the sum of household shares for an end-use does not necessarily add up to 100%. In LEAP these are termed 'saturation' shares

The household surveys investigated the extent of ownership and usage of efficient appliances. All electrified households use CFL light bulbs. The Ghanaian government instituted a wide-scale National Efficiency Lighting Project in 2006/07 aimed at conserving electricity in response to an electricity supply crises. In 2008, the government legislated against the manufacture and sale of incandescent lamps. The Ghanaian Energy Commission has also instituted minimum energy-efficiency standards for refrigeration appliances as well as a refrigeration rebate scheme whereby households can swap old inefficient appliances for newer efficient ones. However, none of the households surveyed reported making use of the Energy Commission's scheme. The table below indicates that ownership of efficient refrigeration appliances is higher in the higher-income category. Despite the widespread usage of charcoal and wood, efficient products 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'.

Table 11: Efficient appliance usage – share of households in the sample

	Electrified			*Unelectrified*		
	Household 1	*Household 2*	*Household 3*	*Household 1*	*Household 2*	*Household 3*
CFL light bulbs	100%	100%	100%	-	-	-
Refrigeration	30%	9%	9%	-	-	-
Charcoal stoves	4%	9%	8%	9%	0%	0%
Wood stoves	0%	0%	0%	0%	0%	0%

4.2 Methodology

The consumption profiles of households in terms of appliance ownership and the total amount of final energy of energy carriers consumed by households for the various income groups are based on the survey data collected by the University of Ghana described above. The energy intensities of end-uses input to the model were estimated based on the typical observed energy profiles of households in the sample, assuming typical appliance ratings and hours of usage. These were further adjusted where necessary to calibrate against the total energy consumption of households in the sample, as shown in Table 9 above.

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

> ***Number of households in sub-category*** *(e.g. Household 1 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).* Equation 2

Table 12: Electricity consumption estimates for 'Household 1 electrified'

Energy service	*Share of households using energy service*	*Share of households using electricity for energy service*	*Average daily consumption (kWh)*	*Days per year used*	*Average household energy intensity kWh/yr*	*Total consumption estimate for population (annual kWh)*
Cooking and water heating	100%	50%	1.512	320	484	5 182 752
Lighting	100%	100%	0.432	365	158	3 395 456
Fridge	80%	100%	2.835	365	1035	17 883 282
Entertainment	100%	100%	0.516	320	165	3 555 668
Space cooling	86%	100%	1.210	350	424	7 833 488
Other	80%	100%	1.148	350	402	6 921 839
Total						**44 772 485**

Table 13: Electricity consumption estimates for 'Household 2 electrified'

Energy service	*Share of households using energy service*	*Share of households using electricity for energy service*	*Average daily consumption*	*Days per year used*	*Average household energy intensity kWh/yr*	*Total consumption estimate for population (annual kWh)*
Cooking and water heating	100%	40%	1.416	320	453	253 924
Lighting	100%	100%	0.432	365	158	220 906
Fridge	80%	100%	2.100	365	767	859 079
Entertainment	100%	100%	0.387	320	124	173 497
Space cooling	96%	100%	0.615	350	215	289 498
Other	92%	100%	0.628	350	220	283 300
Total						**2 080 205**

Table 14: Electricity consumption estimates for 'Household 3 electrified'

Energy service	*Share of households using energy service*	*Share of households using electricity for energy service*	*Average daily consumption*	*Days per year used*	*Average household energy intensity kWh/yr*	*Total consumption estimate for population (annual kWh)*
Cooking and water heating	100%	22%	2.162	320	692	384 245
Lighting	100%	100%	0.432	365	158	394 087
Fridge	67%	100%	2.100	365	767	1 277 134
Entertainment	100%	100%	0.486	320	156	388 689
Space cooling	82%	100%	0.615	350	215	442 332
Other	62%	100%	1.518	350	531	826 230
Total						**3 712 716**

Table 15: Household wood consumption estimates

Household category	*Share of households using wood for cooking*	*Appliance type*	*Percentage that use appliance type*	*Average estimated annual consumption (kg/household)*	*Total estimated consumption for population (kg)*
Electrified					
Household 1	8%				907 867
		Efficient stove	0%	-	
		Inefficient stove	100%	527	907 867
Household 2	16%				221 691
		Efficient stove	0%	-	
		Inefficient stove	100%	989	221 691
Household 3	13%				321 333
		Efficient stove	0%	-	
		Inefficient stove	100%	989	321 333
Unelectrified					
Household 1	24%				1 247 472
		Efficient stove	0%	-	
		Inefficient stove	100%	721	1 247 472
Household 2	35%				196 990
		Efficient stove	0%	-	
		Inefficient stove	100%	1200	196 990
Household 3	35%				351 421
		Efficient stove	0%	-	
		Inefficient stove	100%	1200	351 421

Table 16: Charcoal consumption estimates

Household category	*Households that use charcoal for cooking*	*Appliance type*	*Percentage that use appliance type*	*Average estimated annual kg/household*	*Total estimated consumption for all households (Kg)*
Electrified					
Household 1	**81%**				**4 632 356**
		Efficient stove Inefficient stove	4% 96%	136 271	94 538 4 537 818
Household 2	**92%**				**340 269**
		Efficient stove Inefficient stove	9% 91%	138.0 276.0	15 467 324 803
Household 3	**100%**				**661 250**
		Efficient stove Inefficient stove	8% 92%	138 276	27 552 633 698
Unelectrified					
Household 1	**94%**				**2 866 945**
		Efficient stove Inefficient stove	9% 91%	222 443	135 092 2 731 854
Household 2	**96%**				**122 921**
		Efficient stove Inefficient stove	0% 100%	- 234	- 122 921
Household 3	**96%**				**219 287**
		Efficient stove Inefficient stove	0% 100%	- 325	- 219 287

Table 17: LPG consumption estimates

Household category	*Households that use LPG for cooking*	*Average estimated annual kg/household*	*Total estimated consumption for all households (kg)*
Electrified			
Household 1	82%	131	2 307 744
Household 2	76%	97	102 753
Household 3	64%	97	155 436
Unelectrified			
Household 1	40%	113	327 188
Household 2	14%	72	4 824
Household 3	15%	72	9 268

The aggregated survey data for household generator usage in GEM is presented below, along with the estimate for the entire household population usage of generators. Equations 8 and 11 discussed below in Section 6.2.4 were used to convert annual fuel use and generator rating into electricity generated, assuming an average load factor of 0.75. There were 19 households using generators in the survey, all in the Household 1 category, of which one was un-electrified. The aggregated data below is scaled up to be representative of the population and compared to the scaled-up electricity demand estimate for the entire household population.

Table 18: GEM Household (class 1) 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	28 737	111 807	140 544	20%	10 557	3 638	0.5
	Unelectrified	285		285	100%	221		0.7
Population (estimate)	Electrified	1 586 729*	44 849 577#	46 436 307	3%	582 926	200 863	
	Unelectrified	15 336		15 336	100%	11 905		

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

The data indicate that while not many people own generators, such that they only account for about 3% of total electricity supply to Household 1 households in the sample, 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. This may be indicative of substantial suppressed demand of the order of 20% or greater.

5. Industry

This section describes the industry sector of GEM and the model data which were derived from the data provided by the SAMSET team and the survey conducted.

5.1 Data

Based on the classification of the industries in the survey, the industry sector is comprised of the following subsectors as given in the SoE report (Bawakyillenuo & Agbelie, 2014): construction, manufacturing, and water and sewerage. The survey conducted by the SAMSET team covered 50 of the approximately 70 industry entities that were identified in the survey preliminary analysis. Their electricity consumption and their total productivity in tonnes output are given in in the table below.

Table 19: Industry data from the survey for GEM in 2013

Sub-sector	*Output (tonnes)*	*Electricity consumed (kWh)*
Construction	524 360*	104 145
Manufacturing	816 089	89 777
Water and sewerage	1 938 855	284 444

* From the SoE report it is unclear as to what the output for the construction subsector entails.

Proportionally scaling up the construction and manufacturing activities to the full 70 industries of GEM, the following industrial activity is assumed to represent GEM industry.

Table 20: GEM industry activity sample data extrapolated to represent the full sector

Sub-sector	*Production Tonnes output*	*Electricity consumed kWh*
Construction	734 105	145 803
Manufacturing	1 142 525	125 688
Water & Sewerage	2 714 396	284 444

Presumably the larger local industrial concerns are in the sample and industry consumption per firm is typically skewed towards a few large consumers, so this may overstate total consumption but, given the large sample size, this source of error was assumed to be limited.

Table 21: The electricity consumption in industry by end use for GEM 2013 after extrapolation

Sub-sector	*kWh consumption*				
	Machinery	*Lighting*	*Cooling systems*	*Other machine drive*	*Other*
Construction	98 966	37 849	5 037	4 145	2 024
Manufacturing	64 690	37 642	13 852	4 518	749
Water and sewerage	309 524	110 098	1 008	465	0

As shown below, the majority of energy consumed in the industry sector is in machinery and in lighting.

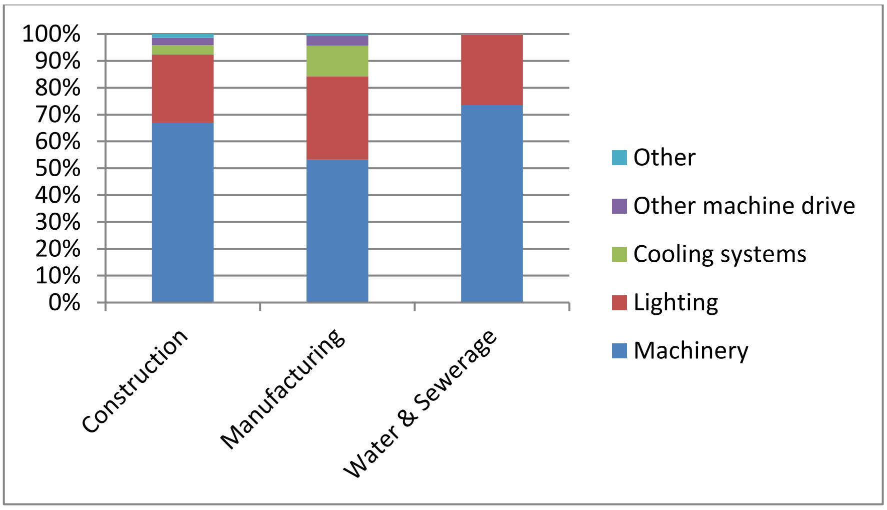


Figure 4: The end use shares of electricity consumption industry for GEM, 2013

The consumption of liquid fuels in industry as indicated by the survey and extrapolated to represent the full population size is estimated to be as follows.

Table 22: The consumption of diesel in various end uses for industry in GEM, 2013

Sub-sector	*Diesel (litres)*	*Petrol (litres)*		
	*Machinery**	*Machinery*	*Other machine drive*	*Other*
Construction	34 499	840	84	
Manufacturing	-	1 428	13 415	
Water and sewerage	123 618	-	-	
* Typically this would include machinery like bulldozers and earth movers.				

The data for diesel and petrol generators used in GEM for the year 2013 is given below, after extrapolating to represent the whole industry sector.

Table 23: Industry diesel and petrol generators sample data scaled to full sector for GEM 2013

Sub-sector	*Litres consumed*		*kWh output*		*Installed capacity (kW)*		*Capacity factor*	
	Diesel	*Petrol*	*Diesel*	*Petrol*	*Diesel*	*Petrol*	*Diesel*	*Petrol*
Manufacturing	758	3 271	2 374	6 958	2	57	12.9%	1.6%
Construction	33600	1 210	105 263	2 486	21	19	57.2%	1.5%
Water and sewerage	128383	0	402 203	0	162	0	28.2%	

The prevalence of generator ownership and the share of electricity consumed by generator owners in the sample is shown below.

Table 24: Rates of generator ownership and use for GEM, 2013

Sub-sector	*Share of sample operating generators*	*Electricity share of own generation of generator owners*
Manufacturing	38%	21%
Construction	11%	93%
Water and sewerage	71%	86%

5.2 Methodology

Using the data provided by the survey and after extrapolating to represent the full industrial sector of GEM, the energy intensities for each end use in industry was calculated (Table 25). This was done for liquid fuel consumption as well (Table 26).

Table 25: Final energy intensities of electricity use in industry for GEM 2013 (kWh/tonne)

	Machinery	*Process heating*	*Lighting*	*Cooling systems*	*Other machine drive*	*Other*
Construction	0.1348	-	0.0516	0.0069	0.0056	0.0028
Manufacturing	0.0566	-	0.0329	0.0121	0.0040	0.0007
Water and sewerage	0.1140	-	0.0406	0.0004	0.0002	-

Table 26: Liquid fuel energy intensities for industry in GEM 2013 (L/tonne)

Diesel	*Petrol*			
Machinery	*Machinery*	*Process heating*	*Other machine drive*	*Other*
0.0470	0.0011	-	-	0.0001
-	0.0012	-	-	0.0117
0.0455	-	-	-	-

It is most likely that the diesel consumption for 'machinery' is earth-moving equipment or other industry=specific special vehicles or stand-alone internal combustion engines, but this should be more clearly defined in future iterations of the model to avoid confusion with diesel-fuelled generators.

The following end uses were implemented into the LEAP model with their associated electricity kWh/tonne and liquid fuel L/tonne intensities as tabulated above:

- lighting;
- cooling;
- machinery;
- other machine drive; and
- other.

Future energy demand for energy could therefore be projected by projecting tons of production. Scenarios of energy efficiency can be implemented by assuming reductions in the currently observed energy intensities based on the relative efficiencies of new technologies.

6. Commercial sector

This section describes the representation of commercial activities in GEM, including formal and informal businesses.

6.1 Data

The University of Ghana surveys collected data on energy carriers used, end-uses, and own generation with petrol and diesel generators, the floorspace of premises and the costs of energy consumption. A total of 313 businesses were surveyed, including 61 formal businesses and 252 informal businesses. It is thought that this constitutes the whole of the commercial sector for GEM (from communications during SAMSET network meetings). The types of businesses classified as commercial (based on University of Ghana classifications include the following:

Formal:

- hotels and 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.

Energy consumption is driven by floorspace in the model. The total floorspace of the sample was dominated by the formal sector as shown below even though these only accounted for about 20% of the premises surveyed.

Table 27: Floorspace of sample

	Number of businesses sampled	*Floor space of sample (m^2)*
Formal	61	94,285
Informal	252	14,966
Total	313	109,251

Schools. and to a lesser degree hotels and guest houses, however, account for a disproportionate share of floorspace area in the formal sub-sector and the sample as a whole, as shown below. 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:

- The entire commercial sector was sampled, so the energy baseline of the sample was not scaled up and therefore a risk of the contribution of schools becoming more disproportionate was not incurred.
- The methodology of determining floorspace area and the need for clear metadata in this regard for this data set is discussed in the data issues section. While possible inconsistencies here may mean the average energy intensity per unit area is relatively very low, the model itself. which projects area geometrically into the future. is still internally consistent. The area of more energy-intensive sub-sectors like banks, for example, still grows at the assumed growth rate independently, thus growing their absolute energy demand at the assumed rate. The data

set, particularly when averaged, should, however, be compared to other data and to energy efficiency benchmarks with great caution.

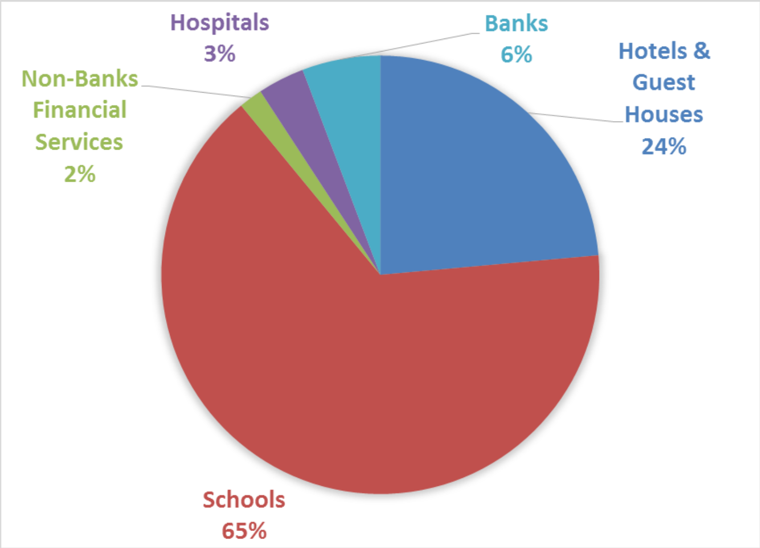


Figure 5: Share of formal commercial floorspace by activity type

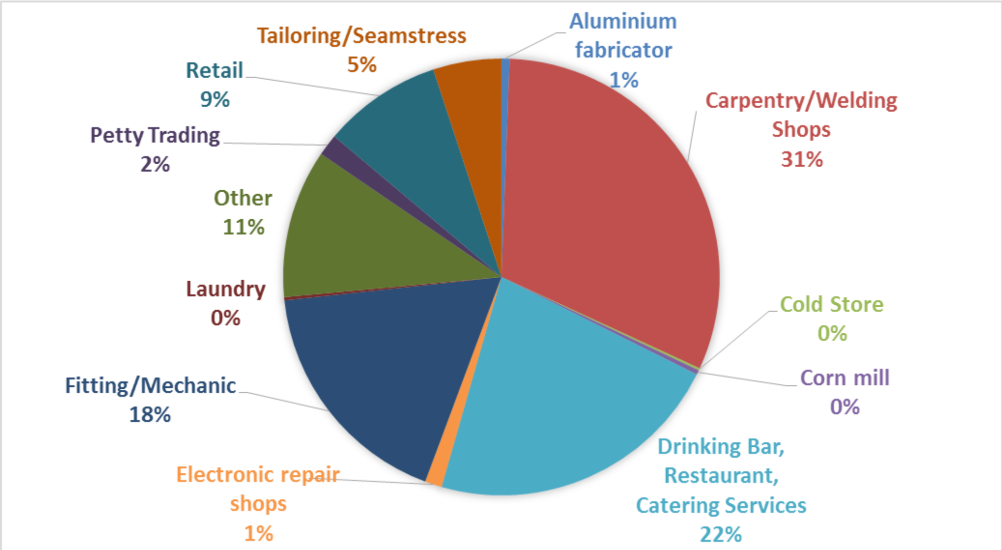


Figure 6: Share of informal commercial floorspace by activity type

The survey data shows the following estimated consumption of fuel by energy services for formal and informal sectors.

Table 28: Formal sector: Survey results of annual consumption by fuel and end-use for sample

	HVAC	*Cooking/ water heating*	*Lighting*	*Refrig-eration*	*Machine operation*	*Entertain-ment*	*Other*	*Total*
Electricity (kWh)	259 245	32 172	360 554	51 565	196 091	61 855	6 869	968 352
LPG (kg)	-	8 904	-	-	-	-	214	9 117
Charcoal (kg)	-	13 050	-	-	-	-	-	13 050
Wood (kg)	-	1 250	-	-	-	-	-	1 250
Kerosene (L)	-	1	-	-	-	-	-	1

Table 29: Informal sector - Survey results of annual consumption by fuel and end-use for sample

	HVAC	*Cooking/ water heating*	*Lighting*	*Refrig-eration*	*Machine operation*	*Entertain-ment*	*Other*	*Total*
Electricity (kWh)	33 779	11 422	108 248	38 197	177 685	53 463	6 903	429 697
LPG (kg)	-	7 532	-	-	229	-	360	8 121
Charcoal (kg)	-	18 648	-	-	-	-	88	18 736
Wood (kg)	-	18 300	-	-	-	-	-	18 300
Kerosene (L)	-	7	-	-	-	-	2	9

The survey also included a questionnaire on own-generator use, although it is thought that the 61 formal businesses constitutes the entire formal sector most of them have gensets (a total of 39), while the informal sector has just 47 (out of 252 informal businesses). This data is tabulated below.

Table 30: Generator survey sample data for commercial sector of GEM

	Com subsector	*Capacity (kW)*	*Litres used*	*Electricity generated (kWh)*	*Capacity factor*	*Sample count*
Petrol	Formal	161	18 282	37 827	2.7%	16
	Informal	141	24 483	44 002	3.6%	46
Diesel	Formal	498	49 726	155 782	3.6%	23
	Informal	25	234	734	0.3%	1

6.2 Methodology

6.2.1 Estimating energy intensities by end-use and fuel

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 (we calibrate this from an initial estimate)

Equation 3

6.2.2 Formal sector calculations

Table 31 shows the relevant results of the survey.

Table 31: Percentage of floorspace with end-uses

% of total floor space with end uses	*HVAC*	*Cooking/ water heating*	*Lighting*	*Refriger-ation*	*Machine operation*	*Entertain-ment*	*Other*
Formal	98%	62%	99%	56%	87%	65%	19%

Table 32: 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	99%	53%	99%	99%	98%	98%	100%
LPG	-	69%	-	-	-	-	4%
Charcoal	-	45%	-	-	-	-	-
Wood	-	7%	-	-	-	-	-
Kerosene	-	1%	-	-	-	-	-

Calibrated:

Table 33: Formal sector: 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)	2.83	1.03	3.93	0.99	2.43	1.04	0.38
LPG (kg/m^2)		0.22					0.33
Charcoal (kg/m^2)		0.50					
Wood (kg/m^2)		0.31					
Kerosene (L/m^2)		0.001					

6.2.3 Informal sector

Based on survey results, the informal sector utilises lighting and 'machine operations' mostly with a mix of other uses.

Table 34: Percentage of floorspace with end-uses

% of total floor space with end uses	*HVAC*	*Cooking/ water heating*	*Lighting*	*Refriger-ation*	*Machine operation*	*Entertain-ment*	*Other*
Formal	26%	20%	95%	29%	70%	58%	7%

Table 35: 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	99%	94%	100%	100%	95%	100%	30%
LPG	-	61%	-	-	2%	-	1%
Charcoal	-	82%	-	-	-	-	2%
Wood	-	23%	-	-	-	-	-
Kerosene	-	1%	-	-	-	-	-

Calibrated:

Table 36: Formal sector: 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)	8.65	4.11	7.60	8.84	17.89	6.12	21.27
LPG (kg/m^2)		4.22			1.22		31.25
Charcoal (kg/m^2)		7.72					3.78
Wood (kg/m^2)		27.37					
Kerosene (L/m^2)		0.17					0.69

6.2.4 Own-generation

The following methodology 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 below

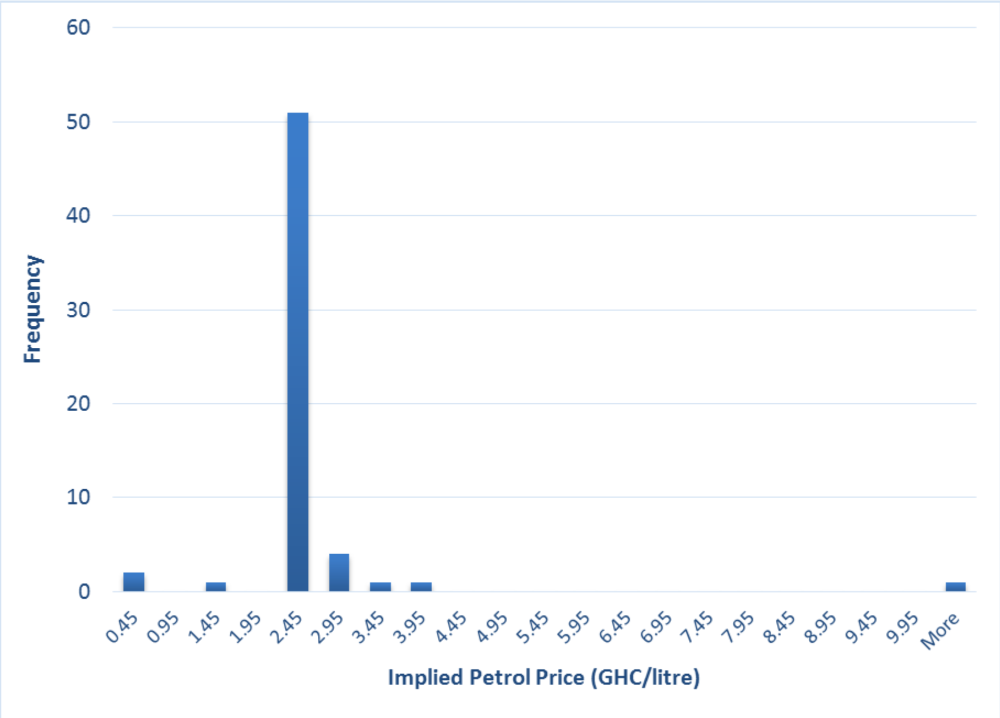


Figure 7: Histogram of implied prices obtained by dividing petrol volume data into petrol expenditure data

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 four 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:

$FC_P = 0.398\ R_P + 0.566$ Equation 4[2]

$FC_D = 0.3192\ R_D$ Equation 5[3]

$E_P = V_P / (FC_P/R_P)$ Equation 6

$E_D = V_D / (FC_D/R_D)$ Equation 7

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:

$\eta_P = 1.03X10^{-1}\ \text{Load factor} + 4.04X10^{-3}\ R_P + 6.18X10^{-2}$ Equation 8

$FC_P = R_P / (CV_p\ X\ \eta_P)$ Equation 9

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

$FC_P = 5.33\ X10^{-1}\ R_P + 5.00\ X10^{-2}$ Equation 10

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

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

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

$$\eta_D = 1.26E\text{-}01 * \text{Load factor} + 5.13E\text{-}04 * R_D + 1.69E\text{-}01 \quad \text{Equation 11}$$

$$FC_D = R_D / (CV_D \times \eta_D) \quad \text{Equation 12}$$

Where:

FC = Volumetric consumption (litres/hour)
R = Generator cating (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 is distributed as shown in Figure 8.

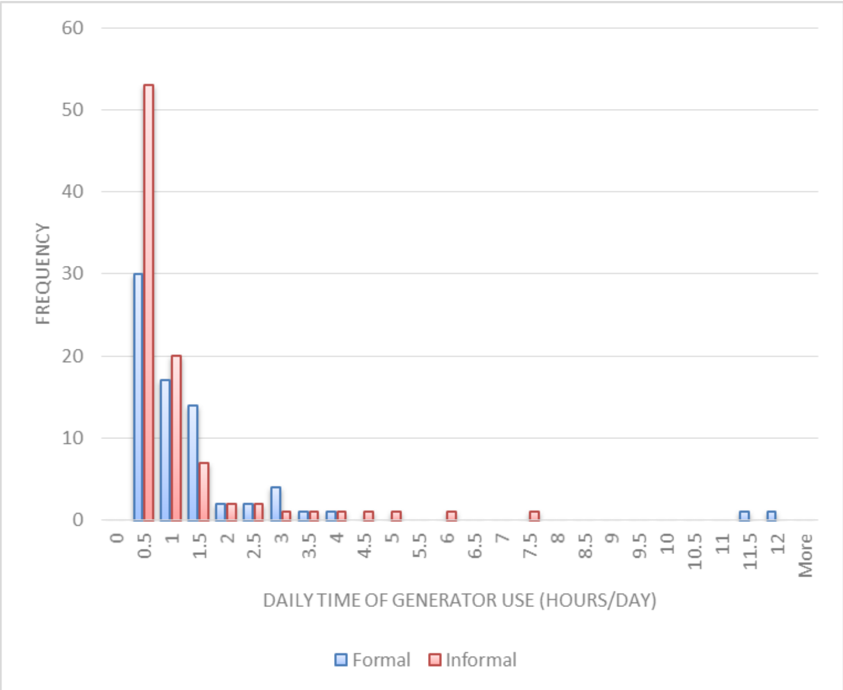


Figure 8: Distribution of calculated daily generator use for informal and formal businesses in both Ga East and Awutu Senya East

On average, formal businesses use generators for 1.2 hours a day and informal businesses 0.85 hours per day.

A summary of the data obtained from the survey for own generator use is presented below.

Table 37: Commercial sector own-generator data summary

		Total sector kW	*Litres used*	*Electricity generated (kWh)*	*Capacity factor*	*Sample count*	*Share of commercial sector*
Petrol	Formal	161	18 282	37 827	2.7%	16	26.2%
	Informal	141	24 483	44 002	3.6%	46	18.3%
Diesel	Formal	498	49 726	155 782	3.6%	23	37.7%
	Informal	25	234	734	0.3%	1	0.4%

7. Transport sector

This section describes the data and methodologies used for representing the transportation energy demand in GEM and projecting it into the future. In this methodology, transport is split into passenger and freight demands, each with its own driver (of demand).

7.1 Data

The data for the transport sector of GEM comes largely from the State of Energy report by Bawakyillenuo and Agbelie (2014). The data for this was obtained from the focus group discussions with fuel service stakeholders and representatives from the municipality and the municipal assembly that were part of the SAMSET survey in GEM. While part of the exercise including the direct surveys undertaken in the residential, commercial and industrial sectors, the data collection for the transport model did not derive from direct survey as was the case for other sectors.

The data obtained from the SAMSET data collection process indicated a large population of vehicles in the municipality (Bawakyillenuo & Agbelie, 2014). A total of 23 315 vehicles from trucks to minibuses were estimated to be active within the GEM area from the data obtained from the SAMSET project partners. With a population of 161 441 in 2013, this implies a motorisation of 144 vehicles/1000 people, substantially higher than the apparent national value and around the same as the average for Turkey and Jordan, both countries with significantly higher income levels (World Bank n.d.). GEM would therefore be a relatively prosperous area as reflected in the levels of motorisation presented in Table 38.

Table 38: The vehicle count for GEM in 2013

Vehicle type	*Passenger*		*Freight*	*% share by fuel*		
	Public	*Private*		*Petrol*	*Diesel*	*LPG*
Heavy passenger vehicle >12	3				100	
Light passenger vehicle <12		18 672		71	29	
Mini buses (trotrolikes)	2 759	120			100	
Taxi	1 491			43	14	43
Motorbikes	108	12		100		
Light trucks			60		100	
Medium and heavy trucks			90		100	

The total fuel sold in the GEM municipality as obtained from the focus group discussions was as follows:

Table 39: Fuel data for GEM in 2013 as reported by focus groups

Description	*Data*	*Unit*
Fuel station	32	Count
LPG stations	8	Count
Average volume petrol sold per station	75 000	L/station
Average volume diesel sold per station	87 500	L/station
Average volume LPG sold per station	12 246 370	kg/station

The focus group discussions indicated that demand for fuels fluctuated in the period 2010 and 2013 with petrol and diesel demand increasing steadily but LPG demand levelling off.

Table 40: Estimated total fuel sold in GEM 2010 - 2013

	2010	*2011*	*2012*	*2013*
Diesel (L)	2 700 000	2 700 000	2 750 000	2 800 000
Petrol (L)	2 200 000	2 200 000	2 400 000	2 400 000
LPG (kg)	83 330 133	111 363 640	110 931 120	97 970 960

Collating all the data on diesel, petrol and LPG use within the other model sectors – commerce, residential, industry, and the local municipality, the following liquid fuel energy balance was obtained for GEM:

Table 41: The GEM liquid fuel energy balance for 2013 from the data obtained for the SAMSET project

			Diesel (L)	*Petrol (L)*	*LPG (kg)*
Supply	**From petrol stations in GEM:**		**2 800 000**	**2 400 000**	**97 970 960**
Demand	*Sector*	*Use*			
	Industry	Machinery	122 798		
		Process heating		2 268	
		Other		13 499	
		Generators	116 244	3 200	
	Residential	Cooking			2 907 455
		Generators	200 079	678 623	
	Commercial	Cooking			7 532
		Machine operations			229
		Other			360
		Generators	49 960	42 765	
	Local covernment*	Vehicles	56 250		
		Generators	1 503		
Demand subtotal			546 833	740 356	2 915 576
Remaining balance to transport model			**2 253 167**	**1 659 644**	**95 055 384**
Implied transport use % share of supply			**80.4%**	**69.1%**	**97.0%**

***** It is assumed that the local authority obtains fuel from the petrol stations within the municipality.

The balance indicates that the diesel demand from transport dominates as expected while private electricity generators account for a substantial share of petrol demand, exceeding 30%. The direct survey of industrial, residential and commercial LPG use accounts for only a small fraction of total demand however this large volume could not be allocated to transport given that the focus groups reported a relatively low conversion rate of vehicles, mostly sedan taxis, to LPG as shown in Table 38 above.

7.2 Methodology

GEM is located on the boundary of the Accra municipality, and this would presumably greatly influence the characteristics of transportation demand from households in GEM, and thus the fuel consumed within GEM as well. Due to this proximity, it is likely that the vehicles which travel outside the boundary of GEM, and presumably into Accra, would obtain a significant portion of their fuel there. Having said that, the number of fuel stations (32) is smaller than, but close to, that of Awutu Senya (36) the other municipality studied, which has a similar sized population. The reported quantity of fuel sold per station is, however, substantially less, as is discussed in more detail below.

The general approach to the LEAP model of Ga East 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 below 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.

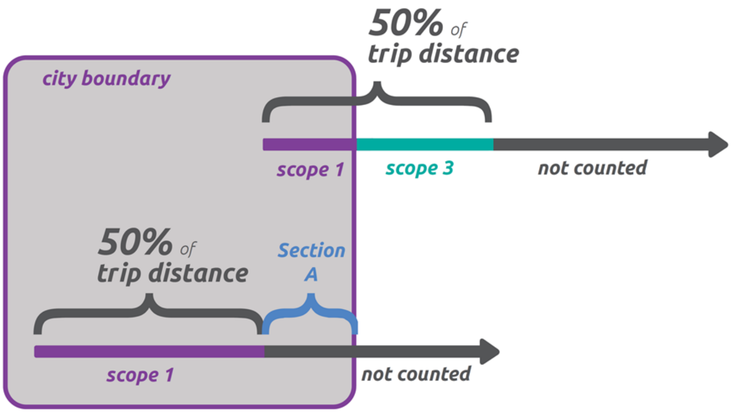


Figure 9: Induced activity method for accounting for transboundary trips in GHG Inventories
WRI (2014)

The GPC protocol (WRI 2014) advocates 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 trans-boundary 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 models, make these estimates (WRI, 2014).
- *Resident activity approach:* Only GHG emissions from activity by city residents is included. This requires 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 approaches. 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 Ga 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, so it was 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 41) 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 proposed, however, 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 GEM 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.

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 annual km 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, cars 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) (assumptions taking into account indicative values from focus groups)
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 GEM (assumption)

Model detail

The vehicle count for passenger vehicles is adjusted slightly to account for vehicles registered in GEM but not operating there.

Table 42: Vehicle count adjustment assumption

	Vehicle count adjustment	*New vehicle count*	*Comment*
Bus	None	3	
Car	90%	16 805	Assuming 10% are registered in GEM but do not operate here or are out of service
Minibus	90%	2 591	As above
Taxi	90%	1 342	As above
Motorbikes	90%	108	As above

As discussed above, the model needs to take into account the fuel consumed by GEM vehicles but sourced from outside of GEM. Thus, the total pass-km demand for this model is set up to account for local and 'Accra' trips that the average vehicle may make during the year with the proportion that is fuelled within GEM being based on data provided and various assumptions where necessary. The Calculation of the total passenger-km that is fuelled from within GEM is outlined in the equations below, showing how the assumptions made on Local and Accra trips affect the total passenger-demand:

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

$$Total\ pass.km\ demand = \sum_v EAM_v \times Veh\ count_v \times Avg.Occupancy_v \qquad \text{Equation 13}$$

Where EAM is the Effective Annual Mileage[4] (in km per year) of each vehicle type (v):

$$EAM_v = \sum_t R_{t,v} \times (\%\ Trips\ Serviced\ by\ GEM)_{t,v} \qquad \text{Equation 14}$$

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:

$$R_{t,v} = 2 \times (1way\ trip\ distamce)_{t,v} \times (total\ Return\ trips\ per\ year)_{t,v} \times (\%\ trip\ split)_{t,v} \qquad \text{Equation 15}$$

These equations are used in conjunction with assumptions on trips splits based on two different scopes adopted for study here. The first scope (scope 1) is a calibrated (to the total fuel sold within GEM) transport model, and the second (scope 3) is one where transboundary travel (mainly to Accra) is accounted for as well as the fuel associated with the transboundary trips that may be sourced outside of GEM

7.2.1 Scope 1 methodology

In this scope, the portion of transboundary trips occurring within municipal boundaries as shown in Figure 9 are estimated and combined with local trips presumed to be serviced by GEM such that the energy demand from the total is calibrated to the total fuel sold in GEM. The assumptions and data to populate the equations above and thus determine the total passenger-km demand that GEM supports is given in the following tables. Table 43 shows assumptions for the trip distances (in order to derive vehicle activity).

Table 43: Transport model passenger trips assumptions

	*Trips split**		*Km/1way trip**		*Days of travel***	*Total trips*
	Accra	*Local*	*Accra*	*Local*	*Days/year*	*Return trips/yr*
Bus	75%	25%	12	8	312	1 248
Light	50%	50%	12	8	312	312
Minibus	50%	50%	12	8	312	1 248
Taxi	30%	70%	12	8	312	1 872
Motorbikes	0%	100%	12	8	312	780
* These are assumptions ** Communication with Ghanaian SAMSET partners						

Table 44 shows the total vehicle-km travelled by each vehicle using these assumptions (from Table 43) and shows the assumptions on the share of return trips that GEM would be servicing.

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

Table 44: GEM passenger transport model fuel servicing assumptions and effective vehicle mileages for scope 1 methodology

	Total km of return trips		*True mileage (km/year)*	*% return trips/day serviced by GEM (assumptions)*		*Veh-km serviced by GEM*		*Effective annual mileage EAM (km/year)*
	Accra	*Local*		*Accra*	*local*	*Accra*	*Local*	*Total*
Bus	22 464	4 992	27 456	25	100	5 616	4 992	10 608
Car	3 744	2 496	6 240	10	10	374	250	624
Mini buses	14 976	9 984	24 960	25	0	3 744	0	3 744
Taxi	13 478	20 966	34 445	25	50	3 370	10 483	13 853
Motorbike	0	12 480	12 480	0	100	0	12 480	12 480

The mileage on the light passenger vehicles is very low. This is a result of the assumptions used for all vehicles in this setup to be consistent with the assumptions across all vehicle types and fuel consumption. These assumptions will need to be revised in future using a transport use survey.

Using the EAM and occupancy as well as the vehicle population (Table 42) the total passenger-km demand is calculated.

Table 45: Vehicle occupancies and final passenger-km demand

Vehicle type	*Occupancy (people/veh per trip)*	*EAM (veh-km/year)*	*Total all vehicles Pass-km per year*
Bus	60	10 608	1 909 440
Car	2	624	20 972 390
Mini buses	20	3 744	194 021 568
Taxi	3	13 853	55 767 217
Motorbike	1	12 480	1 347 840

The fuel economy for the vehicles and their overall fuel consumption using the detail from above (vehicle mileages and vehicle count) is given in Table 46.

Table 46: Fuel economy assumed for the passenger vehicles in GEM and the total fuel consumed for 2013 in this model

	Fuel economy (L/100 km)			*Consumption (L)*		
	Petrol	*Diesel*	*LPG*	*Petrol*	*Diesel*	*LPG*
Bus	35	30		-	9 547	-
Light	10	8		747 818	240 641	-
Minibus	18	15		-	1 455 162	-
Taxi	10	8	6.5	806 152	206 098	516 836
Motorbikes	3.5			47 174	-	-
Total				**1 601 145**	**1 911 448**	**516 836**

Freight

Freight transport modelling is represented using tonne-km demand which is estimated based on data provided and assumptions made where there is no data available. The freight transport model data used for the model is given in the tables below.

Table 47: Freight model data input

	Vehicle count	*Load (assumed)*	*Fuel split*		*Mileage (assumed)*	*Served by GEM*	*Effective mileage*
Truck:		*(Tonnes/trip)*	*Petrol*	*Diesel*	*(km/year)*	*(%)*	*(km/year)*
Light	60	0.5	0%	100%	20 000	70%	14 000
Medium & heavy	90	20	0%	100%	35 000	10%	3 500

Table 48: Freight model data input continued

	Fuel economy (L/100 km)		*Total (tonne-km)*		*Fuel consumption (L)*	
Truck	*Petrol*	*Diesel*	*Petrol*	*Diesel*	*Petrol*	*Diesel*
Light	20	18	0	420 000	-	151 200
Medium & heavy	44	38	0	6 300 000	-	119 700

The above data for demand of tonne-km and passenger-km were used as inputs into the LEAP model along with the associated fuel consumption per unit of demand, despite the total fuel consumption being larger than the data for fuel sales estimates. The final fuel balance for the transport sector is given below:

Table 49: GEM transport model fuel consumption (litres) and errors

	Petrol	*Diesel*	*LPG*
Fuel to transport	1 659 644	2 253 167	176 028 488
Fuel consumed	1 601 145	2 182 348	516 836
Error	-3.52%	-3.14%	-99.71%

The remaining fuel is assigned to the corridor component to balance out the fuel sold in GEM, using the assumptions given below.

Table 50: Remaining fuel to 'other corridor' component assumptions

	Fuel left over	*Split between transport demands (assumptions)*		
	Litres		*Diesel*	*Petrol*
Diesel	70 819	Passenger	20%	100%
Petrol	58 500	Freight	80%	0%

Combining the corridor balancing with the freight and passenger model set up, the final transport model set up for Scope 1 methodology is given in Table 51.

Table 51: Passenger transport sector of GEM model input for Scope 1 methodology

Locally refuelled	*Pass-km*	*% share*	*MJ/pass-km*
Passenger	272 887 635		
Transboundary	214 889 164		
Public	208 597 447		
Bus	1 010 880	0.5%	0.179
Minibus D	194 021 568	93.0%	0.241
Taxi D	1 879 951	0.9%	0.955
Taxi P	5 882 731	2.8%	1.070
Taxi LPG	5 802 317	2.8%	0.505
Prvt.	6 291 717		
Car D	1 804 809	28.7%	2.864
Car P	4 486 908	71.3%	3.210
Local	48 643 096		
Public	43 100 778		
Bus	898 560	2.1%	0.179
Minibus D	-	0.0%	0.241
Taxi P	18 301 831	42.5%	0.955
Taxi D	5 848 735	13.6%	1.070
Taxi LPG	18 051 652	41.9%	0.505
Prvt.	5 542 318		
Car D	1 203 206	21.7%	2.864
Car P	2 991 272	54.0%	3.210
Motorbike	1 347 840	24.3%	1.124
Other Corridor	9 355 375		
Public	9 355 375		
Mini bus D	2 106 172	22.5%	0.241
Mini Bus P	7 249 203	77.5%	0.2889
	tonne-km	*% share*	*MJ/tonne-km*
Freight	9 701 834		
Local	420 000		
Light	420 000	100.0%	12.888
Corridor	9 281 834		
MCV-HCV	9 281 834	100.0%	0.680

7.2.2 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 – all of local and all of transboundary trips. We use the same data and assumptions as Scope 1 for the trip splits and trips per year as given in Table 43, but new assumptions for the quantity of fuel serviced by GEM.

Table 52: GEM passenger transport model fuel servicing assumptions and effective vehicle mileages for scope 3 methodology

	Total km of return trips		*True mileage*	*% return trips/day serviced by GEM (Assumptions)*		*Veh-km serviced by GEM*		*EAM (km/year)*
	Accra	*Local*	*Km/year*	*Accra*	*Local*	*Accra*	*Local*	*Total*
Bus	22 464	4 992	27 456	100	100	22 464	4 992	27 456
Car	3 744	2 496	6 240	100	100	3 744	2 496	6 240
Mini buses	14 976	9 984	24 960	100	100	14 976	9 984	24 960
Taxi	13 478	20 966	34 445	100	100	13 478	20 966	34 445
Motorbike	0	12 480	12 480	100	100	-	12 480	12 480

Using occupancy and the total vehicle count as well as the EAM, the total passenger-km demand for this methodology is given in the table below.

Table 53: The total passenger-km demand for scope 3 methodology

	Occupancy People/veh	*EAM Veh km/year*	*Total all vehicles Pass-km*
Bus	60	27 456	4 942 080
Light	2	6 240	146 806 733
Minibus	20	24 960	1 293 477 120
Taxi	3	34 445	138 664 431
Motorbikes	1	12 480	1 347 840

Using fuel economies of each vehicle type and their total mileages (EAM in scope 3), the total fuel consumed in Scope 3 is given below.

Table 54: Fuel consumption of passenger transport model for Scope 3 methodology

	Fuel Economy (litres/100 km)			*Consumption - Litres*		
	Petrol	*Diesel*	*LPG*	*Petrol*	*Diesel*	*LPG*
Bus	35	30		-	24 710	
Light	10	8		7 478 181	2 406 412	
Minibus	18	15		-	9 701 078	
Taxi	10	8	7	2 004 486	512 461	1 285 106
Motorbikes	4			47 174	-	
Total				**9 529 841**	**12 644 661**	**1 285 106**

Freight

Using the same approach for freight as in Scope 1, GEM services all freight trips for all freight vehicles in the municipality, given in Table 55.

Table 55: Freight data and assumptions for Scope 3 methodology

Truck	*Vehicle count (numbe)r*	*Load (assumed) (tonnes/trip)*	*Fuel split*		*Mileage (assumed) (km/year)*	*Served by GEM (%)*	*Effective mileage (km/year)*
			Petrol	*Diesel*			
Light	60	0.5	0%	100%	20 000	100	20 000
Medium & heavy	90	20	0%	100%	35 000	100	35 000

Using fuel economies, the fuel consumed by freight in this methodology is given below.

Table 56: Freight fuel consumption for scope 3 methodology

Truck	*Fuel Economy (litres/100 km)*		*Tonne-km*		*Fuel consumption*	
	Petrol	*Diesel*	*Petrol*	*Diesel*	*Petrol*	*Diesel*
Light trucks	20	18	0	600 000	-	216 000
Light	44	38	0	63 000 000	-	1 197 000

Combining the freight and passenger model set up, the final transport model set up for scope 1 methodology is given in Table 57.

Table 57: The passenger transport sector of GEM model input for scope 3 methodology

Locally refuelled	*Pass-km*	*% share*	*MJ/pass-km*
Passenger	1 168 043 311		
Transboundary	480 112 065		
Public	417 194 893		
Bus	2 021 760	0.5%	0.179
Minibus D	388 043 136	93.0%	0.241
Taxi D	3 759 901	0.9%	0.955
Taxi P	11 765 463	2.8%	1.070
Taxi LPG	11 604 633	2.8%	0.505
Prvt.	62 917 171		
Car D	18 048 088	28.7%	1.432
Car P	44 869 083	71.3%	1.605
Local	687 931 246		
Public	602 693 844		
Bus	898 560	0.1%	0.179
Minibus D	517 390 848	85.8%	0.241
Taxi P	36 603 662	6.1%	0.955
Taxi D	11 697 471	1.9%	1.070
Taxi LPG	36 103 304	6.0%	0.505
Prvt.	85 237 402		
Car D	24 064 117	28.2%	1.432
Car P	59 825 445	70.2%	1.605
Motorbike	1 347 840	1.6%	1.124
Other corridor	-		
Public	-		
Mini bus D	-	0.0%	0.241
Mini Bus P	-	0.0%	0.2889
	tonne-km	*% share*	*MJ/tonne-km*
Freight	63 600 000		
Local	600 000		
Light	600 000	100 %	12.888
Corridor	63 000 000		
MCV-HCV	63 000 000	100 %	0.680

The total for passenger and freight transport in the scope 3 methodology approach for transport in GEM is given below, and shows that the fuel consumed is on the order of 315% to 357% of fuel supply (when excluding LPG).

Table 58: Total transport fuel consumption for scope 3 methodology

	Petrol	Diesel	LPG
Fuel available	1 659 644	2 253 167	176 028 488
Fuel consumed	9 529 841	14 057 661	1 285 106
Error	574.21%	623.91%	0.73%

7.2.3 Discussion on fuel sold in GEM

On the model calibration

Reliable local fuel sales data is essential for transport energy representation because of the complexity of transport systems and the difficulty in collecting data from the diversity of modes that are by definition mobile and difficult to observe. A calibration of activity or part of activity against the supply-side data, which is generally easier to determine reliably, gives the modeller some assurance that their assumptions are reasonable. This methodology was developed with this in mind, adapting this aspect of the GPC protocol, but as discussed the fuel supply statistics for GEM seem questionable and this needs to be cleared up as recommended before the outputs can be considered finalised.

The quantities of petrol and diesel sold within GEM are particularly low when compared to the data from the Awutu Senya East municipality (ASEM) model (McCall et al, 2016) and an estimate for the Greater Accra region as shown below in Table 59. The numbers for Greater Accra are based on a population of 4.38 million people (this is 4.01 million people in 2010 extrapolated to 2013 at a 3% pa growth rate) and using data on fuel sales to the Greater Accra region taken from the website for the National Petroleum Authority of Ghana (NPA, 2016).

Table 59: Comparison of data for per capita fuel sales in GEM and ASEM compared to Greater Accra (L/person)

	GEM	*ASEM*	*Greater Accra*
Diesel	14.0	140.7	120.3
Petrol	10.3	136.4	129.8
LPG	1090.4	576.5	17.8

A further source of concern is raised by converting the data on fuel sold per station for GEM, presented in Table 39, to average annual income for the fuel station. Assuming GHC 2.56/L and GHC 2.44/L for petrol and diesel respectively with a 10% mark-up this would equate to a turnover of GHC 40 550/year or USD 10 227/year at current exchange rates, before salary and site maintenance expenses for an average fuelling station. This does not, therefore, seem viable unless quite heavily subsidised by other commercial activity on the site. This and the low per capita fuel consumption suggest that the supply-side fuel data for GEM requires review and clarification before the datasets are finalised.

8. Business as usual (BAU)

This section describes the assumptions and methodologies used for projections of energy demand into the future that will serve as a baseline against which scenarios and interventions can be measured.

8.1 Main drivers and assumptions

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

GDP and economy

The figure below shows national annual GDP growth rates. Although the country has sustained high national growth rates for the last 15 years, 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.

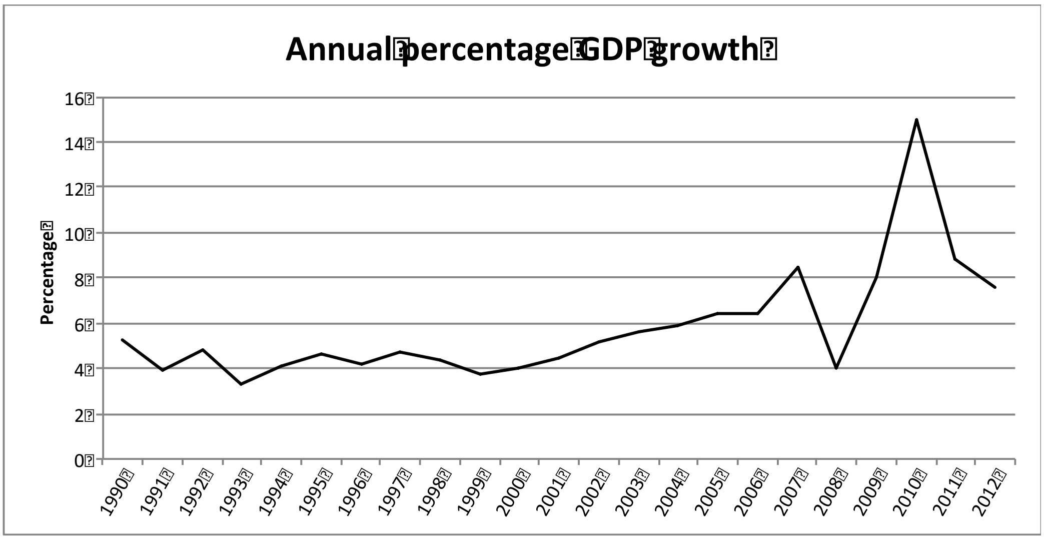


Figure 10: Ghana GDP growth rates
www.databank.worldbank.org

The economy of Ghana grew between 4% and 9.6% annually between 2009 and 2013 when excluding the oil related econometrics; this is as given in the table below. Ghana currently enjoys 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%.

Table 60: The growth rates for Ghana (%)
Ghana Statistical Services (2014a)

Growth rates (%)	*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
Change in GDP deflator	16.6	12.3	16.8	15.2	16.4

It is assumed that since GEM is in close proximity to Accra, which is a major centre for Ghana's economy, the local economy of GEM would closely track that of the country. 'TradingEconomics' website[5] which compiles many indicators and statistics for countries, indicates that the growth trend for Ghana will likely remain relatively high through to 2020 of around 6.6%.

The following assumptions were made for this scenario on the economic growth:

[5] 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

- 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 five years.
- Between 2020 and 2030, the economy will 'slow' somewhat to 6.5% on average.

Population

The Ghana population census data released in the "Population and housing census 2010" indicated that Accra and the greater Accra region had a population growth rate of about 3.1% between the last two censuses. In this scenario, 3.1% is used as the growth rate for the population in GEM.

Fuel costs

The prices of liquid fuels for GEM was obtained from the SoE report as indicated in the table below (Bawakyillenuo & Agbelie, 2014):

Table 61: The average cost in GHC of fuel in GEM

Fuel type	*Unit*	*2010*	*2011*	*2012*	*2013*
Petrol	L	1.44	1.78	2.00	2.56
Diesel	L	1.33	1.67	2.00	2.44
LPG	Kg	2.12	2.37	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 below (the 2030 value is interpolated based on World Economic Outlook and the 2025 World Bank figure).

Table 62: 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 cost of charcoal as reported by the SAMSET survey was 0.63 GHC per kg in 2013. It is assumed that the price of charcoal will remain constant in real terms (i.e. - it will fluctuate only with inflation).

Table 63: Charcoal cost (GHC per kg) in GEM

	2011	*2012*	*2013*
SAMSET survey	0.35	0.44	0.63

The cost of fuel sold per unit in 2013 using the data provided and converted to USD (using 2.3 Cedi to a dollar) is given below.

Table 64: GEM fuel costs in USD in the model

	Per unit	*2013*
Petrol	litre	1.11
Diesel	litre	1.06
LPG	Kg	1.18
Charcoal	Kg	0.27

Electricity costs are adapted from the public utilities regulatory commission notice on electricity tariffs changes for 2013

Table 65: Electricity prices approved by Ghana Public Utilities Regulatory Commission in 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%

Using these prices, the prices given below are assumed for households and for non-residential customers. It is assumed the electricity price will remain constant at 2013 values from the year 2015 onwards.

Table 66: Electricity prices for GEM in 2013 and 2014

GEM users	*Grouping*	*Cedi Pesewas*	*USD*	
	kWh	*2013*	*2013*	*2014*
Household 3	0-150	13.54	0.06	0.11
Household 2	151-300	20.19	0.09	0.16
Household 1	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	600+	42.43	0.18	0.33
Commercial informal	0-300	25.27	0.11	0.20

8.2 Transport

Freight transportation

The operation of light-to-heavy trucks is assumed to continue with similar characteristics to the base year – in terms of fuel efficiency. Light-truck freight demand growth into the future is assumed to follow the overall activity (tonnes output) from the local industry of GEM excluding water and sewerage. Heavy freight (medium-to-heavy trucks) is driven more by the regional economic activity – this would be heavily influenced by Accra. So it is assumed that heavy freight demand (in tonne-km) grows proportional to local GDP (which is the same as the regional activity – see the General section).

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 exploring increased population growth would result in a decrease in transport demand. Thus 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 assumed to be directly proportional to motorisation (vehicles per thousand people), and motorisation is assumed proportional to GDP per capita[6] and can be written as some linear function of GDP per capita:

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

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:

$$cars = M \times population \times 1000 \quad \text{Equation 17}$$

Again this is calibrated to the base year value for Ga East (this is 16 805 active 4-wheel private vehicles).

Then the population that is motorised (privately) is:

$$mpop = Occupancy \times cars \quad \text{Equation 18}$$

Where occupancy is the assumed base year value of 2 people per vehicle.

And thus:

$$Private\ pass.km\ demand = Occupancy \times Avg\ Mileage \times cars \quad \text{Equation 19}$$

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 using motorised public transport mostly is then:

$$NCAP = Population - mpop \quad \text{Equation 20}$$

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

$$pass.km\ public = x \times NCAP \quad \text{Equation 21}$$

Where *x, the total annual public transport distance travelled per person,* 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.

Bus rapid transport (BRT) system

BRT is planned to be implemented in Accra by the end of 2015, with only a few buses starting in the initial phase from Amasaman and Achimota areas as part of a trial phase. The BRT system will be extended in time, based on the success of the initial phase to include Kasoa (Awutu Senya) and Adenta (not indicated on map – see Appiah 2015) which is on the border with GEM (Appiah, 2015; Okoye et al., 2010). The second phase of the BRT which may operate within GEM, will likely be a few years after the initial phase – provided it is proved successful.

[6] 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.

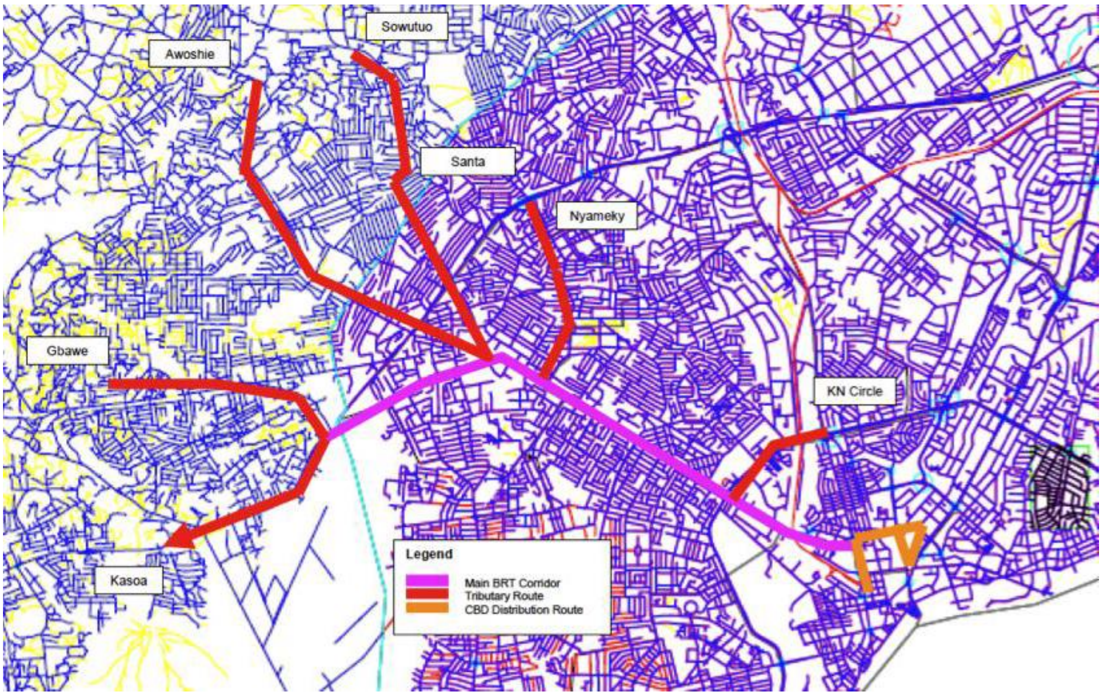


Figure 11: Map of the pilot BRT in Accra
Okoye et al (2010)

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 trotros and buses. This is assumed to be the case in the BAU scenario, and that once BRT comes into effect within and around GEM 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 by the growth in the population without access to a car.
- It is assumed that the BRT system will come into effect in GEM by 2020, with about 10% of bus and trotro users switching to BRT in 2020, and that about 40% of bus and trotro passengers switch to BRT by 2025. This scenario also assumes that the buses operate at about 10% more efficiently (fuel wise) than standard buses in GEM even with the same occupancy – owing to new engines on the BRT buses.
- Private transportation: light vehicles and motorbikes are assumed to retain the operating characteristics of the base year – no change in occupancy rates, and similar fuel efficiencies.
- The passenger corridor component is assumed to follow GDP per capita, which itself is an approximation to national economic growth figures.
- Freight tonne-km for light trucks is driven by local industry growth.
- Freight tonne-km for medium and heavy trucks are assumed to grow with GDP (which is directly proportional to national and regional economic growth rates).

8.3 Household sector

Ghana’s population growth rate has previously been very high, attributable to declining mortality rates and high fertility rates (NPC, 2011). 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. Ga East, lying on the outer periphery of Greater Accra, receives a lot of inward migration of households seeking access to opportunities afforded by the city. Geographically, the Greater Accra region is experiencing one of the highest rates of urban growth in Ghana (Owusu, 2011). Annual household growth to 2030 is assumed to be an average of 2.5% per annum until 2030. Based on a focus group with municipal officials, the composition of household categories is projected to change as shown in the table below. It is assumed that there will be no change in the shares of 2nd and 3rd class households and the greatest change will come from increased service delivery within the 1st class household category.

Table 67: Changes in household composition by category

	Share in 2014	*Projected share in 2030*
Household 1 electrified	63%	75%
Household 1 unelectrified	21%	11%
Household 2 electrified	4%	4%
Household 2 unelectrified	1%	1%
Household 3 electrified	7%	7%
Household 3 unelectrified	2%	2%
	100%	100%

8.4 Municipal sector

Municipal sector floorspace is projected to grow at 10% of the household growth rate, while the diesel consumption from municipal vehicles is assumed to follow household growth rates (with an elasticity of 1) as they serve more households through time. The water treatment system operated by the municipality is assumed to consume more energy in line with the growth of the city population – treating more water as the population grows. Embedded generation by diesel and petrol generators is assumed to follow the overall floorspace growth rate for the municipality.

8.5 Commercial sector

The formal sector commercial floorspace is assumed to grow at 90% of the economic growth rate for the formal sector. The informal commercial sector, however, which makes up a significant part of the economy, is assumed to follow population growth rates, since the informal sector by nature is driven largely by the formal economy being unable to create new jobs – pushing people into the informal sector (Ose-Boateng and Ampratwum, 2011). Embedded generation capacity for the commercial sector is assumed to follow the overall floor space growth rate above.

8.6 Industry

The following growth rates for the various industry categories in Ga East are assumed:

- Construction – follows GDP growth with 0.8 elasticity.
- Manufacturing – follows GDP growth with 0.8 elasticity.
- Water and sanitation – assumed to grow in line with the population growth rate.

Furthermore, the overall capacity of embedded diesel and petrol generators is assumed to follow the sector's output through the years.

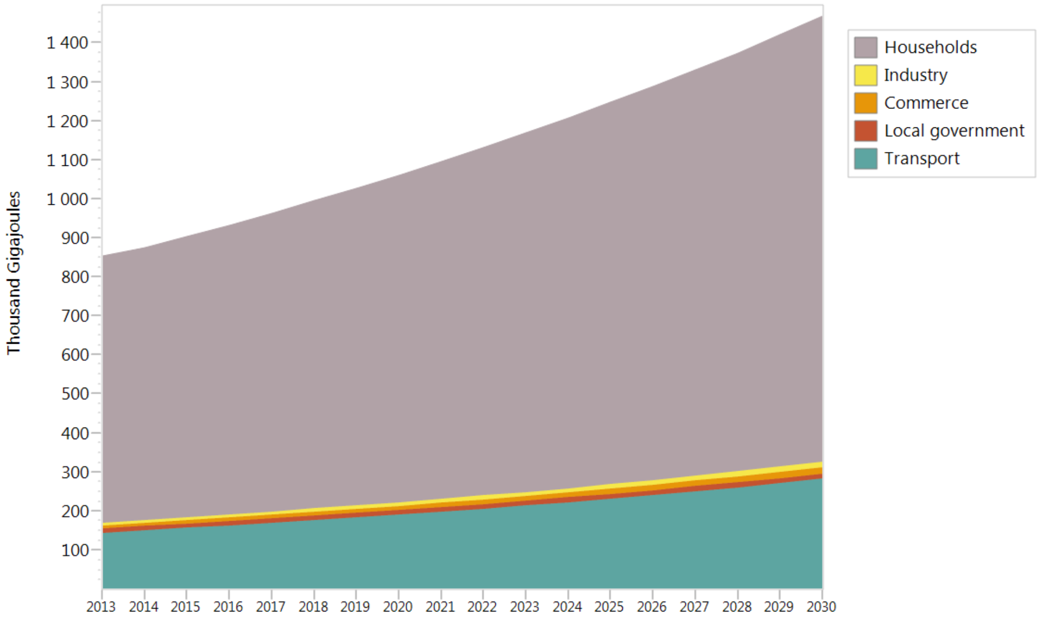
9. BAU LEAP results

A model has been developed using the data collected by the University of Ghana in an energy systems modelling platform called LEAP. The model has a node-based structure that allows the user to disaggregate the energy system into sectors, subsectors and individual plants. The results in this report reflect an initial assessment of which of these to include as energy demands but other users may wish to deselect some of them if they are deemed to be outside municipal boundaries, outside the realm of policy influence of the city or outside the scope of reporting conventions. One of the advantages of the modelling platform selected is that the in-country teams can elect to select and de-select items in reporting results to suit their purpose. The in-country teams can also review and change the key assumptions discussed above very easily through LEAP's user-friendly interface and quickly generate a new BAU case.

This section will present the results of the LEAP model projections. Given the large difference in the contribution of transport for the different assumptions around spatial scope of the model, separate sets of results assuming 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.

9.1 GEM scope 1 and 3 methodologies compared for BAU

The energy consumption of GEM in the BAU scenario, where very limited transboundary transport trips are accounted for so as to calibrate the fuel consumed to the fuel supplied strictly within the municipal area, is presented below. While the household sector is the dominant player in energy consumption for these scope 1 results, the transport fuel supply-side data for Ga East in particular are, however, in question, as discussed in Section 7.2.3



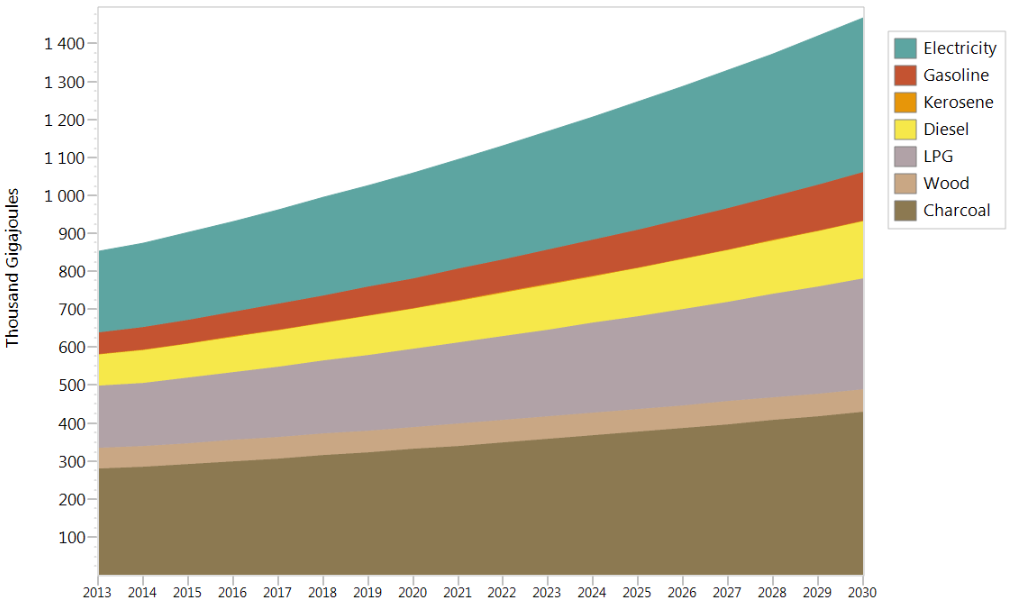


Figure 12: Ga East Municipality BAU scenario energy demand by sector (above) and fuel (below) for scope 1 methodology

The following figures present the results for the scope 3 methodology, where all estimated transboundary trips are included and all local (intraboundary) trips are included. A strictly GPC compliant GHG inventory would report 50% of transboundary trips, but for a view of energy consumption by sector it was thought that 100% of transboundary trips was more useful. The share of trips to include in reporting is quickly adjusted in the LEAP interface. Comparatively, the transport sector consumes about half the total energy of the municipality in the base year becoming increasingly dominant with time, considerably more than in the scope 1 methodology.

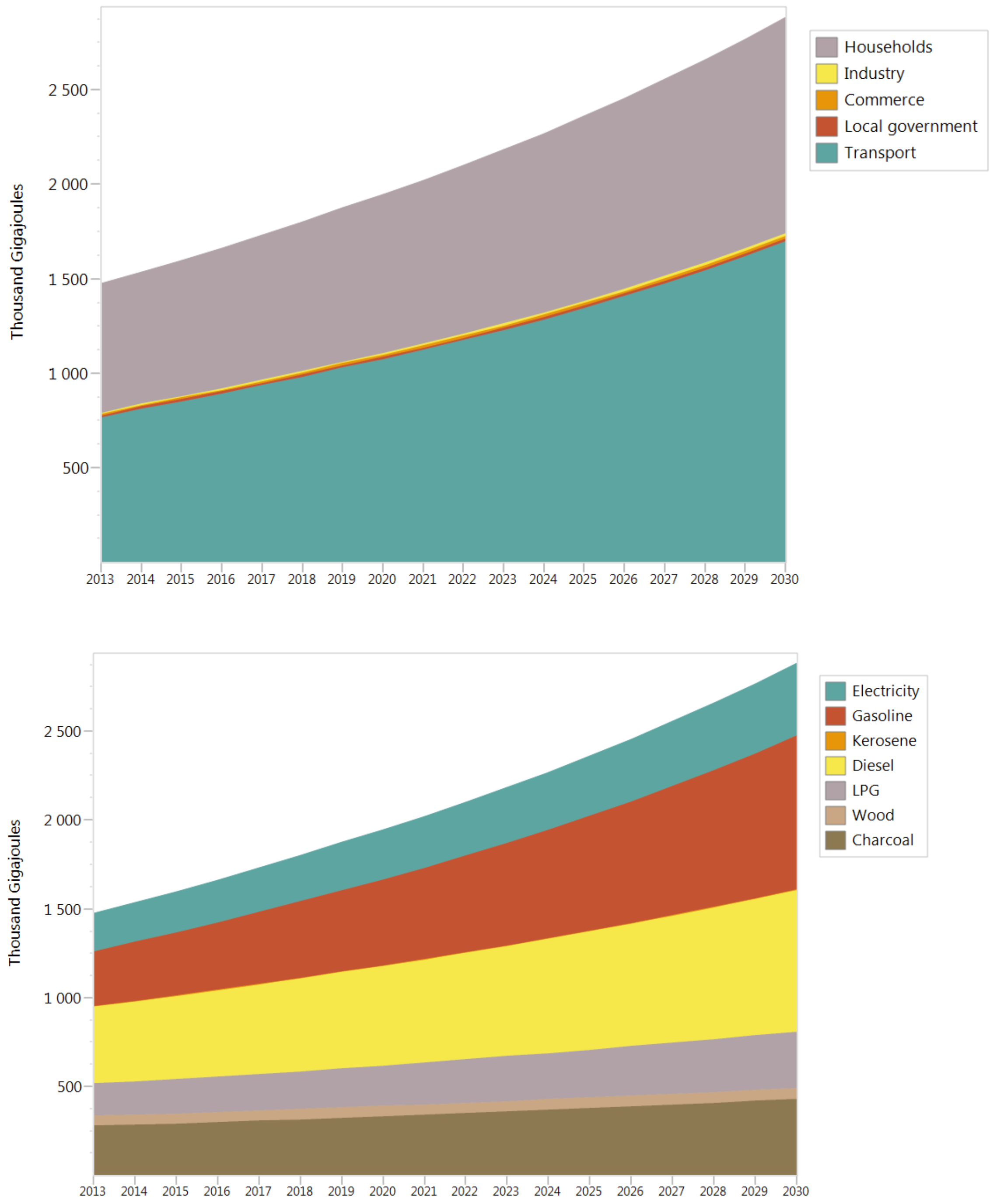


Figure 13 Ga East Municipality BAU scenario energy demand by sector (above) and fuel (below) for scope 3 methodology

The majority of fuel consumed by GEM in scope 1 methodology is in charcoal, with electricity the next single largest fuel source, followed by LPG.

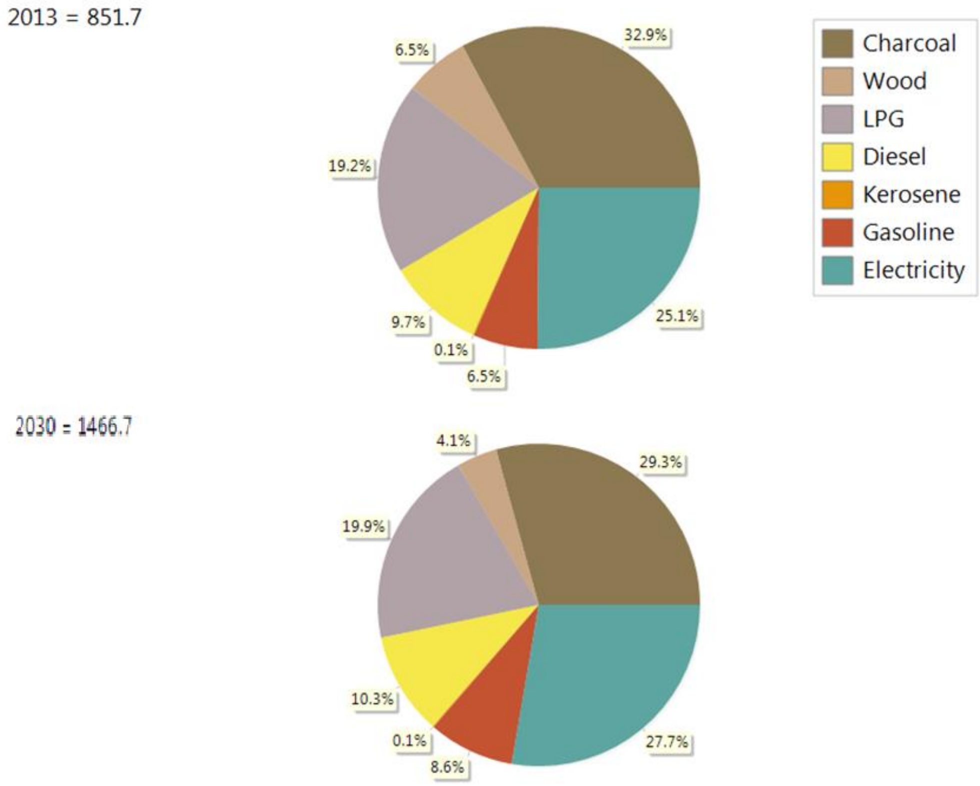


Figure 14: GEM fuel consumption shares for the base year and for 2030 in scope 1 methodology

Liquid fuels in scope 3 make up the majority of fuel consumed in the base year, and in the BAU scenario this share of fuel consumption increases from just under half, to two thirds of fuel consumed in 2030.

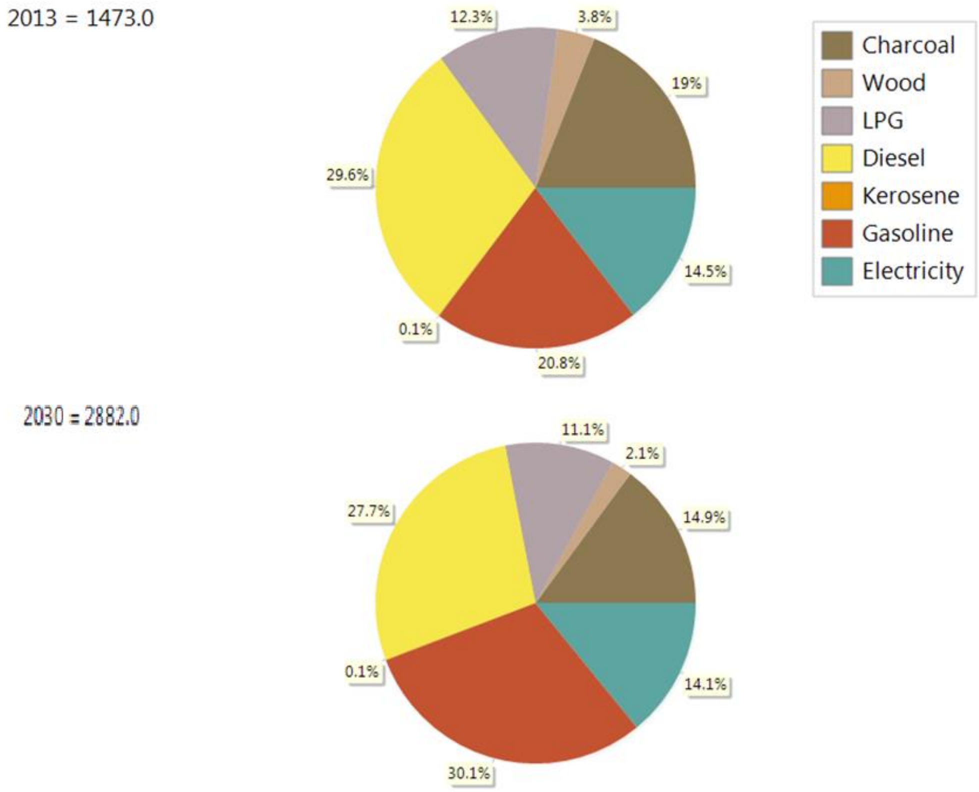


Figure 15: GEM fuel consumption shares for the base year and for 2030 in scope 3 methodology

The underlying assumptions on transport distances in the model will play a bigger role in the scope 3 methodology than in the scope 1 methodology, as without calibrating to a total fuel supply the fuel consumed will be directly proportional to the average trip distances assumed. In this work we have kept those assumptions (on trip distances and frequencies) the same for scope 1 and scope 3.

9.2 Transport sector energy consumption

Scope 3 transport energy demand is mainly in the transboundary trips with private vehicles accounting for the majority share:

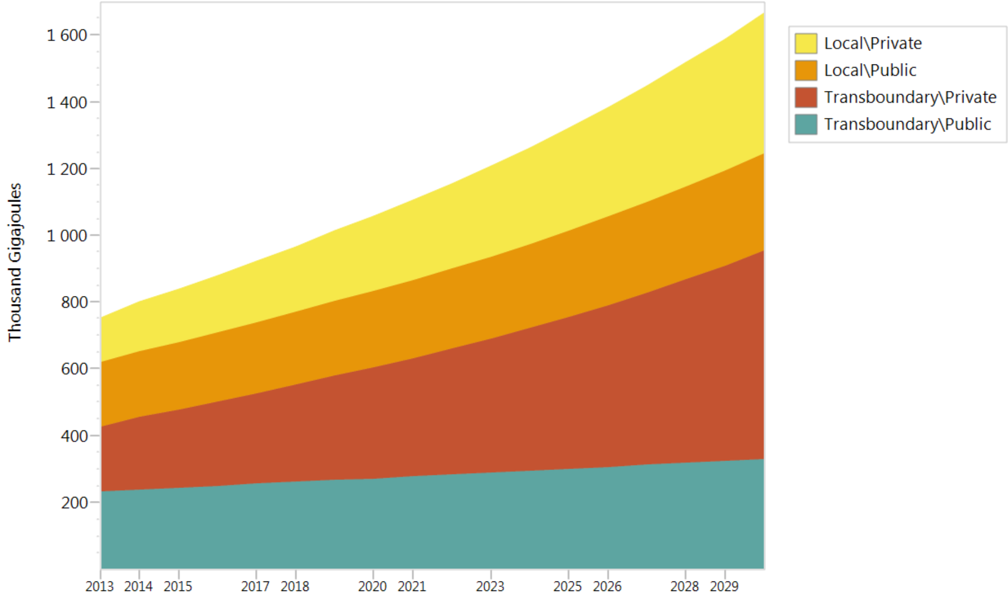


Figure 16: GEM transport sector energy demand by subsector for scope 3 methodology

The major growth in the transport subsectors is in the transboundary private vehicles and is a result of the increase in GDP per capita assumptions. This trend is similar (but not on the same scale) for the scope 1 methodology (note that the GDP per capita assumptions are identical in each scope, but accounting for transboundary demand in scope 1 is much less than in scope 3):

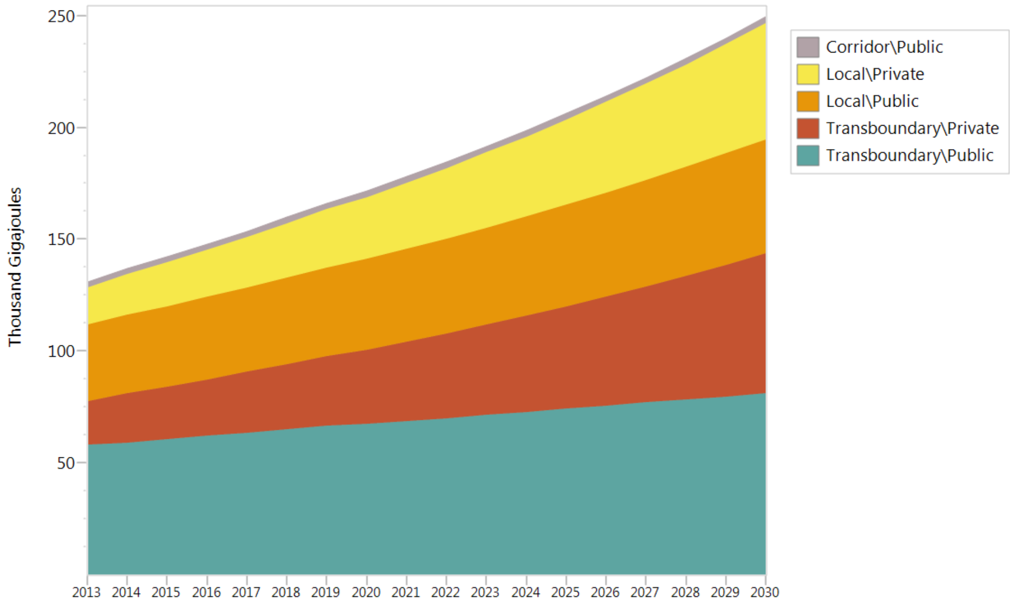


Figure 17: GEM transport sector energy demand by subsector for scope 1 methodology

9.3 BAU general results

In this section we present some results where the scope 1 or 3 methodologies do not impact the model – i.e. the other sectors. Looking at the household sector, most of the energy consumption is in charcoal and electricity consumption, with LPG also playing a significant role.

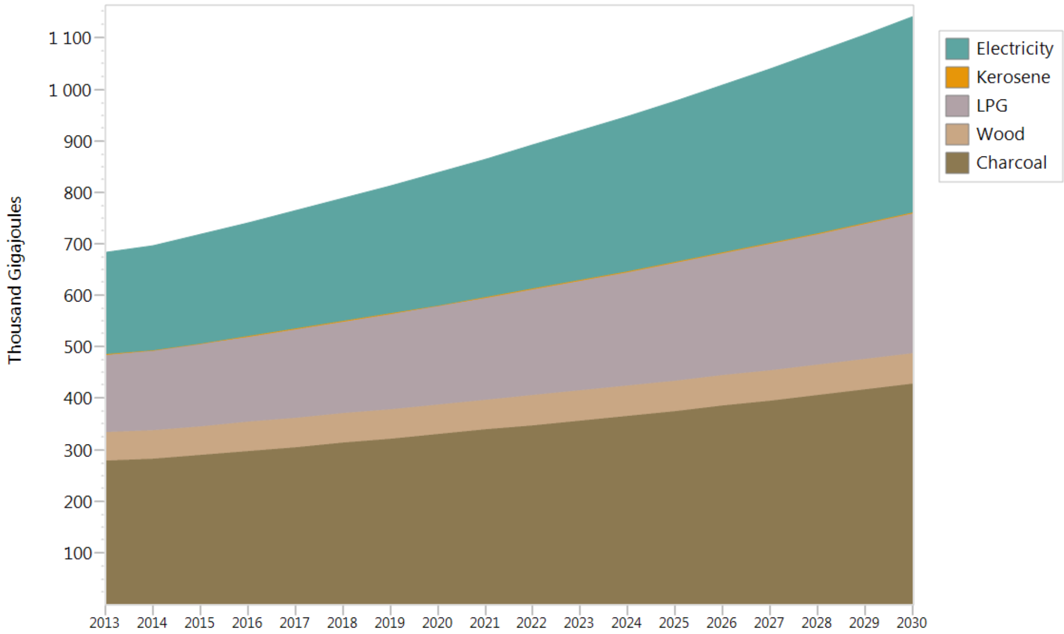


Figure 18: Household energy consumption by fuel for Ga East in the BAU scenario

Most of the energy consumed in households comes from class 1 households, while demand from the non-electrified households are flat to 2030 (see Figure 19). This is a result of an expected increase in the number of electrified households and a decreasing share of non-electrified households for GEM in the BAU assumptions.

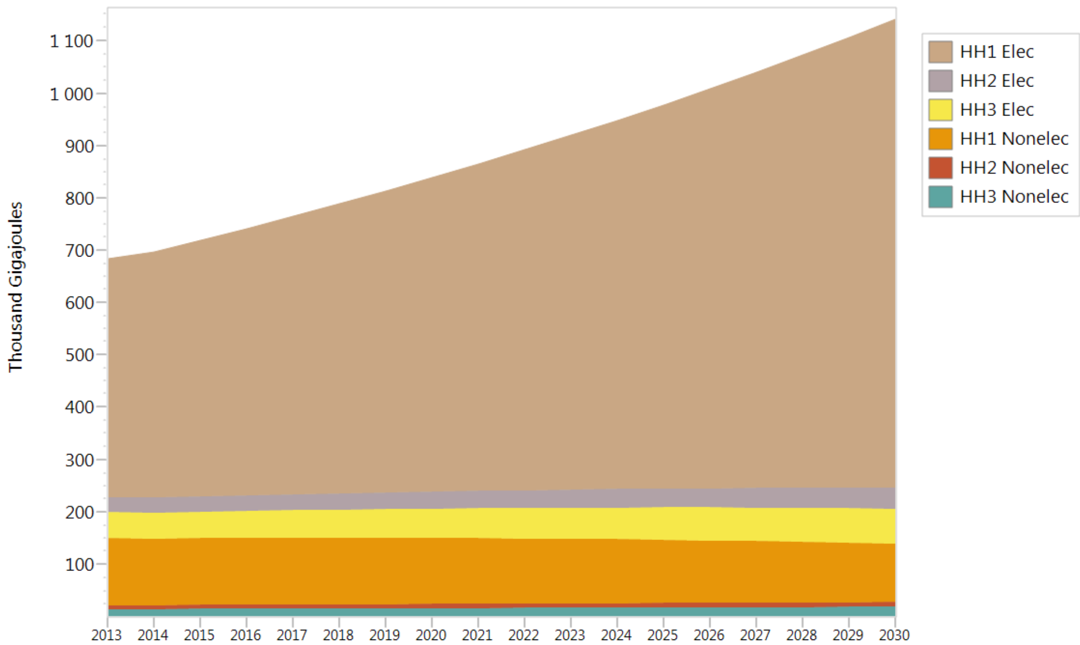


Figure 19: Energy consumption of the household subsectors of GEM in the BAU scenario

9.4 Sensitivity scenario tests

In this section we explore the impact of altered economic growth or population growth has on the energy consumption of GEM.

Population increase (sPOP)
In this scenario, there is a sudden increase in population from 2016 onward and the city grows at 4% pa instead of 3.1% as in the BAU.

Economic growth increase (sGDP)
In this scenario, from 2018 the general economy of GEM does not decrease in growth by 2020 as in the BAU scenario (7.4% until 2020, 6.5% thereafter) and continues to grow at 7.4% pa.

Comparing the sensitivity scenarios to the reference scenario, we see that the energy consumption of GEM is more sensitive to population than to economic growth.

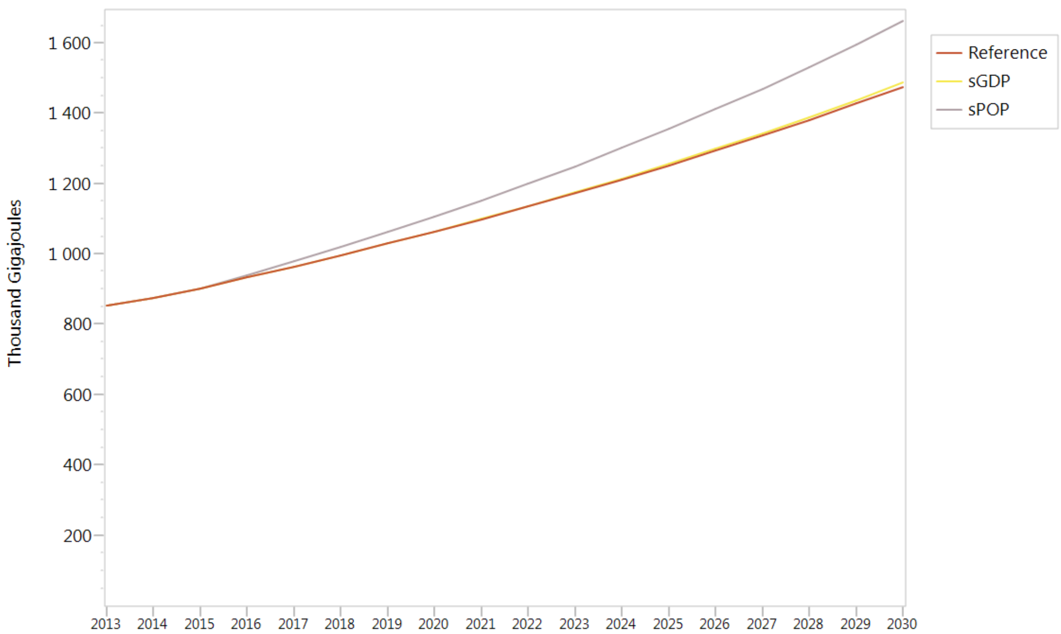


Figure 20: Energy consumption of GEM in the sensitivity scenarios for population and economic growth rates increases (scope 1)

The largest energy-consuming sector in GEM, households, does not respond to the economic growth rates in the model, but obviously responds greatly to the population increase as indicated in the figure below.

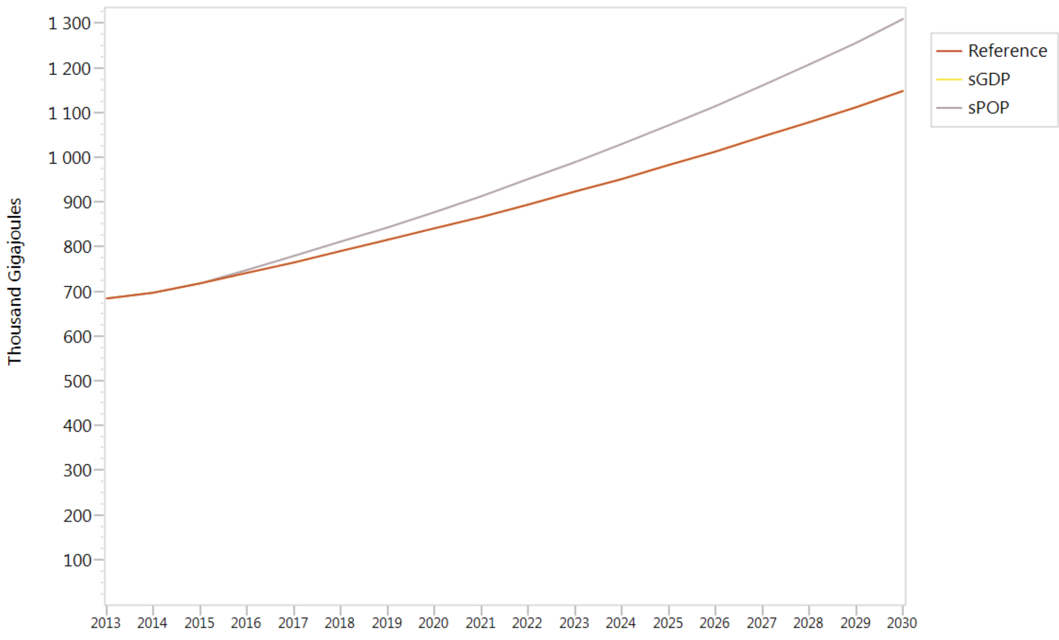


Figure 21: GEM household sector energy consumption for the sensitivity scenarios

The second-largest energy-consuming sector in GEM, transport, responds to both population and economic growth.

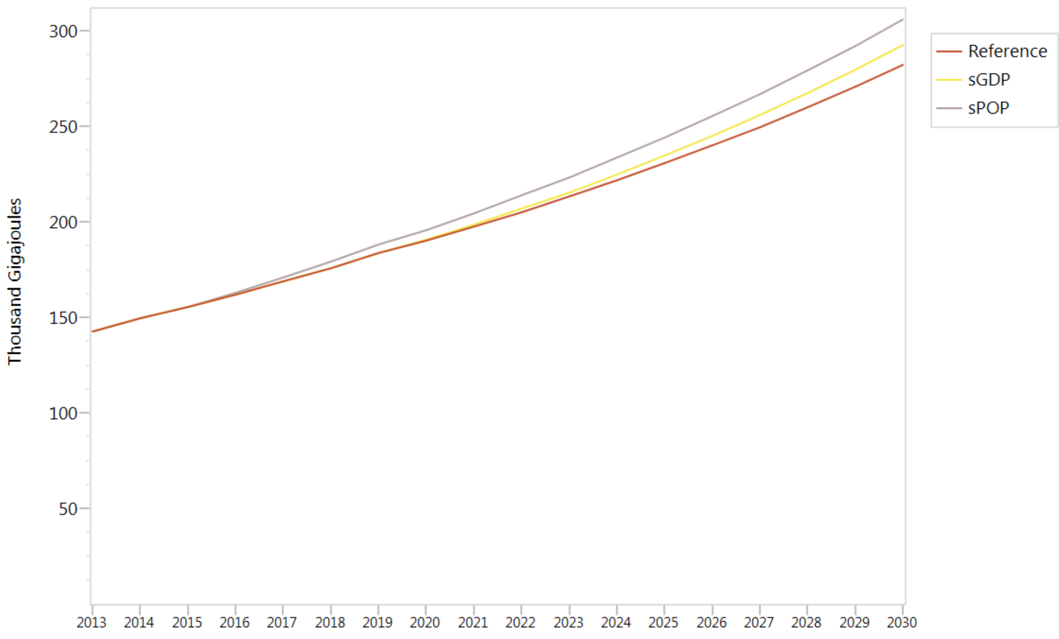
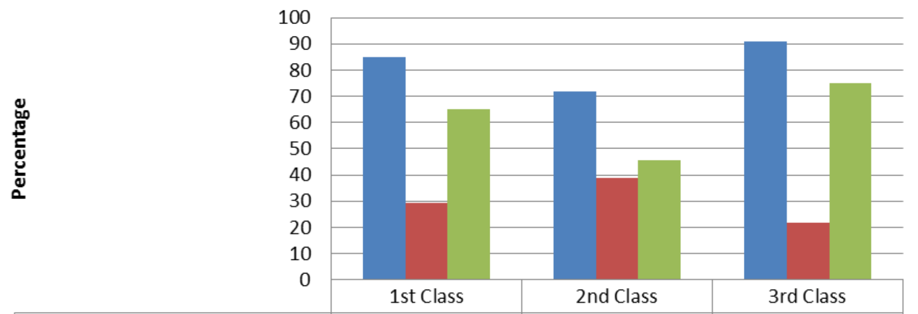


Figure 22: Transport sector energy consumption in GEM for the sensitivity scenarios tests (scope 1)

All subsectors of the passenger transport sector respond to population more than the economic growth rates. This is due to the majority of demand arising from public transport rather than the private, and an increase in population (without an increase in GDP) leads to more public transport, while the same increase in GDP will have a comparably smaller impact on the use of private transportation.

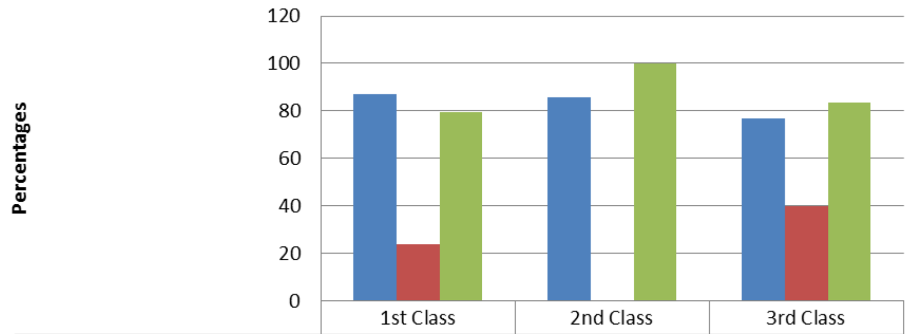
10. Efficient charcoal stoves scenario

The household survey undertaken by the Ghanaian SAMSET team, included a question on the use of efficient charcoal cook stoves. About 20–40% of the households that are electrified use these Gyapa cook stoves.



	1st Class	2nd Class	3rd Class
% who have knowledge of efficient cook stove	85.13	72	91.11
% who use efficient cook stove	29.22	38.89	21.95
% who wish to use efficient cook stove	65.11	45.45	75

A: Electrified households



	1st Class	2nd Class	3rd Class
% who have knowledge of efficient cook stove	87.27	85.71	76.92
% who use efficient cook stove	23.71	0	40
% who wish to use efficient cook stove	79.45	100	83.33

B: Non-electrified households

Figure 23: Household questionnaire on the use of efficient charcoal cookstoves from the SAMSET survey

In this scenario it is assumed that:

- A five-year roll-out program of Gyapas to the household sector of GEM begins in 2016, and by 2021 all households that indicated in the survey that they wished to have a Gyapa, get one.
- By 2030, it is assumed that everyone that used charcoal wanted to obtain a Gyapa, and so 90% of all households that use charcoal cook on a Gyapa.
- It is assumed that the Gyapa cookstoves are 50% more efficient, as indicated by the Gyapa webpage.[7]

[7] www.gyapa.com.

- Gyapa stoves cost USD 10 in 2013, and have a three-year lifespan.[8]

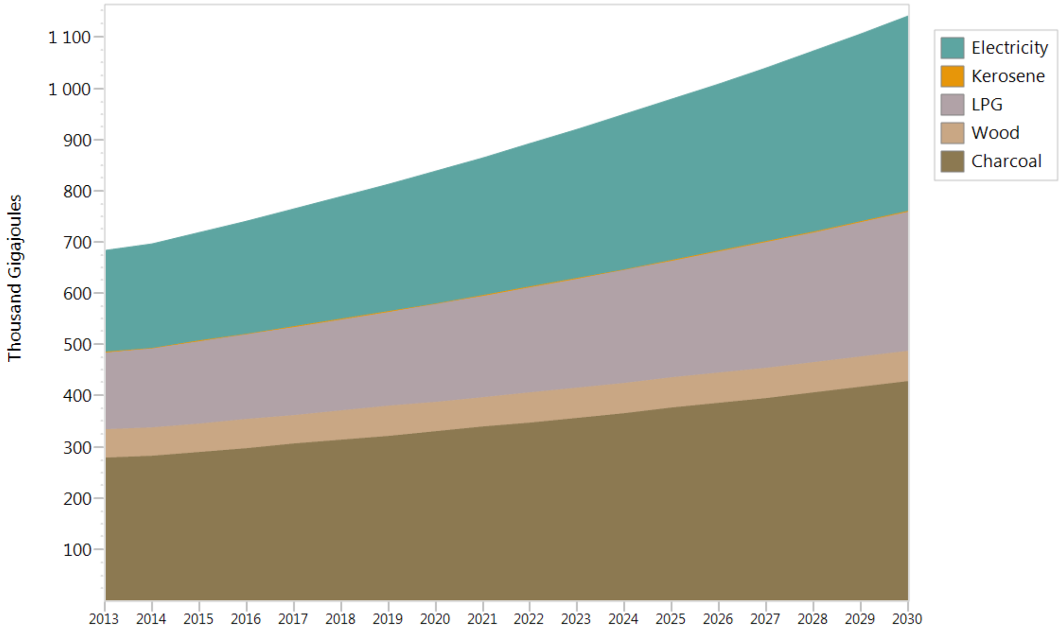


Figure 24: Household sector energy consumption in the reference scenario by fuel

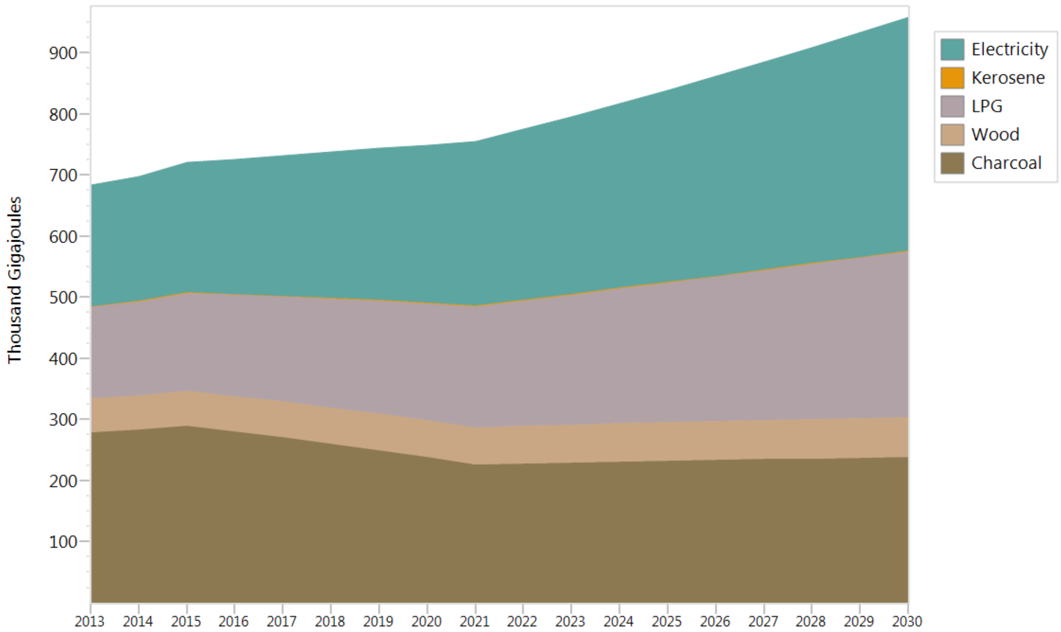


Figure 25: Household energy consumption for the efficient stove scenario

8 Lifespan information from www.climatecare.org.

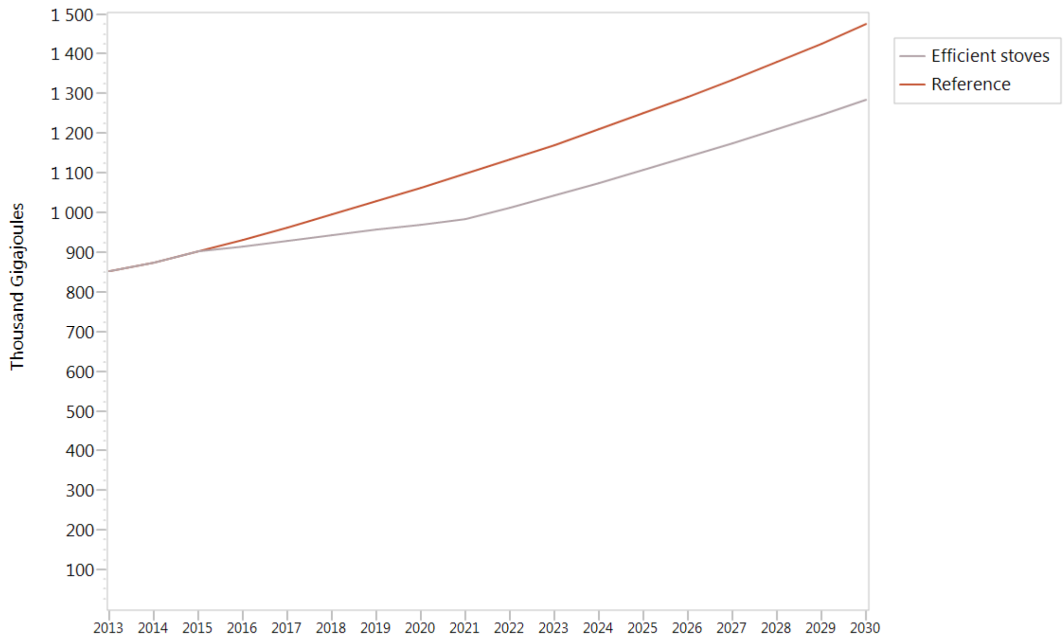


Figure 26: Total Ga East Municipality energy consumption for the efficient stove scenario

The total monetary savings for this charcoal stove scenario is GHC 38.4 million (constant 2013) as presented in the table below.

Table 68: Cumulative energy and cost savings for the efficient charcoal stoves scenario, relative to the reference scenario (Ghanaian cedi)

	2016	*2020*	*2025*	*2030*
Charcoal tonnes saved	582	9 296	31 487	61 051
Cost impact* (incl. capital cost)	142 973	2 282 536	7 719 548	14 943 191

11. Household access to modern fuels for cooking

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 utilising clean fuels increases in this scenario (ACC) 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 them 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 the table below.

Table 69: The share of households using fuels change for cooking for the ACC scenario

	Household class	End use	*Shares* in % for 2030 (2013)*		
			Electricity	*LPG*	*Charcoal*
Electrified	Household 1	Cooking	30 (0)	100 (82)	20 (81)
		Other appliance use	85 (50)		
	Household 2	Cooking	30 (0)	100 (76)	30 (92)
		Other appliance use	70 (40)		
	Household 3	Cooking	10 (0)	100 (64)	30 (100)
		Other appliance use	55 (22)		
Non-electrified	Household 1	Cooking		100 (41)	50 (94)
		Other appliance use			
	Household 2	Cooking		100 (15)	50 (96)
		Other appliance use			
	Household 3	Cooking		100 (15)	50 (96)
		Other appliance use			

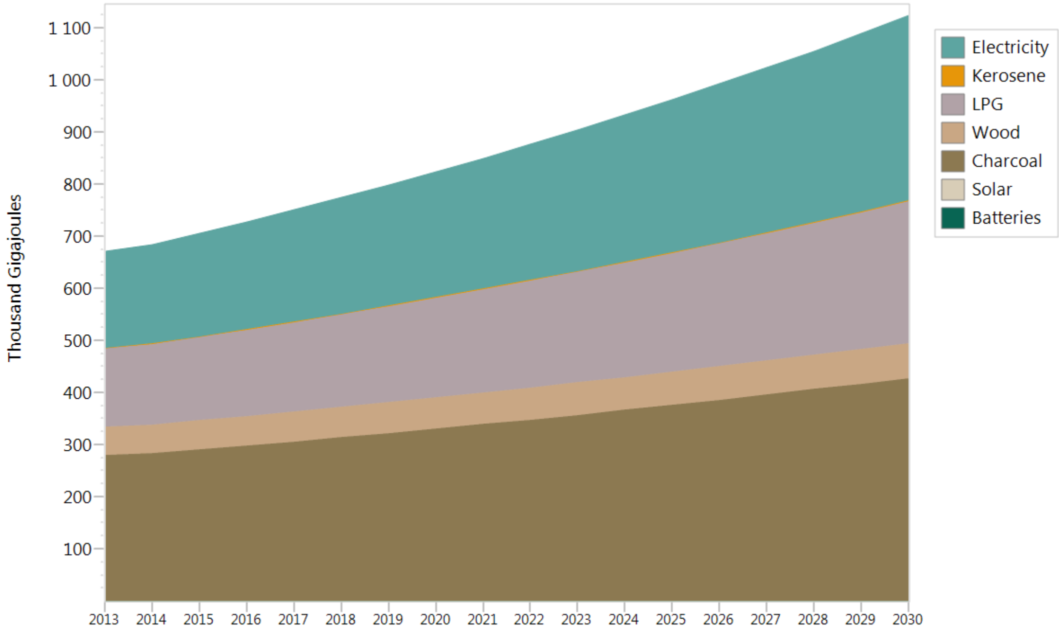
* Note that shares in this case do not need to sum to 100% as most households use more than one fuel at a time.

While households start the uptake of more frequent use of clean fuels, the use of charcoal is assumed to decrease – so 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 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 70: Intensity change in fuel usage for the ACC scenario

	Household class	*End use*	*Intensity value GJ/Household for 2030 (2013)*		
			Electricity	*LPG*	*Charcoal*
Electrified	Household 1	Cooking	3.5 (1.5)	6.5 (5.1)	1 (7.7)
		Other appliance use	1.7 (1.7)		
	Household 2	Cooking	3 (1.5)	5.5 (3.5)	0.75 (7.6)
		Other appliance use	1.1 (1.1)		
	Household 3	Cooking	3 (1.5)	5 (2.9)	0.75 (7.6)
		Other appliance use	1.5 (1.5)		
Non-electrified	Household 1	Cooking		4 (2.1)	2.25 (12.2)
		Other appliance use			
	Household 2	Cooking		3.5 (0.5)	1 (7.9)
		Other appliance use			
	Household 3	Cooking		3.5 (0.5)	1 (7.9)
		Other appliance use			

The results for this scenario are presented below.



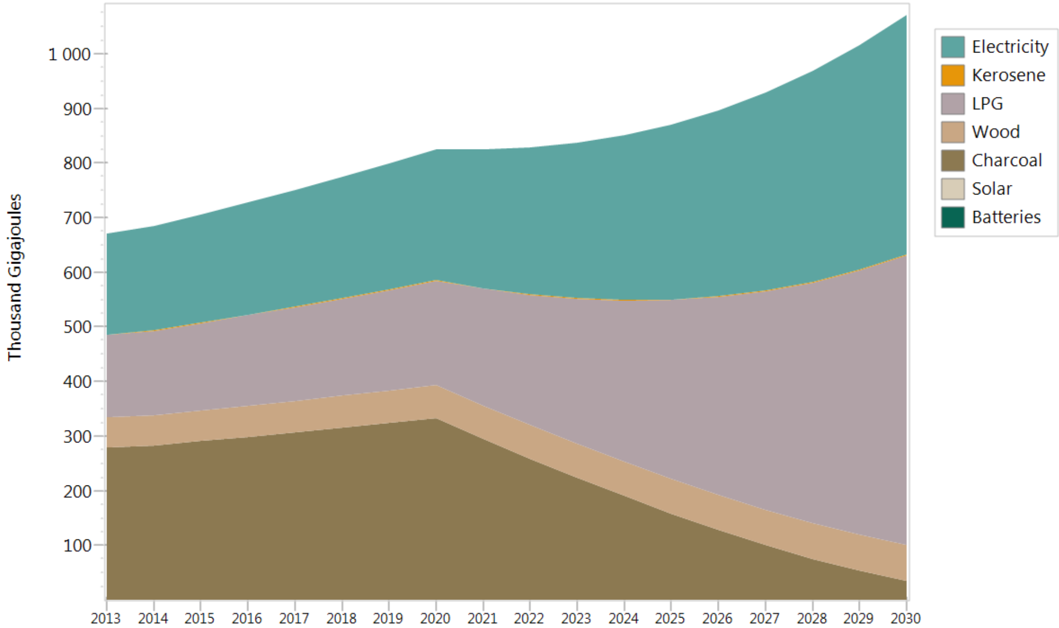


Figure 27: Household energy consumption of GEM in the reference scenario (above) and for the ACC scenario (below)

The results show that the total energy consumption difference between the two scenarios is very small by 2030, but there is a deviation in total energy consumption between 2020 and 2030.

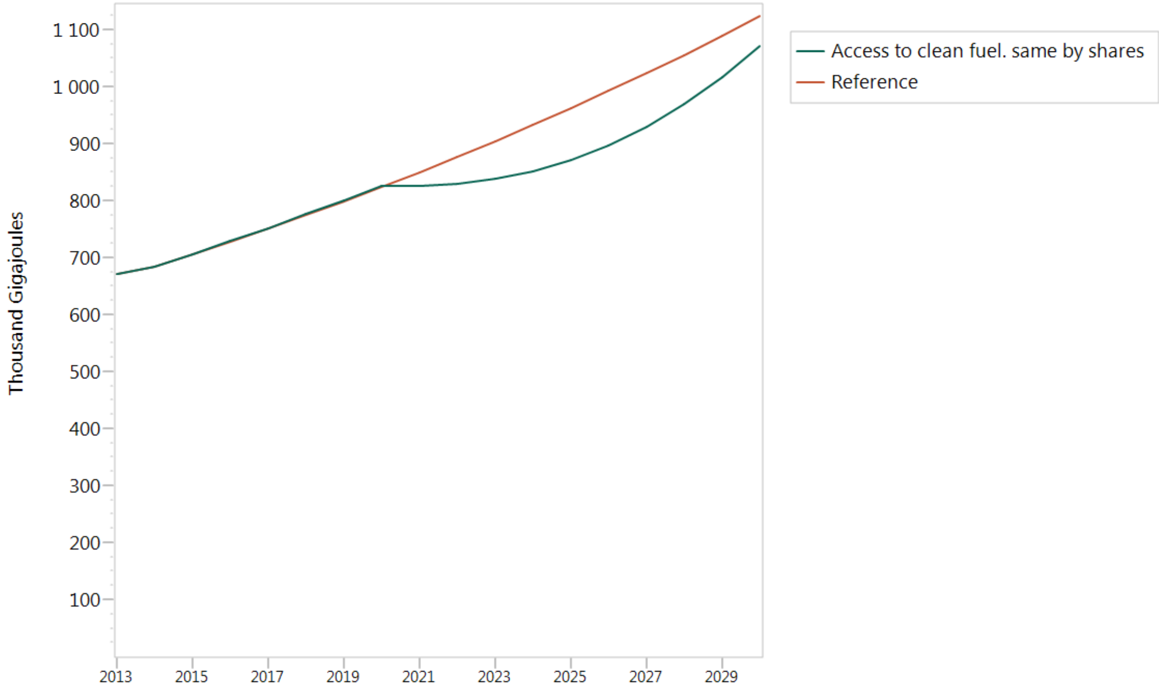


Figure 28 Total fuel consumption for the household sectors for GEM for the access to clean fuels scenario compared to the reference scenario

The change in fuel consumption for this scenario is presented in the table below, showing a very large increase in electricity consumption and LPG.

Table 71: Scenario cumulative impact results for access to clean fuels for cooking (ACC) in GEM

	2021	*2025*	*2030*
Electricity (MWh)	1135	21 500	103 904
LPG (Tonnes)	328	5 819	25 794
Charcoal (Tonnes)	-1193	-22 604	-79 589
Note: Positive numbers indicate increase in consumption, negative a decrease.			

Using the costs for fuel as presented in Section 8.1, the total cost associated with the fuel consumption in this scenario is GHC16.4 million cumulative by 2030 with the majority of the cost associated with the use of LPG mainly due to the fact that this scenario has all households using LPG as their main fuel for cooking.

Table 72: Fuel cost impact results for the ACC scenario for GEM (in constant 2013 cedi)

	2021	*2025*	*2030*
Electricity	262 762	1 852 003	5 458 407
LPG	891 790	15 827 372	70 158 859
Charcoal	-632 165	-11 975 609	-42 166 473
Sum of fuel costs	**522 386**	**5 703 765**	**33 450 793**

12. Conclusions

The University of Ghana have developed a unique and detailed energy dataset for the municipality of Ga East (GEM) near Central Accra in Ghana using detailed surveys and focus groups with stakeholders and municipal officials. This 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 Ga East with biomass (mostly charcoal) still accounting for just under half of household sector consumption. The fuel shares of the household sector observed in the Ga East (GEM) survey were very similar to those observed in the Awutu Senya (ASEM) survey as shown below. Per Capita energy consumption was however reported as 34% lower in GEM.

Table 73: Comparison of energy carrier shares and per capita energy consumption for the household sectors in Awutu Senya and Ga East 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 view, 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 less than 20% to just under half and this share increases with time in the BAU case. Fuel sales in Ga East are, however, very low on a per capita basis compared to Greater Accra and the other municipality in the survey, Awutu Senya. The implied financial turnover per service station, furthermore, seems very low, and this data should be confirmed before the data sets and models are finalised and released into the public domain.

Some other data issues were identified which should be dealt with before publishing the dataset, particularly the very large discrepancy observed between LPG supply and demand, which was an issue in both surveys. In general, the inclusion of more detailed metadata would make this interesting dataset more useful to the research community.

Significant suppressed demand for electricity was indicated by the industry, commercial and household data. While a minority of enterprises and households owned generators, they accounted for, on average, around 20% of electricity consumption for generator owners in the higher income household group (Household 1), the manufacturing sub-sector, and the formal commercial sector as a whole in spite of the high price of petrol and diesel. The Water and sewerage subsector of Industry appears very reliant on diesel-fuelled own-generation, with five of the seven observations owning generators, which supplied nearly 90% of their electricity consumption. The distribution of own-generation share (Appendix C) 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. 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 was twice that of the formal sector due to biomass use (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 20% for the formal sector and 11% for the informal sector (see Appendix B). While this is a minority share, it increases the final energy intensity of floorspace by 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 GHC 0.29/kWh for petrol, GHC 0.25/kWh for diesel and GHC 0.2–0.4/kWh for electricity, depending on 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.

13. Data issues

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.

Population
The total number of households was given as 33 949. However, the Ga East Municipality 2010 Population and Housing census district analytical report indicated that there were 23 424 households in Ga East in 2010. Using 3% growth rate, the 2013 household count would then be 25 596. Given that future researchers accessing this work will likely contrast these numbers and be in doubt which is the better estimate, the discrepancy should be clarified and documented.

Transport and fuel
With the original data provided by the municipality, the total vehicle count was 18 672 light passenger vehicles, which was estimated by the local stakeholders in GEM based on the assumption that about 55% of the households in GEM own a passenger car.

A passenger transport survey is needed to get hard data on transport by mode (car, mini bus, walking, etc) and trip distances or annual mileages (or how long in hours). This will greatly add to the model and understanding of the largest energy consuming sector in the municipality.

Total fuel sold in GEM for petrol and diesel is considerably lower per person than for ASEM and estimates for the Greater Accra region – see the end of the Transport methodology section. While this could be explained by a lack of service stations in the area, the volumes sold per service station seem too low to cover the costs of such a business.

The consumption of LPG from the bottom-up analysis from all sectors does not calibrate to the total sold with the municipality. There is more than 90% shortfall in LPG usage for this model calibration owing to the very large fuel supply that was indicated in the data. The LPG numbers need to be revised.

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, the share of area of these activities is very large and, furthermore, as indicated by Table 74 below, 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 74: Spread of electricity intensity for selected commercial activities in Ga East

Indicator	*Schools*	*Hotels*	*Banks*	*Non-bank financial services*	*Drinking bar, restaurant, catering services*
Observations	*26*	*18*	*10*	*4*	*34*
	Specific electricity consumption (kWh/m²yr) (including own generation)				
Minimum	0.0	3.8	18.0	8.1	0.0
Median	3.8	10.6	121.2	92.0	48.8
Average	1.4	9.5	94.9	18.6	25.2
Maximum	164.8	79.1	783.0	448.1	452.2

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, while it does not affect the internal consistency of this model in that absolute energy demand is likely correct, 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.

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 lack services currently, particularly HVAC.

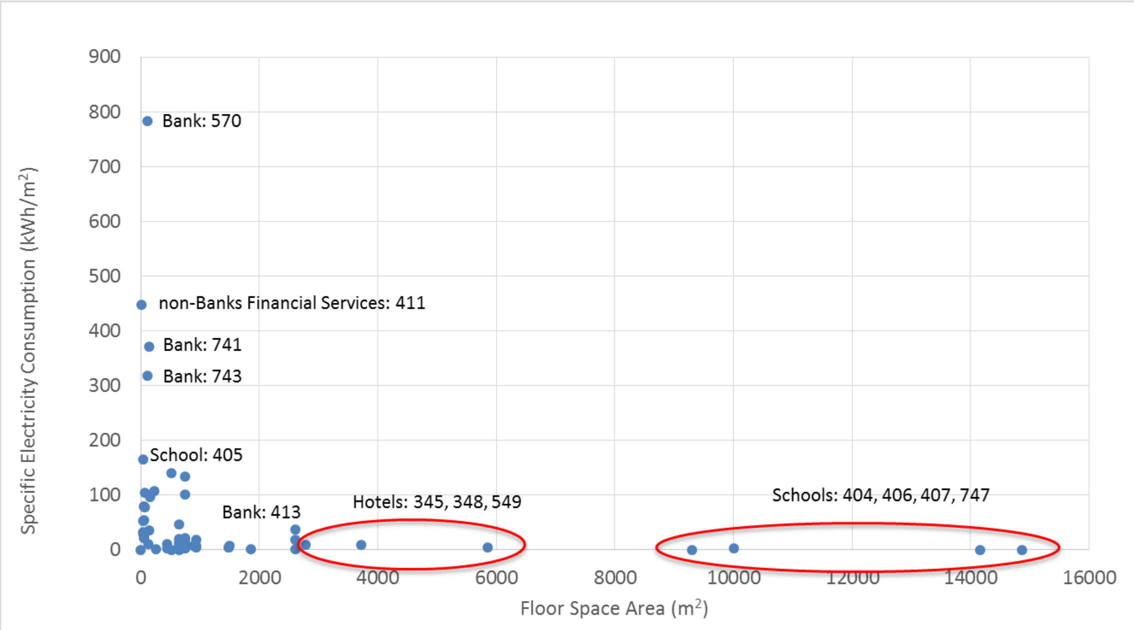


Figure 29: Ga East formal commercial sector – specific electricity consumption vs floorspace (Data labels indicate activity and survey ID)

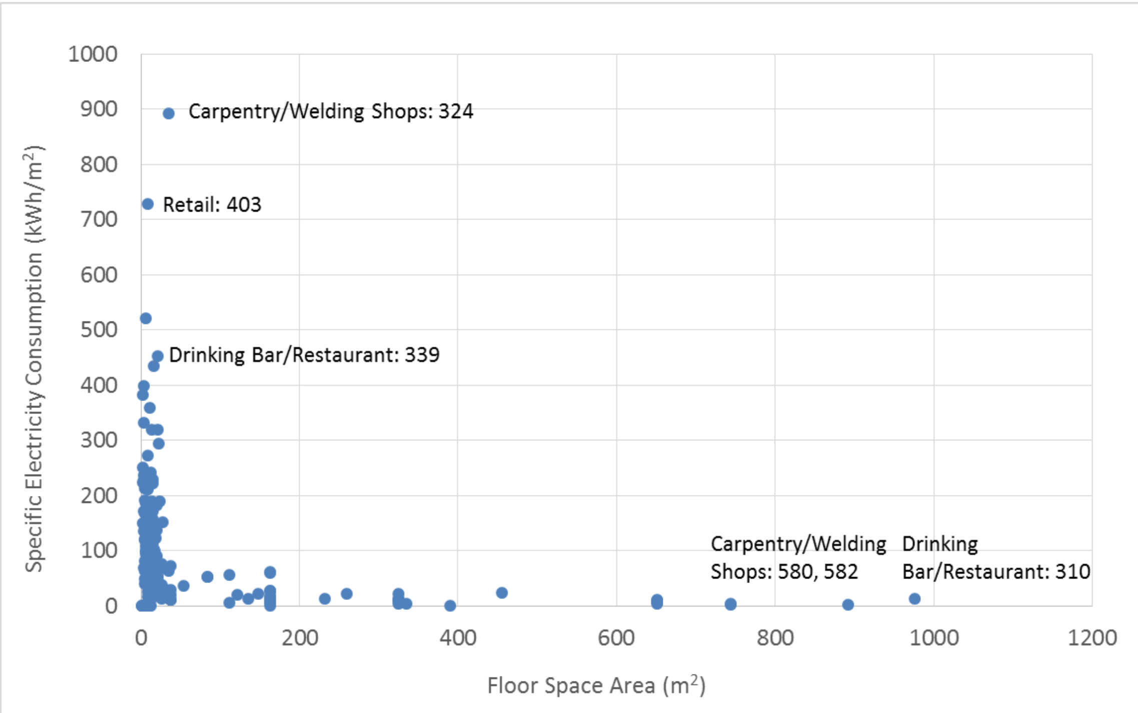


Figure 30: Ga East informal commercial sector – specific electricity consumption vs floorspace (Data labels indicate activity and survey ID)

Metadata

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 floor space 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.

- The method by which focus groups determined petroleum fuels supply data. Was this expert judgement or based directly or indirectly on industry statistics of volume or turnover?

14. Efficient Fridges scenario (EFR)

The Energy Commission of Ghana initiated a programme in 2011 to introduce efficient fridges, in an attempt to reduce energy consumption by refrigerators by half. The new fridges were expected to consume 250 kWh a year as compared to the old inefficient ones, which consumed about 1200 kWh a year on average. Moreover, importers and retailers of appliances such as light bulbs, air conditioners and fridges are required by Ghanaian standards to meet a minimum energy consumption requirement (SOE, 2013), but it was also shown from the survey that many households still buy second-hand and inefficient appliances. The survey showed that there is almost a 50/50 divide between new[9] fridges (which are not part of the fridge replacement programme – see survey results in Figure 31) and second-hand fridges. The results of the SAMSET GEM survey of household refrigerators bought new or second-hand, compared with proportion of households with efficient fridges, are shown below.

Table 75: Survey of GEM refrigeration ownership and efficient fridge penetration

	Survey of GEM fridge ownership		*Fridges with* EE label '1'
	New	*Second hand*	
Household 1	50%	48%	30%
Household 2	52%	48%	20%
Household 3	29%	68%	17%

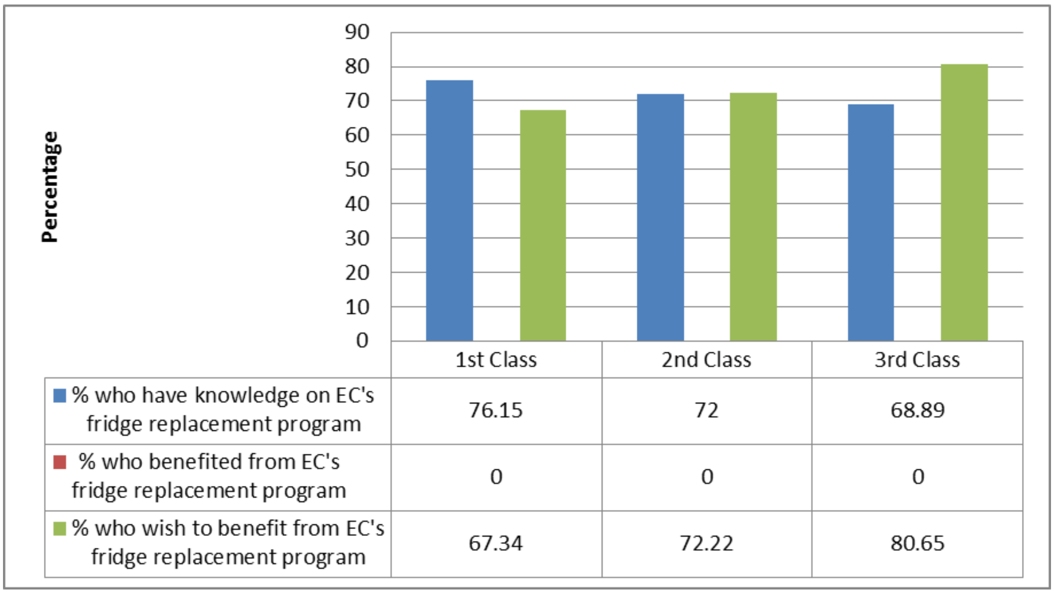


Figure 31: Efficient fridge programme participation and awareness results for GEM SAMSET survey

The cost of efficient fridges is assumed to be, on average, GHC 1400, or USD 444 in 2013, and are assumed have a 15 year lifespan.

[9] New fridges are assumed meet minimum energy efficiency standards as part of newly established legislation on imported appliances into the country (UNDP, nd).

Table 76: Cost of new fridges
(www.jumia.com.gh/frdges-freezers/)

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

In this scenario:

- It is assumed that a new programme which makes it affordable to participants to buy or replace their old fridges with efficient new ones (specifically marked with efficiency label 1) begins in 2016 and is completed by 2021,
- This replacement programme affects all those that wish to have benefited from the program as indicated in the survey results presented above.
- The remainder of households who do not participate in this programme buy or replace their fridges between 2021 and 2030.
- New fridges are assumed to be 80% more efficient than second-hand fridges.
- New fridges on average are 444 USD in 2013 and have a 15 year lifespan.
- Second hand fridges are assumed to be 173 USD and have a 7.5 year lifespan.

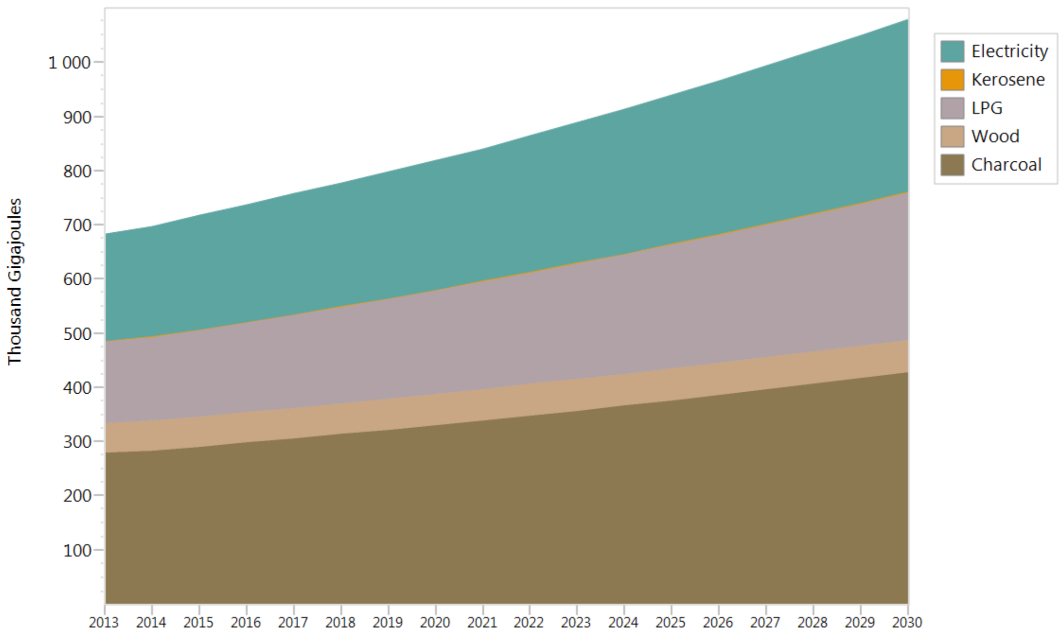


Figure 32: Household sector fuel consumption in the efficient fridges scenario

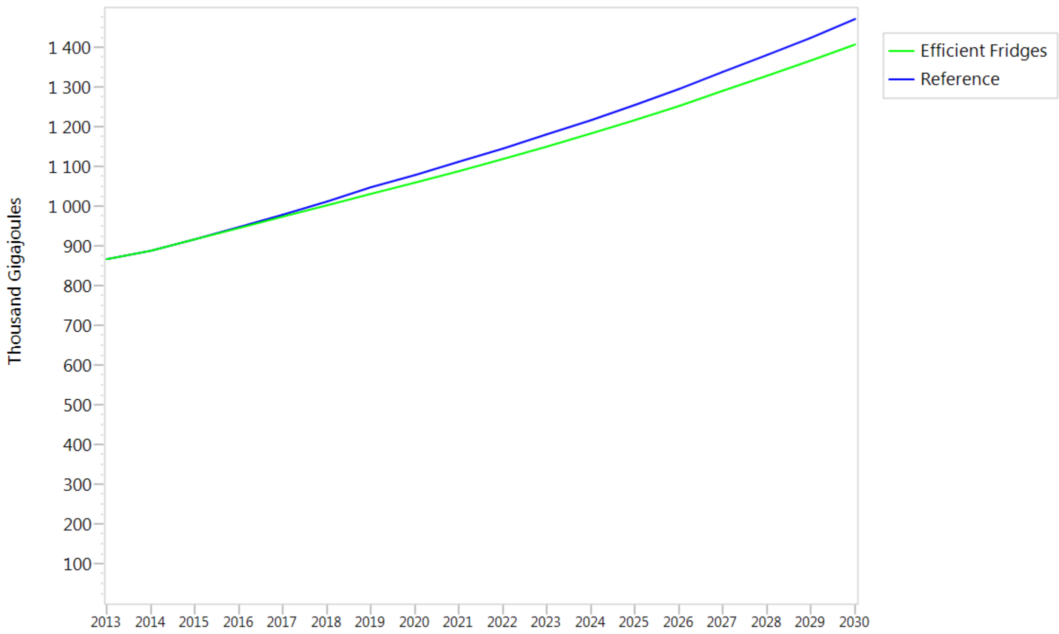


Figure 33: Total Ga East Municipality energy consumption comparing reference scenario and efficient fridges scenario (scope 1)

Table 77: Cumulative energy and cost savings of the efficient fridges scenario

	2016	***2020***	***2025***	***2030***
kWh saved	928 377	15 459 651	58 840 041	131 394 800
GHC saved	178 805	2 977 529	11 332 592	25 306 638

The total energy saved in the stoves scenario has a larger impact than the fridges scenario, as shown below.

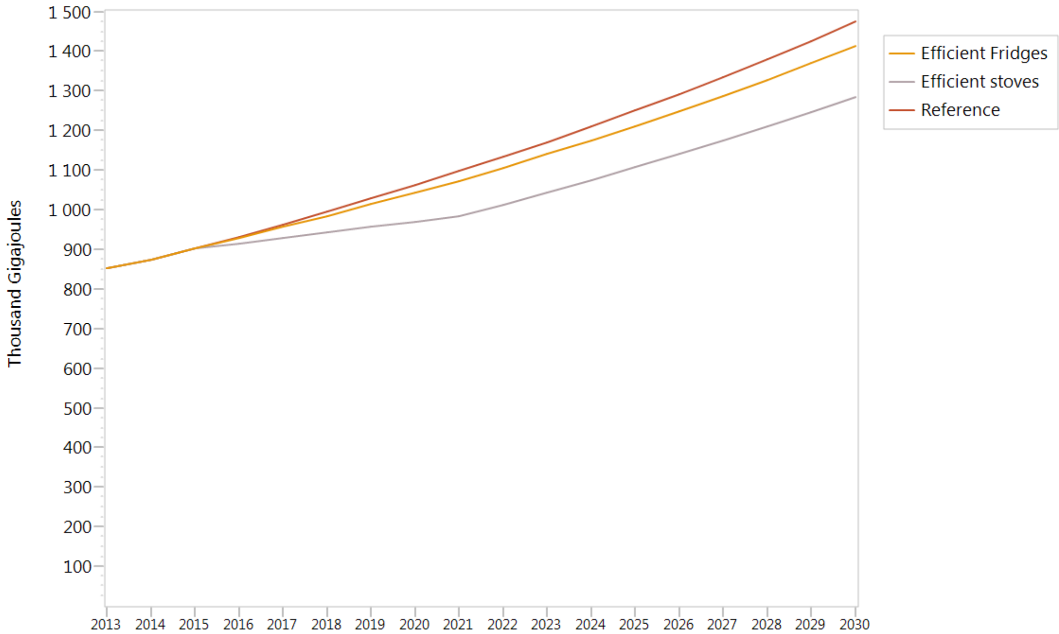


Figure 34: Energy consumption for Ga East Municipality comparing household scenarios

This large difference in impact of the two scenarios is mainly due to the limited number of fridges in use compared to those households which use charcoal. However, the monetary savings are comparable between the two scenarios, mainly due to the increase in electricity costs in the BAU case.

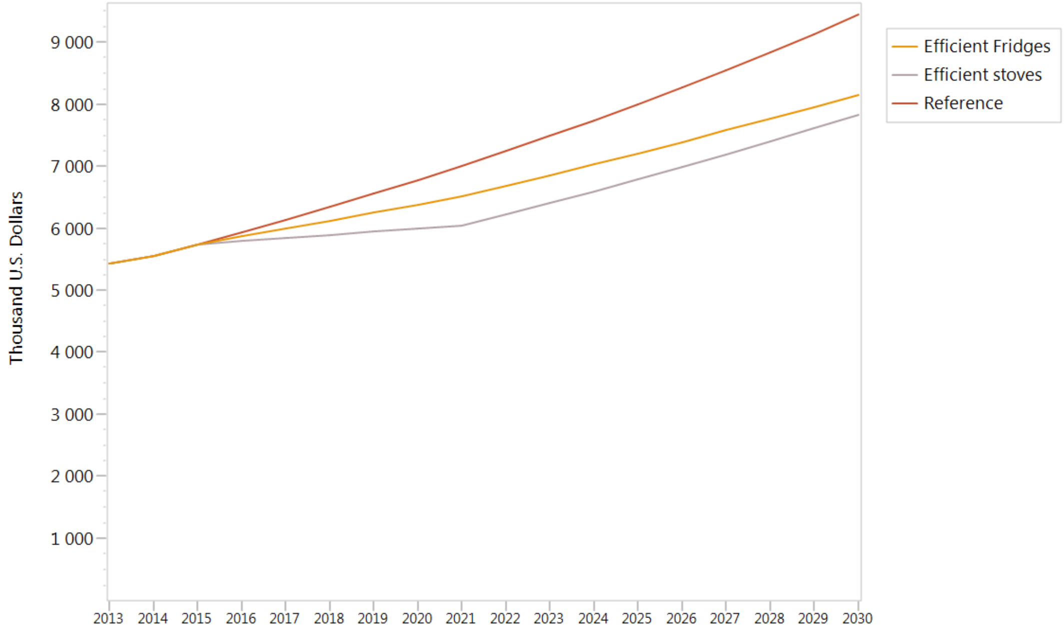


Figure 35: Total cost to GEM comparing the household scenarios

Table 78: Comparison of cumulative cost impacts (2013 GHC) for household scenarios

	2016	*2020*	*2025*	*2030*
Efficient fridges	178 805	2 977 529	11 332 592	25 306 638
Efficient stoves	365 483	5 840 364	19 781 486	38 354 876

References

Appiah, S. 2015. Bus rapid transit system to begin in Accra in November, Graphic online, June 2015, available at: http://graphic.com.gh/news/general-news/44697-bus-rapid-transit-system-to-begin-in-accra-in-november.html

Bawakyillenuo, S and Agbelie, I. 2014. *Ga East State of Energy Report*, ISSER, University of Ghana.

Bessey, B. 2014. *First phase of bus rapid transport to commence in July*, AllAfrica, 2014 available at http://allafrica.com/stories/201401300987.html

Cowan, B., 2008. *Alleviation of poverty through the provision of local energy services (APPLES*). Project no. EIE-04-168. Cape Town, South Africa

Currency historical exchange rates available at: www.xe.com

Ghana Statistical Service. 2014a. Gross domestic product. Accra, Ghana

Ghana Statistical Service. 2014b. 2010 population and housing census district analytical report – Awutu Senya East Municipality. Accra, Ghana

Ghana Statistical Service. 2012. P*opulation and housing census 2010. Summary report of final results*. Accra, Ghana

International Monetary Fund (IMF) 2013. *World Economic Outlook*.

McCall, B, Tait, L and Stone, A. 2016. Awutu Senya East LEAP model technical report. SAMSET project.

National Petroleum Authority (NPA). 2016. Regional consumption 2010 to 2014 statistics. Accessed January 2016. Available at http://npa.gov.gh/npa_new/Downloads.php.

National Population Council (NPC). 2011. *Ghana Stabilisation report 2011*. Available at: http://www.npc.gov.gh/web/images/ICPD/Ghana_Population_and_Stablisation_Report.pdf.

Okoye, V, Sands, J and Debrah C. 2010. The Accra pilot bus-rapid transit project – transport land use research study. Millennium Cities Initiative.

Osei-Boateng, C and Ampratwum, E. 2011. The informal sector in Ghana. Friedrich Ebert Stiftung

Owusu, G. 2011. Spatial patterns and trends of Ghana's contemporary urbanization: Polarization reversal or urban primacy? Institute of Statistical, Social and Economic Research.

Public Utilities Regulatory Commission. 2013. Press release October 2013. Available at: https://www.giz.de/fachexpertise/downloads/2013-en-ghana-approved-electricity-and-water-tariffs-2013.pdf,

Simons, A and Nunoo, S. 2009. Liquefied petroleum gas as an alternative vehicle fuel in Ghana. *Petroleum Science and Technology*, 27:18: 2223-2233, DOI: 10.1080/10916460802686624.

Tait, L, McCall, B and Stone, A. 2014. Energy futures modelling for African cities – selecting a modelling tool for the SAMSET project. Energy Research Centre, University of Cape Town,

United Nations Development Programme (UNDP). n.d. Promoting of appliance of energy efficiency and transformation of the refrigerating appliances market in Ghana. Available at; http://www.gh.undp.org/content/ghana/en/home/operations/projects/environment_and_energy/Susdevclusterprojects.html.

World Bank. n.d. The world development indicators database. Available at data.worldbank.org. Accessed 18th December 2013.

World Bank projections from http://knoema.com/yxptpab/crude-oil-price-forecast-long-term-2015-to-2025-data-and-charts

World Resources Institute (WRI). 2014. Global protocol for community-scale greenhouse gas emission inventories: An accounting and reporting standard for cities/ World Resources Institute, C40 Cities Climate Leadership Group and ICLEI - Local Governments for Sustainability. Available from URL: http://ghgprotocol.org/files/ghgp/GHGP_GPC.pdf.

Appendix A. Own-generation efficiency model

In order to convert the own-generation data from the survey, which consisted of generator ratings an 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 79: Gasoline generator data used to derive a model of generator fuel consumption and efficiency as a function of rating and load factor

Model	*Rating (kVA/kW)*	*Load Factor*	*Consumption (L/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%

Sources:
http://www.centralmainediesel.com
http://www.globalspec.com
http://www.buffalotools.com
http://gens.lccdn.com
http://powerequipment.honda.com
http://www.homedepot.com
http://www.northerntool.com

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 80: Diesel generator data used to derive a model of generator fuel consumption and efficiency as a function of rating and load factor

Model	*Rating*	*Load factor*	*Consumption (L/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%

Sources:

http://www.centralmainediesel.com

http://www.dieselserviceandsupply.com/Diesel_Fuel_Consumption.aspx

http://www.kohlerpower.com/onlinecatalog/pdf/g5412.pdf

https://powersuite.cummins.com/PS5/PS5Content/SiteContent/en/Binary_Asset/pdf/Commercial/Diesel/d-3372.pd

Appendix B. Commercial sector energy intensity by activity type

Table 81: Average breakdown of electricity and energy intensity by type of use in the Ga East commercial sector

Type and Activity of Use	*Floor-space (m^2)*	*Average specific electricity consumption ($kWh/m^2.yr$)**	*Average specific electricity consumption (inc. gen fuel) ($kWh/m^2.yr$)#*	*Average specific energy consumption ($kWh/m^2.yr$)+*	*Average share of own generation ($kWh/m^2.yr$)x*
Formal	94 285	10	104	137	21%
Formal (less Schools)	32 562	26	291	301	23%
Hotels & guest houses	22 228	9	82	97	17%
Schools	61 722	1	5	51	6%
Non-banks financial services	1 640	19	330	330	31%
Hospitals	3 253	39	619	619	29%
Banks	5 441	86	932	932	23%
Informal	14 966	28	229	600	11%
Aluminium fabricator	90	100	872	872	9%
Carpentry/welding shops	4 680	22	133	133	7%
Cold store	25	142	142	142	0%
Corn mill	49	118	118	118	0%
Drinking bar, restaurant, catering services	3 301	25	307	1934	18%
Electronic repair shops	188	82	590	636	7%
Fitting/mechanic	2 635	9	9	21	0%
Laundry	36	299	3 259	3 259	16%
Other	1 646	40	716	716	25%
Petty trading	240	22	22	569	0%
Retail	1 320	43	126	129	3%
Tailoring/seamstress	756	49	130	143	2%

*: 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

x: Share of own generation of all electricity consumed

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 shown 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.

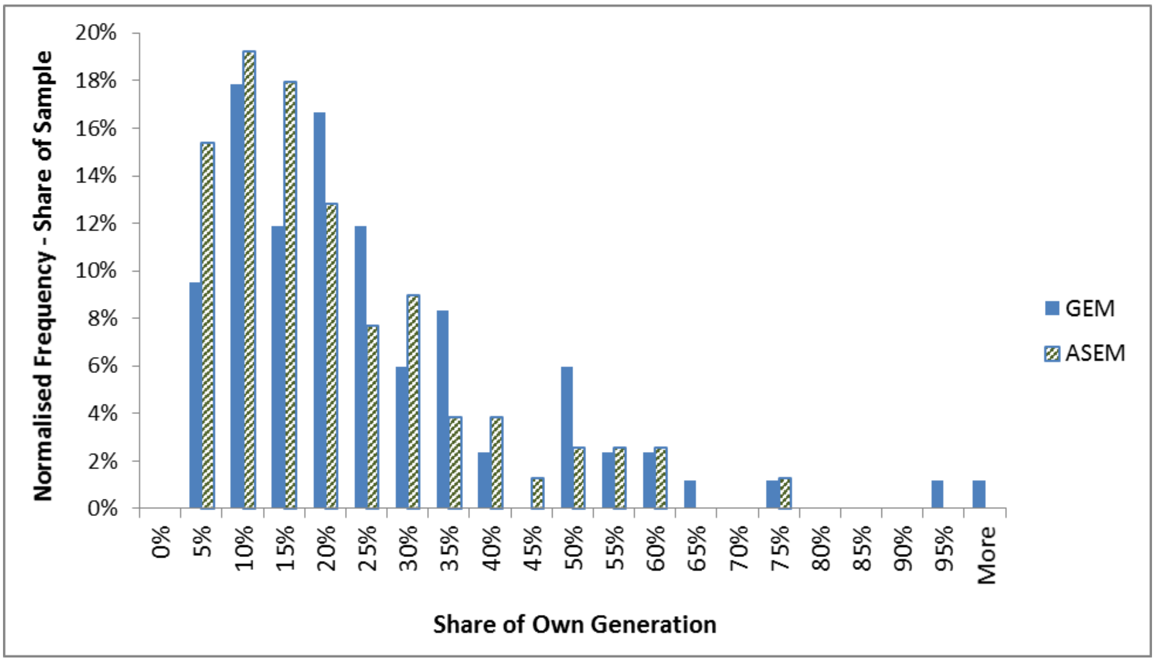


Figure 36: Comparison of share of own-generation distributions for ASEM and GEM commercial sector generator owners

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 Ga East 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.

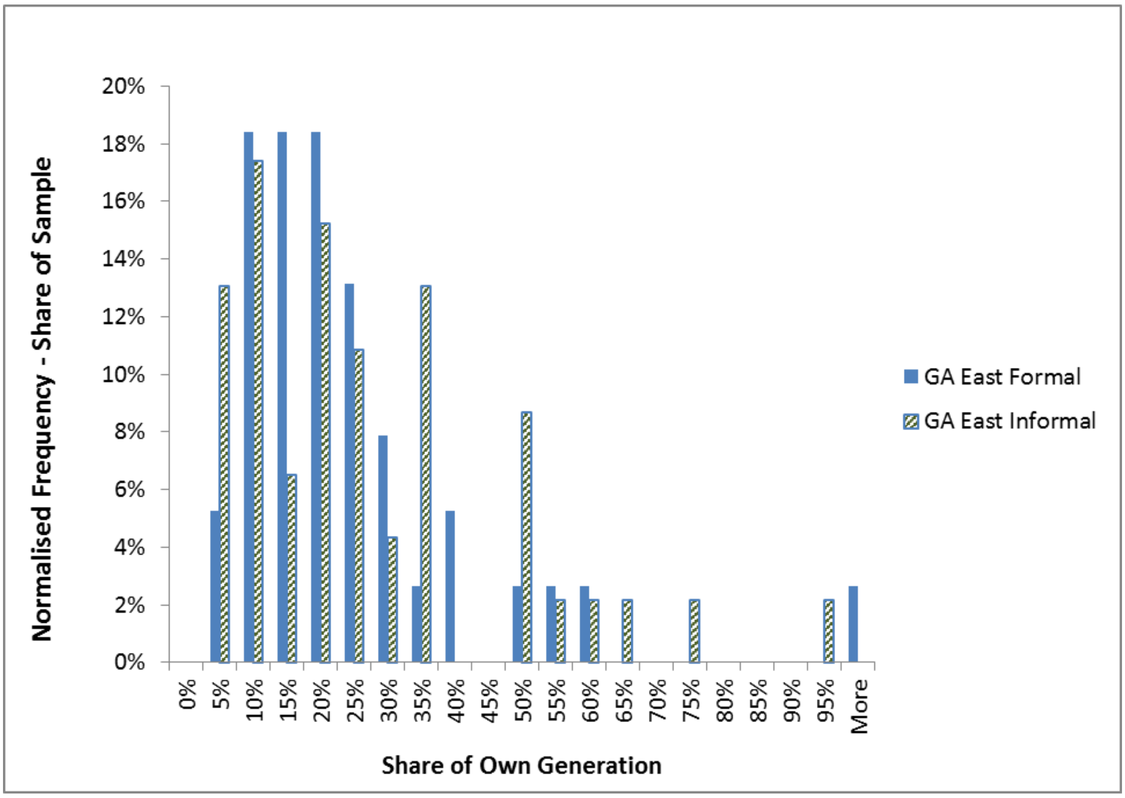


Figure 37: Comparison of share of own-generation distributions for formal and informal commercial sector generator owners in Ga East Municipality Sample