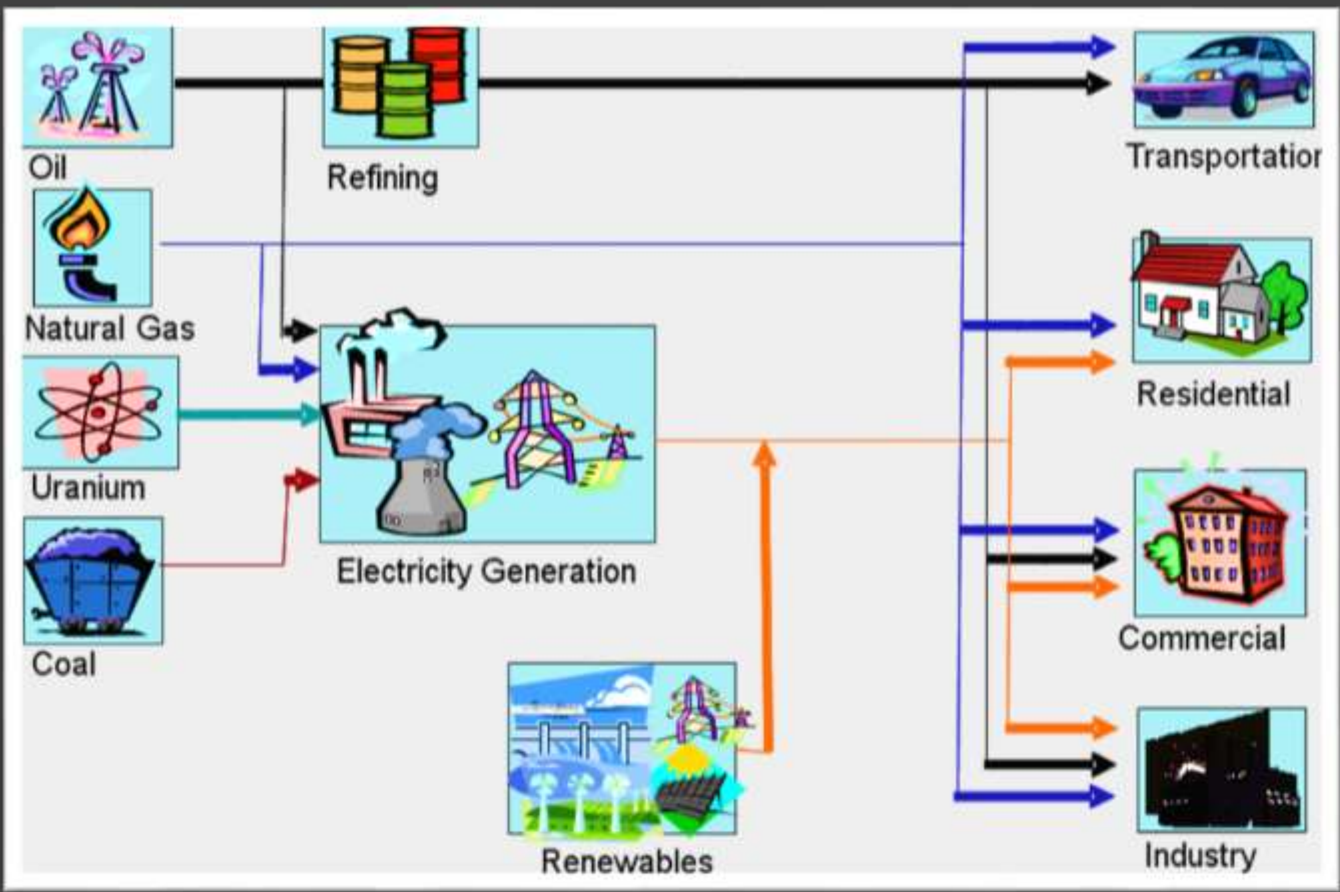
ENHANCING CAPACITY FOR LOW EMISSION DEVELOPMENT STRATEGIES (EC-LEDS) CLEAN ENERGY PROGRAM

COOPERATIVE AGREEMENT NO. 114-A-13-00008

MARKAL-GEORGIA GUIDEBOOK FOR BUSINESS AS USUAL (BAU) SCENARIO DEVELOPMENT



September, 2016

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This report was prepared under the technical assistance provided to the Government of Georgia for development of the Low Emission Development Strategy in the framework of the "Enhancing Capacity for Low Emission Development Strategy" (EC-LEDS) project.

The report presents the description of MARKAL-Georgia model, also the templates and data sources used for preparation of Business As Usual (BAU) scenario.

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1 Introduction

The US Agency for International Development (USAID) Enhancing Capacity for Low Emissions Development Strategy (EC-LEDS) Clean Energy Program for Georgia supports increased climate change mitigation by building capacity to stimulate private sector investment in energy efficiency and green buildings, raising public awareness, and strengthening Government of Georgia (GOG) capacity to develop and implement a national LEDS. Under Component 3, the EC-LEDS Clean Energy Program is supporting the National EC-LEDS Steering Committee (SC) and associated technical working groups (WGs.) by providing advisory assistance to the GOG to articulate concrete actions, policies, programs and implementation plans under the US-Georgia bilateral EC-LEDS initiative, including supporting Georgia's preparation of policy measures needed to achieve their Intended Nationally Determined Contribution (INDC) as submitted to the United Nations Framework Convention on Climate Change (UNFCCC) 21st Conference of Parties (COP-21) in Paris December 2015.

This report documents the MARKAL-Georgia model used to develop the Business-as-Usual (BAU) scenario under this EC-LEDS technical assistance program. The report describes the structure of the MARKAL-Georgia Reference Energy System, the data templates for each sector of the energy system, the Base Year (BY) calibration process, and the development of the BAU scenario. Because this report focuses on the model data and assumptions, only one example policy analysis scenario (for GHG mitigation) is presented. The detailed results of the BAU scenario and the various GHG mitigation scenarios that have been analyzed can be viewed in the BAU scenario report[1] and the Mitigation measures report[2] .

The purpose of this guidebook is not to explain the MARKAL/TIMES framework, but rather to describe the specific model, which is MARKAL-Georgia, and the data sources and assumptions used for constructing the BAU scenario. Understanding the report requires a general understanding of the MARKAL/TIMES modeling platform and the associated ANSWER and Veda-BE software[3]. This report is primarily intended for the Analytic Department of the Ministry of Georgia (MoE-AD), who have already had MARKAL related training and who actively participated in data development for the current version of model. It is intended to continue the process of enhancing the capacity of the MoE-AD towards ownership and responsibility for the stewardship of MARKAL-Georgia going forward.

MARKAL-Georgia was initially developed under US Agency for International Development (USAID) Regional Energy Security and Market Development (RESMD) project and in conjunction with the joint SYNENERGY Strategic Planning (SSP) effort undertaken with Greece Hellenic Aid. In this project MARKAL models[4] were developed for 10 Energy Community Contracting Parties and Observer Countries, including Georgia. The Ministry of Energy and Natural Resources was actively involved in the process. At the end of the project a Policy Brief was prepared, which described the Reference (business-as-usual) scenario along with policy scenarios to examine energy efficiency and renewable energy opportunities in Georgia. By the end of 2013 USAID's regional project "Low

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[1] USAID, Enhancing Capacity For Low Emission Development Strategies (EC-LEDS)/ Clean Energy Program Georgia, Updated MARKAL-Georgia BAU Scenario Report, April 2016.

[2] USAID, Enhancing Capacity For Low Emission Development Strategies (EC-LEDS)/ Clean Energy Program Georgia, MARKAL-Georgia Mitigation Scenarios Report, May 2016.

[3] For guidebooks and details on MARKAL/TIMES framework and associated software please visit http://iea-etsap.org/.

[4] The initial model structure was developed under the USAID Regional Energy Demand Planning (REDP) project.

Emissions Strategies and Clean Energy Development in Europe& Eurasia" supported an update of the MARKAL-Georgia database and trained the Analytical Department of Ministry of Energy in the use of MARKAL-Georgia. DWG, working under IRG and Tetratech, lead the model development and capacity building undertakings for these projects mentioned. The update of the model and training continued under the Hydro Power and Energy Planning Project (HPEP) project by Deloitte and World Experience Georgia (WEG).

Under the current phase of EC-LEDS project the MARKAL-Georgia model has been substantially revised and updated by Sustainable Development Centre Remissia and DWG. The major change involved moving the model's Base Year to 2014 and calibrating the model to the 2014 energy balance, prepared by National Statistics Office of Georgia (Geostat), which is an improvement over the 2012 and 2013 energy balances. In addition, the model was restructured into 2-year periods out to 2040, compared to 3-year periods out to 2036 in the previous version. Furthermore, all input data were reviewed and updated where appropriate. A summary of these changes may be found in Appendix A of the BAU Report[1].

MARKAL-Georgia is built using the MARKAL integrated energy system modeling platform, developed under the auspices of the International Energy Agency's Energy Technology Systems Analysis Program (IEA-ETSAP, www.iea-etsap.org). The following are key features of a MARKAL model:

- Encompasses the ***entire energy system*** from resource extraction through to end-use demands as represented by a Reference Energy System (RES) network (see the example in **Error! Reference source not found.**);
- Employs least-cost ***optimization***;
- Identifies the most ***cost-effective*** pattern of resource use and technology deployment over time;
- Provides a framework for the evaluation of mid-to-long-term ***policies and programs*** that can impact the evolution of the energy system;
- Quantifies the ***costs and technology choices***, and the associated emissions, that result from imposition of the policies and programs, and
- Fosters **stakeholder buy-in** and consensus building.

2 Overview of the MARKAL-Georgia Reference Energy System

The starting point of for any MARKAL/TIMES model is the definition of a standard Reference Energy System (RES) structure. The RES is a network that links resource supplies, energy conversion and processing technologies, with end-use devices that meet the demands for energy services, tracking the flows of energy and the associated emissions. The model finds the least-cost path through the network to meet all end-use demands, subject to constraints that enforce network integrity as well as any user-imposed (policy) constraints. Figure 1 shows summary diagram of a generic RES, providing examples of fuels that could be included and general categories of technologies and end use sectors. The resource supplies are characterized by supply-cost curves, and technologies are described by their investment and operating cost, efficiency, lifetime, and a number of other operational characteristics. Supply technologies (power plants and refineries) convert primary energy into energy carriers, which are consumed by end-use devices to meet energy service demands (light, heat, travel, or industrial process drive) that are tied to drivers, such as GDP and population growth, expected changes in lifestyle as GDP per capita grows, and other sectoral drivers of growth.

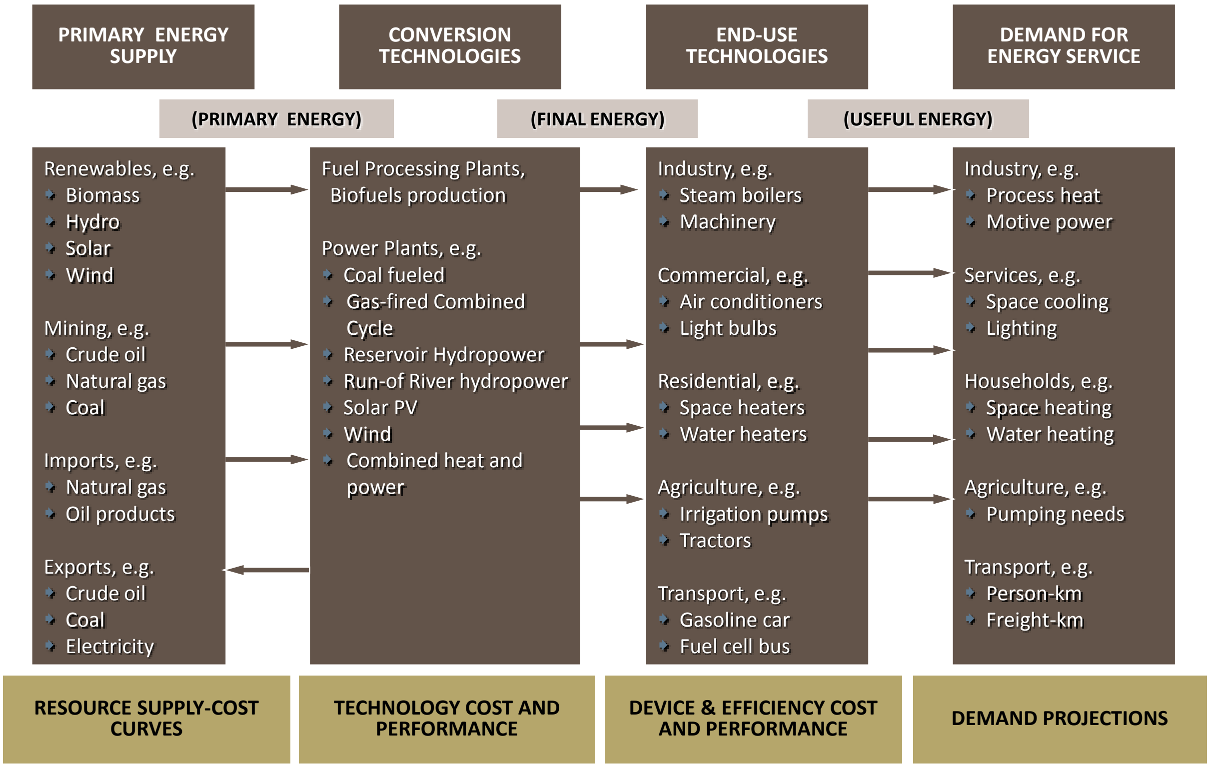


Figure 1. MARKAL Reference Energy System Overview

The first step in developing a MARKAL/TIMES model is to customize this generic RES for the situation at hand. The sectors, fuels, and end use demands to be included are defined at the desired level of detail, and the existing and new technological options for each are enumerated. "Dummy" process devices are also included, which do not represent real technologies but rather are modeling techniques to make the analyst's job easier.

MARKAL-Georgia RES is based on 2014 National Energy Balance developed by National Statistics Office of Georgia and the purposes of Low Emission development Strategy (LEDS) analysis to be performed under EC-LEDS project. The resulting RES is too large and detailed to picture as a whole, but parts of it will be depicted in corresponding sectors. The figure below shows the RES Screen shot Using Natural Gas, Electricity, and Apartment Space Heating as an example, and will be used farther on to explain the main principles of the RES.

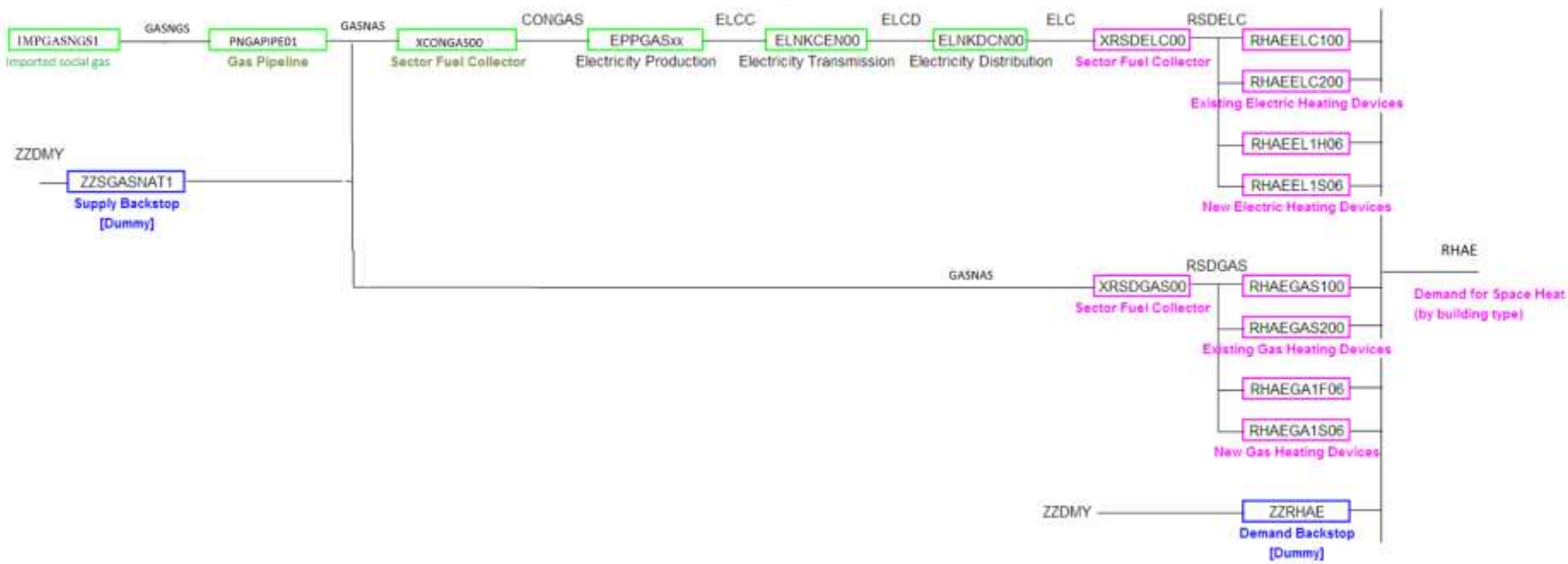


Figure 2. MARKAL-Georgia RES Screen shot Using Natural Gas, Electricity, and Apartment Space Heating as Examples

The fuel supply chains for natural gas and for electricity are shown in Figure 2, along with sample devices to generate electricity from natural gas and to provide apartment heating from electricity and gas. This general structure is repeated for many other fuels, devices, and demands throughout the RES.

The boxes in the RES represent fuel supplies and/or technologies, while the lines represent energy carriers (fuels and electricity). The names of the supplies/technologies are shown within the boxes, while the names of the energy carriers are shown above the lines. These "short" names or codes are defined using strict naming conventions that, once learned, make identifying and working with model components much easier. These naming conventions are described in detail for each sector of the RES in Section 3 of this report.

Working from the right hand side of the RES in Figure 2, the rightmost item is the demand for energy service, in this case Apartment Space Heating. An important distinction needs to be made between energy services demand (often called useful energy demand or end-use demand) and the final energy consumed to enable technologies to meet these end-use demands. Energy services are what users actually need – the light, heat, travel, or industrial process drive provided by energy consuming devices. Final energy is the last time that physical energy forms (e.g., electricity, gasoline, distillate) can be explicitly recognized in the model, before the demand service devices (e.g., cars, light bulb, heater, air conditioners, industrial heat) convert said energy into services (e.g., passenger travel, lighting, heating, cooling, preparing pulp for making paper). **A MARKAL/TIMES model is *driven by* energy service demands and *computes* final energy consumption**.

The demands for energy services in this kind of models are usually categorized into the following main sectors: Agriculture, Commercial, Industry, Residential and Transport. MARKAL-Georgia also includes sector for Territories Electricity Demand (TED) representing electricity delivered to Abkhazia, and non-energy sector representing non-energy consumption of energy carriers. Each sector is then split into a number of sub-sectors. For example, Households may have demands for heating, cooling, hot water, lighting, refrigeration, washing and drying clothes, washing dishes, other electrical appliances. Some demands, like space heating, are further broken down by building type.

These demands are calculated for the base year in the templates through the calibration process. A key aspect of developing a model to assist with future energy demand planning becomes the development of projections for useful energy demand services, which MARKAL will then be required to meet by choosing the least-cost set of fuels and technologies within the various constraints imposed. The demand projection process systematically relates the specific demands identified in a model to the corresponding social, economic and technical factors that affects this demand. This process is conducted in the Demand Projections template, described in Section 4.3.2 of this report.

Moving leftward in the RES depicted in Figure 2, we find a sample of the technologies available to meet the specified demand, in this case a small subset of the electricity and natural gas powered heating devices. The characteristics of the existing devices are specified in the base year (BY) template for each end use sector. The characteristics of the new devices available for purchase are described in the new end-use technology (NEWTCH-DMD) template.

Below the end use devices is a so-called "dummy" backstop technology, named ZZRHARE. This device is a modeler's tool, a nonphysical device that consumes an inexhaustible, nonphysical fuel named ZZDMY and that can meet any amount of apartment space heating demand at very high cost. This device, and similar devices for each demand, prevents infeasibilities during the model run. Infeasibilities are cases where the model cannot meet all the demands and thereby terminates a run without producing the usual reports, making it very difficult to locate the problem area. These backstop processes allow one to trace back where the infeasibilities would otherwise occur and are thus a key diagnostic tool for the modeler. Each time the modeler makes a significant change to the model and creates a new run, the first result to check is for any consumption of ZZDMY. In a working model run, these devices should never be used. A similar set of devices exists to backstop the supply of every resource in the model. The example ZZGASNAT is shown in Figure 2.

Just to the left of the end use technologies, for each demand sector there are a set of dummy technologies whose names always begin with X. Like the ZZ dummy devices, these X processes are nonphysical devices that are inserted into the model to make the modeler's job easier. The X processes change the name of each fuel as it moves from the supply side to where it is consumed (for example, from GASNAS to CONGAS, for the conversion (power) sector or RSDGAS, for the residential sector). This nomenclature makes it easy to quickly track, for example, how much natural gas is consumed in each sector. The delivery markup for sector fuels, which tends to vary by sector, is also charged at these devices. In some cases, these devices are used to collect several upstream fuels into a single demand fuel when this simplicity is warranted (e.g., hard coal, briquettes, and lignite coal are all combined into <sect>COA for the demands). In a few cases where fuel distribution infrastructure is limited and costly, such as for natural gas, these devices are also used to represent the capacity of the existing infrastructure and to charge the model a cost to extend it.

Moving further leftward from XCONGAS and XRSDGAS in Figure 2, the gas supply RES is straightforward. Gas is delivered to the sectors through a transmission pipeline that represents total national transmission capacity (where base year capacity and options for investing in increased capacity may be specified). Gas is supplied to the pipeline through imports and/or domestic production, as applicable to the country-specific situation. The data to characterize the fuel supply options and costs is organized in the Supply template, as described in Section 4.1.

The electricity sector warrants additional description. Shown here is one example of a centralized gas-fired power plant. Electricity only and combined heat and power plants (as well as heat only plants) may be described for a number of fuels, in both centralized and decentralized option. In Georgia we have only three existing gas plants in base year and number of options to be added in the future. The data for describing existing power plants is organized in the power plant (PP) BY template, and options for new plants are characterizing in the new power plant (NewtchPP) template. Electricity transmission and distribution grids (conceived as national aggregates) are represented separately as interconnection (LNK) technologies (ELNKCEN00 and ELNKDCN00), each with its losses. Once electricity has traveled through these grids, it is ready to be fed to the end use sectors by the relevant X<sector>ELC processes.

A consistent set of units must be employed for each component of the RES. The basic units employed throughout the MARKAL-Georgia are:

- Capacity - Gigawatts (GW) for electricity generating facilities; Petajoules/year (PJ/a) everywhere else;
- Demands - Petajoules (PJ); million passenger-kms (mpkm) and million tonne-kms (mtkm) in case of passenger and freight transports;
- Energy and Process Activity - Petajoules (PJ);
- Emissions – Kilotons (kt); and
- Monetary - Million EUR in 2014 base year prices.

Frequently data will be available in other units. The templates provide a structure for performing the necessary unit conversions.

3 Organization of the Sectors

This section works through the RES described above sector by sector, elaborating the structure, level of detail, and naming conventions. We begin with the demand sectors and work leftward through the RES, as above.

3.1 Demand Sectors

There are seven demand sectors depicted by the MARKAL-Georgia RES:

- Residential
- Commercial
- Industry
- Transportation
- Agriculture
- Territory Electricity Demand (TED), representing the electricity delivered to occupied territory of Abkhazia
- Non-energy consumption

In the sections that follow, the organization of the sub-sectors or categories of end-use services within each sector is first presented, followed by the specifics of the RES details (technologies) associated with each sub-sector. Naming conventions for the demand sectors follow. For each sector there are associated calibration and existing device templates, which, along with corresponding data sources, are described in detail in Section 4.2.

3.1.1 Residential

The residential sector (RSD) distinguishes 10 end-uses and 4 building types. Only space heating, water heating and space cooling are broken out by building types, owing to the variance in thermal integrity, seasonal use profile, and device and conservation options for each dwelling type.

The residential sector includes the following end-uses:

- space heating;
- water heating;
- space cooling;
- cooking;
- lighting;
- refrigeration and freezing;
- clothes washing;
- clothes drying;
- dish washing, and
- All other consumption of electricity in households (includes TV, computers, radios, etc.)

The heating, cooling, and water heating demands are divided into the following building types:

- single houses in rural area with local space and water heating;
- single houses in urban area with local space and water heating;
- single houses in urban area with central space and water heating, and
- All apartments (urban areas) with local and central space and water heating.

"Local" in this context means heating systems that heat a single room, while "central" refers to dwellings with central heating systems represented by a furnace that supplies the heat to other parts of dwelling. Thus a single urban house may move from the local to central category by installing a central heating system. For apartments, this distinction was not made.

In transition economies, energy consumption in households is closely linked to their purchasing power. Households with lower purchasing power typically heat one or at most two rooms, which do not exceed 1/3 of the residential area of the houses. Households with higher purchasing power often have central heating installations and preparation of hot water and heat larger percentage of the residential area. In addition, households with lower purchasing power on average are heating daily for a smaller number of hours than households with higher purchasing power. Thus households with higher purchasing power (centrally heated) annually spend around twice the energy for space heating than households with lower purchasing power (locally heated). With rising living standards the share of centrally heated houses is expected to increase.

The influence of purchasing power is less pronounced in the apartment blocks. Due to the physics of construction and the on average smaller areas in comparison to single houses, the average apartment spends less energy for space heating than the average single house. Since this difference is smaller than between centrally and locally heated houses, the apartments in the residential buildings were modeled allowing for either local or central system. With rising living standards an increasing share of centrally heated apartments in relation to the locally heated proportion can be expected. The projection of the demand takes into account the impact of income evolution on a further penetration of central heating and thus rising apartment heating intensities.

A distinction between rural and urban areas for housing is introduced in order to define more precisely the potential areas where energy can be supplied from network systems such as natural gas distribution.

As already noted, space heating, space cooling, and water heating have been differentiated by dwelling category whereas the other end uses have only a single average specification, as the building type does not affect the profile of use or anticipated evolution of the demand. Water heating requires this distinction owing to the use of furnaces that provide both space heating and hot water.

End-use categories such as space heating, cooking, lighting, refrigeration, and clothes washing are typical today whereas categories such as space cooling, clothes drying and dish washing today are not as significant, though rapid increase in these demands can be expected.

Figure 3 summarizes the residential RES employed for MARKAL-Georgia, with energy carriers and technologies used to satisfy demands in Georgia's residential sectors. Data sources and characteristic values of different energy carriers and demands are later discussed in Section 4.2.1.

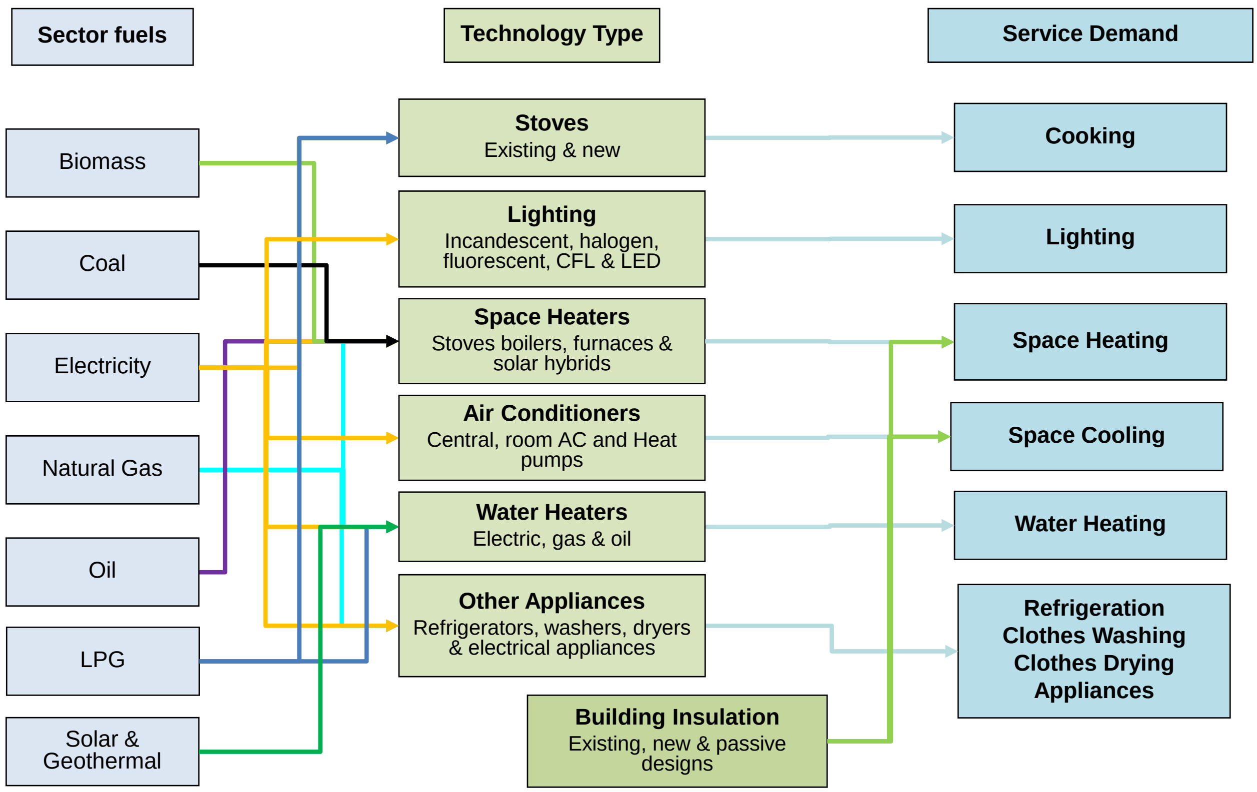


Figure 3. Simplified view of MARKAL-Georgia Residential RES

3.1.2 Commercial (or Services)

The service sector can be classified by sector activities into public services and market services. Public services include: health care, education and other public services (culture, sport, public administration and civil service). Market services include: commerce, hospitality industry (catering and tourism), banking, consulting services, etc.

In terms of energy consumption, the commercial (or services) sector in transition economies is relatively small. Because of the relatively low energy consumption in relation to other sectors, the energy balances show the commercial sector only as one item, not split into sub-sectors (like industry). However, the service sector is expected to grow, both in economic and energy consumption terms. Therefore, it will be increasingly important to improve upon the statistical records regarding energy consumption in the service sector, and correspondingly, MARKAL-Georgia depiction of this sector.

The basic reference used for energy intensity in the service sector is square meters of floor-space in buildings according to the individual sub-groups of services. However, it is difficult to find a comprehensive and public statistical analysis of space used in the commercial sector, particularly by service type. This data must be obtained by means of surveys and energy audits, and thus is costly to obtain and maintain. When this version of MARKAL-Georgia was developed there was no credible survey existing for commercial sector. Due to this sparse data, for the MARKAL-Georgia, the commercial sector has not been divided into any sub-sector groups.

Figure 4 provides a look at the commercial sector RES employed for MARKAL-Georgia, which is very similar to that used in the residential sector. Note that actual fuels and technologies employed are characteristic of the situation in Georgia, based on available data.

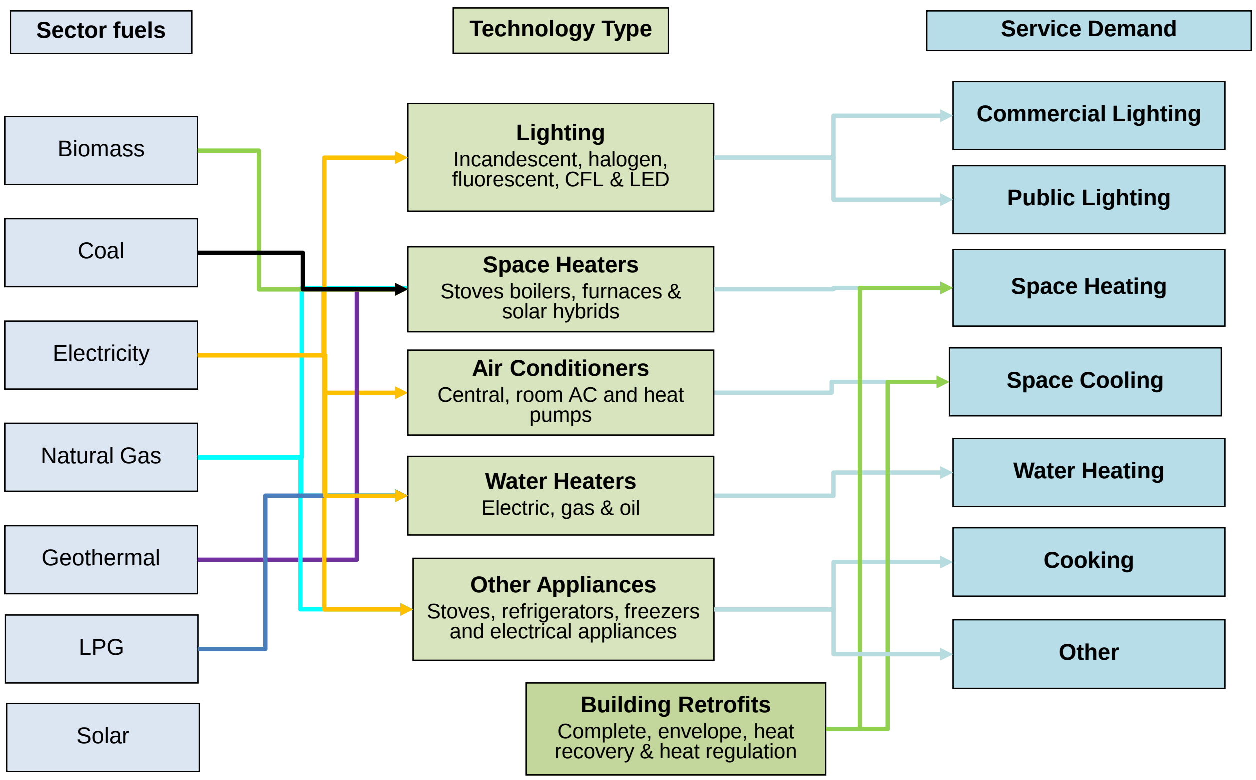


Figure 4. Simplified view of MARKAL-Georgia Commercial RES

3.1.3 Agriculture

Agriculture is treated slightly differently than the Residential and Commercial sectors. For Agriculture only a single demand category is specified, with generic devices provided for each fuel type. Thus we track only final consumption, rather than actual energy services such as tractor use, greenhouse heating, and so on. Generic devices in future years allow more efficient energy use to meet the same implicit service demand. Adding more specific demands will require a survey of energy consumption within this sector.

Figure 5 provides a look at the agricultural RES in MARKAL-Georgia, which is based on 2014 energy balance.

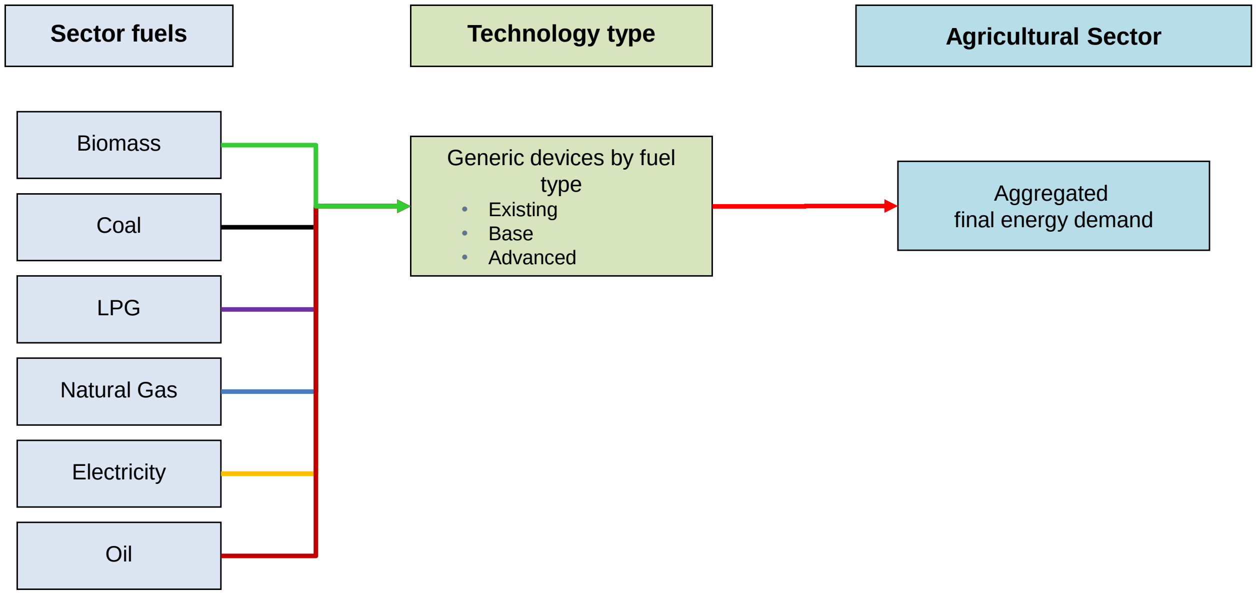


Figure 5. Simplified view of MARKAL-Georgia Agricultural RES

3.1.4 Industrial

MARKAL-Georgia distinguishes the largest energy consuming sub-sectors in Georgia's industry sector. All other minor sectors are combined within "other industry" subsector. Thus, the subsector categories are:

- chemical industry;
- food industry;
- iron and steel industry;
- non-metallic minerals industry;
- construction and
- other industry

Because of differences in the availability of technologies to meet these demands, the industrial sector (IND) distinguishes two end-uses in each of the industry subsectors (other than construction). The end-use categories within each industry are:

- Process heat; and
- Machine drive.

Construction has only one "generic" end use that consumes a variety of fuels according to base-year fuel shares.

Figure 6 provides a simplified look at the industrial RES employed for MARKAL-Georgia, with the actual fuels and technologies employed tailored to the situation Georgia based on available data.

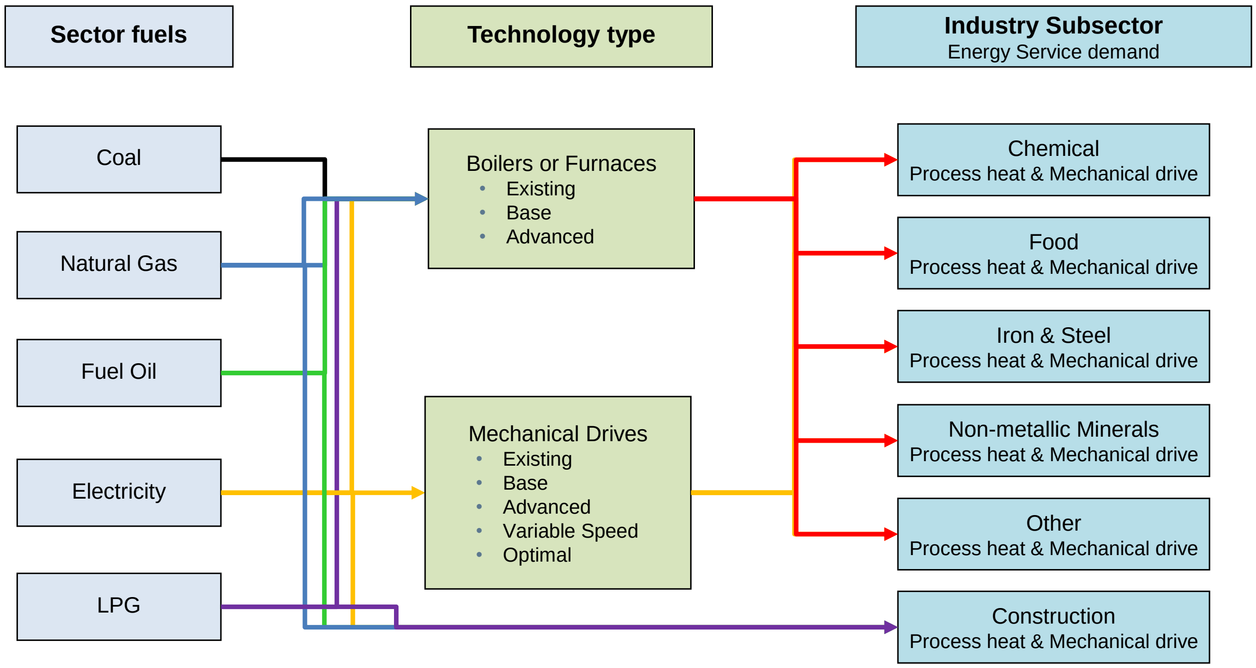


Figure 6. Simplified view of MARKAL-Georgia Industrial RES

3.1.5 Transportation

The transportation sector is sub-divided into passenger and freight transport modes. In addition there is a separate sub-sector for off-road and other (non-classified) types of transport.

The transportation sector in MARGAL-Georgia is characterized by the following end-use service modes :

- Light duty vehicles
- Buses
- Mini-Buses
- Two wheelers
- Heavy goods vehicles
- Light commercial vehicles
- Rail passenger
- Rail freight
- International aviation (bunker)
- Domestic aviation
- International shipping (bunker)
- Domestic shipping
- Off-road

The simplified RES for the Passenger transportation is shown in Figure 7. Each passenger transportation demand uses a suite of vehicle types to deliver the associated service.

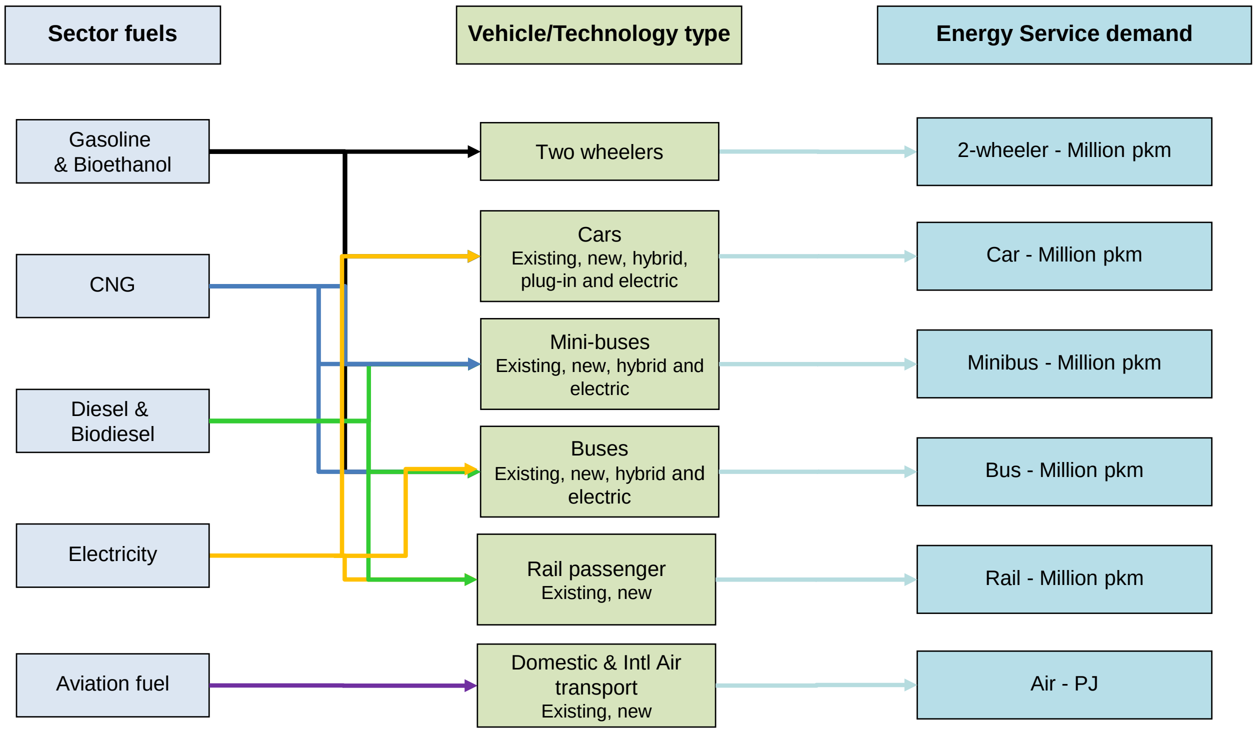


Figure 7. Simplified view of MARKAL-Georgia Passenger Travel RES

Figure 8 shows a simplified RES diagram for Freight transportation. Each freight transportation demand uses a suite of vehicle types to deliver the associated service.

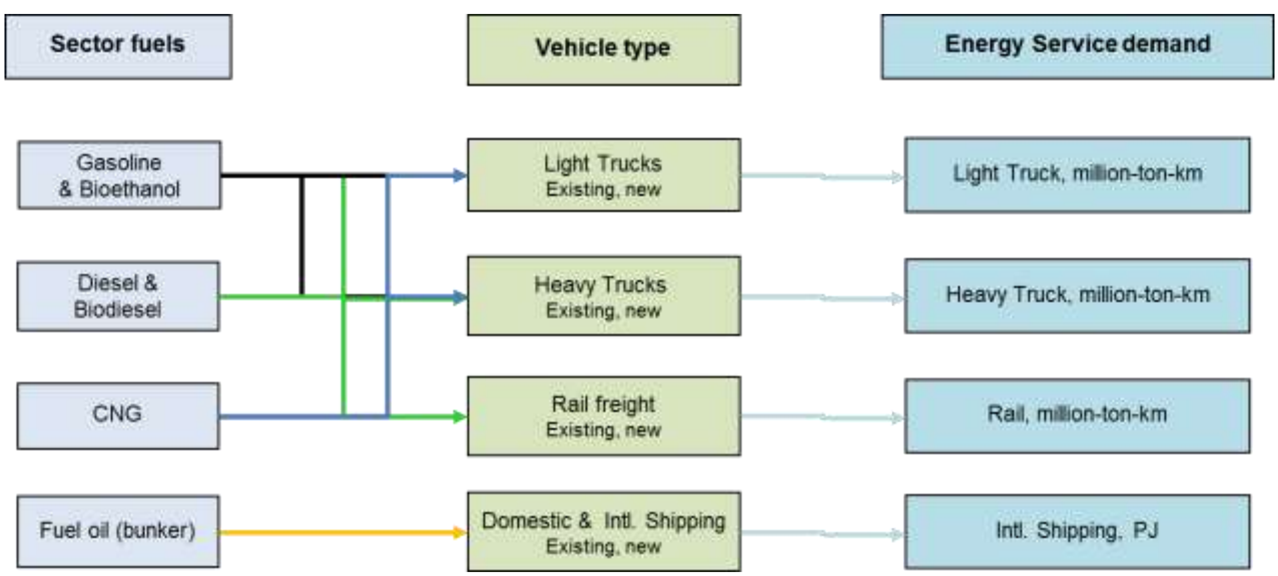


Figure 8. Simplified view of MARKAL- Georgia Freight Transportation RES

3.1.6 Non-energy Consumption and TED sector

TED sector demand represents the electricity delivered to Georgia's occupied territory of Abkhazia. It is modeled as single demand equal to the actual electricity delivered.

Based on Georgia's 2014 energy balance, a number of energy carriers are used for non-energy purposes in transport and industry. As a consequence the following end use demands are modeled for this sector:

- Non Energy - Chemical Industry gas demand
- Non Energy - Industry other
- Non Energy - Transport

Figure 9 shows TED and non-energy sectors RES employed in MARKAL-Georgia.

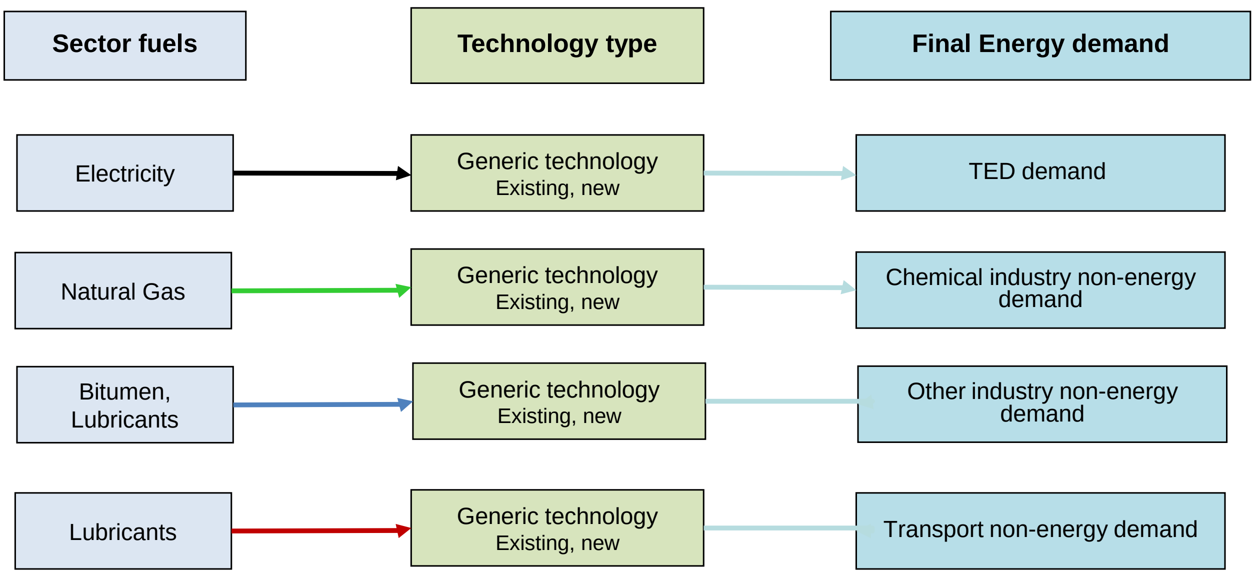


Figure 9. TED and Non energy RES

3.1.7 Naming Conventions for the Demand Sectors

Naming conventions are necessary in MARKAL/TIMES models to make names easy to read and recognize, and to allow the modeling tools to sort and group items readily. Learning the naming conventions greatly facilitates the process of becoming familiar with the model's components.

Demand Names

Each energy service demand (end-use) has a 3-4 character name that follows the rules outlined here:

- The 1st letter designates the sector (R=Residential, C=Commercial, I=Industry, T=Transportation, A=Agriculture, N=Non-energy);

- Within industry, the 2nd character denotes the sub-industry:

- C - chemical
- F - food
- I - iron and steel
- N - Construction
- M - non-metallic minerals
- O - other

➢ In each sector, the subsequent 2nd-4th letters (3rd-4th for Industry) identify the end-use type. For heating/cooling/hot water, the 3rd and 4th letters indicate building type (xx). The sector name indicated in square brackets ([]) below indicates the sector(s) for which the service is specified:

Cxx	Space cooling	[Residential, Commercial]
DRY	Clothes drying	[Residential]
DSH	Dish washing	[Residential]
FOD	Cooking	[Residential, Commercial]
Hxx	Space heating	[Residential, Commercial]
LIT	Lighting	[Residential, Commercial]
OTH	Other electricity consumption	[Residential, Commercial]
PIL	Public lighting	[Commercial]
REF	Refrigerators and freezers	[Residential]
Wxx	Hot water	[Residential, Commercial]
WSH	Clothes washing	[Residential]
HT	Process heat	[Industry]
MD-	Machine drive	[Industry]
LDV	Light duty vehicles	[Transport]
BUS	Buses	[Transport]
MBS	Mini-Buses	[Transport]
TWO	Two wheelers	[Transport]
HGV	Heavy goods vehicles	[Transport]
LCV	Light commercial vehicles	[Transport]
PRL	Rail passenger	[Transport]
FRL	Rail freight	[Transport]
IAV	International aviation (bunker)	[Transport]
DAV	Domestic aviation	[Transport]
ISH	International shipping (bunker)	[Transport]
DSH	Domestic shipping	[Transport]
OFF	Off-road	[Transport]

➢ For demands that are sensitive to the type of building, the 3rd and 4th letters (xx) describes the nature of the building type:
- Residential
  - AE- apartments
  - CE - single house in urban area with central heating
  - LE - single house in urban area with local heating
  - RE - single house in rural area with local heating
- Commercial
  - SE – Single commercial building type (in general there can be several building types denoted by different symbols here)

Note that for Agriculture there is only a single demand category, AGR, and for TED sector only one demand category, TED. Non-energy demand categories have the following names:

- NONG Non Energy - Chemical Industry gas demand
- NONI Non Energy - Industry other
- NONT Non Energy - Transport

Demand Related Technologies

The existing and new demand device technologies are identified with a ten-character code for the Technology Name, as follows:

- The first 3-4 letters indicate the primary end-use demand that the technology services;
- The next 2-3 letters indicate the fuel type (GAS for natural gas, ELC for electricity, etc.);
- The next 1-2 characters indicates the instance of the technology (1/2/3, A/B/C, as desired – these may represent efficiency levels or technology types); and
- The final 2 digits represent the vintage corresponding to the year the technology is first available (00 for 2014, 09 for 2016, 12 for 2018, 15 for 2020 and 18 for 2024).

For example, the code RHAEELC100 represents residential heating equipment in apartments that uses electricity (ELC) as the input fuel and is existing stock in the base year. If another technology exists serving the same demand category and using the same fuel but representing a different technology type (for example, local space heating stove on electricity), this technology will have the code RHAEELC**2**00, where label 2 stands for this (second) instance of an electricity-using technology servicing apartment heating. Taking such a structured approach to the short names will result in proper sorting of similar technologies (side-by-side for each sector) and enable the analyst to search on the names using filters to grab relevant subsets of the database.

In addition to the Technology Name, each technology has a Technology Description (*TechDesc*) that more fully describes the nature of the technology, with each component of the description separated by a '.'. For example, for RHAEELC100 this description is *Rsd.SpaceHeat.Apt.All.ELC.00.Furnace<H>* and for technology RHAEELC200 the description is *Rsd.SpaceHeat.Apt.All.ELC.00.Stove<H>*. Again this structured approach to the description will enable the analyst to query on the description using filters to grab subsets of the database.

Sector Fuels and Fuel Processes

Energy carrier names consist of 3-6 characters throughout the MARKAL-Georgia Reference Energy System. Within each of the demand sectors, the energy carrier names are six characters, as follows:

- The first 3 letters describe the sector (e.g., RSD = residential, COM = Commercial, IND = Industry, TRN = Transportation, AGR=Agriculture, NON=Non-energy); and
- The last 3 letters describe the fuel type (e.g. BIO= biomass based fuels, GAS=natural gas, ELC=electricity, etc.)

As already discussed in Section 2, the name of the same energy carrier changes throughout the RES. Although the physical fuel in different parts of RES may not be physically different (e.g., COMGAS and RSDGAS represent the same physical natural gas commodity), giving them distinct names serves several purposes:

- It facilitates tracking of fuel consumption by sector in model results;

- It allows charging different delivery markups to different sectors (e.g., industrial vs household tariffs); and
- It allows tracking of the capacity and cost of limited infrastructure (e.g., natural gas distribution networks).

As described in Section 2, within each sector a set "dummy" X process technologies are established to create the named sector fuels from the fuels emerging from the supply (or upstream) subsystem of the complete RES. The naming convention for these sector fuel collector technologies is as follows:

- 1st character is X (indicating dummy collector);
- Next 3 letters describe the sector (RSD - residential, COM - commercial, AGR - agriculture, IND - industry, TRN – transportation, NON-Non energy, TED=TED);
- Following 3 letters describe the fuel type – ELC for electricity, GAS for natural gas etc.; and
- Next character is an indicator (can be present or no. usually it is used if processes are to be broken out owing to costs for expanding infrastructure);

Note that in some cases, coal and oil products are "combined," usually when the distinction between the end-use devices using the fuel group is minor. For, example Figure 10 shows the diagram for the technology that produces commercial coal by combining hard coal and lignite. With such approach, we don't need to have different end-use technologies for lignite and hard coal for commercial heating.

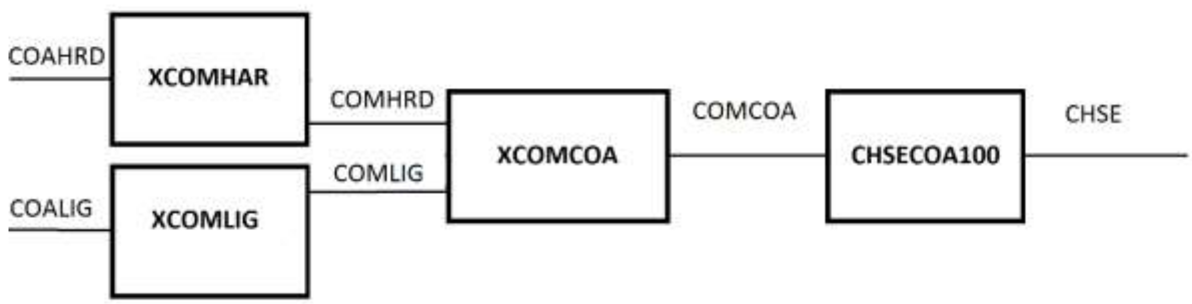


Figure 10. Example of a "dummy" (sector fuel collector technology chain for commercial coal

The shares for the split are taken directly from the initial year energy balance to ensure that consumption and production of these fuels is properly calibrated. These fixed relationships may be adjusted over time or a more flexible representation employed if the model is to make the fuel choices in the future.

Please note that in such cases there are additional X-process before the "combination X-Process" (in this case XCOMCOA), which is due to the needs of emission accounting, depicted in detail under section 3.3.

3.2 Fuel and Electricity Supply

3.2.1 The Fuel Resources Sub-system

For energy carriers at the supply level MARKAL-Georgia has 4-6 character names, as listed in Table 1. The first 3 letters represent the fuel group, which are the following:

COA – Coal
OIL – Oil and oil products
BIO – Biomass
GAS – Natural gas
ELC - Electricity

Box 1. Broad Fuel Groups in MARKAL-Georgia

The remaining three letter represent the fuel type within that group. For example COAANT = Antracite Coal, OILDST = Diesel, OILGSL = gasoline, etc.

The exception of using group naming is made for renewables that don't have fuel group suffix.

Another commodity that has different naming style is electricity, the naming of which is discussed under Electric sector.

For Natural gas, we will have two gas types, representing social gas (GASNAS) and commercial gas (GASNAC).

Based on 2014 Geostat energy balance, there are 25 different types of energy carriers currently in use in Georgia. They are given in Table 1:

Table 1. Base year Energy carriers and their MARKAL codes

Energy Carrier (physical unit)	Group	Markal Codes
Patent fuel (1000 tonnes)	Coal	COABRI
Anthracite (1000 tonnes)	Coal	COAHAR
Other Bit. Coal (1000 tonnes)	Coal	COABIT
Lignite/Brown Coal (1000 tonnes)	Coal	COALIG
Coke Oven Coke (1000 tonnes)	Coal	COACOK
Fuel wood (1000 m3)	Biofuel and Waste	BIOWOO
Natural Gas (mil. m3)	Natural Gas	GASNAS and GASNAC
Crude Oil (1000 tonnes)	Oil and oil products	OILCRD
Liquefied Petroleum Gases (1000 tonnes)	Oil and oil products	OILLPG
Motor Gasoline (1000 tonnes)	Oil and oil products	OILGSL
Kerosene type Jet Fuel (1000 tonnes)	Oil and oil products	OILAVF
Kerosene (1000 tonnes)	Oil and oil products	OILKER
Road diesel (1000 tonnes)	Oil and oil products	OILDST
Heating and other gas oil (1000 tonnes)	Oil and oil products	OILOTH
Fuel oil- low sulphur (< 1%)	Oil and oil products	OILHFO
Lubricants (1000 tonnes)	Oil and oil products	OILLUB
Bitumen (1000 tonnes)	Oil and oil products	OILBIT
Paraffin Waxes (1000 tonnes)	Oil and oil products	OILWAX
Non-specified Petroleum Prods. (1000 tonnes)	Oil and oil products	OILNON
Hydro	Renewables	SUPHYD

Geothermal (TJ)	Renewables	GEOTH
Solar (TJ)	Renewables	SOLAR
Electricity (GWh)	Electricity	ELC

Resource supply technologies make available a specified amount of fuel at a given price. The MARKAL framework distinguishes resource supplies between domestic production and import. Domestic production includes: mining, and biomass harvesting and collection.

For imported fuels, one supply source is modeled for each fuel, other than Electricity and Natural gas.

Fuel supply technologies have 10 character names, where:

- The first three characters indicate the supply type (IMP for import, MIN for domestic production, EXP for export);
- The next 6 letters describe the fuel, (e.g., COAANT, OILDST, etc.); and
- The final number or symbol indicating the supply source (1 in general). For example, you can have several import sources for some commodity and they will be correspondingly numbered as first source, second source, etc.

In MARKAL-Georgia we have 17 import, 4 mining and 7 export technologies in the Base year, as listed in Table 2. Natural gas imports are split into two different technologies, one modeling the import of social gas and another – commercial gas. In addition, there are 48 import and export technologies for electricity representing four different sources (Armenia, Azerbaijan, Russia, and Turkey) and 12 time slices for each.

Table 2. Import technologies in MARKAL-Georgia

IMPCOAHAR1	Import of Anthracite (1000 tonnes)
IMPCOABIT1	Import of Other Bit. Coal (1000 tonnes)
IMPCOACOK1	Import of Coke Oven Coke (1000 tonnes)
IMPOILCRD1	Import of Crude Oil (1000 tonnes)
IMPOILAVF1	Import of Kerosene type Jet Fuel (1000 tonnes)
IMPOILDST1	Import of Road diesel (1000 tonnes)
IMPOILGSL1	Import of Motor Gasoline (1000 tonnes)
IMPOILHFO1	Import of Fuel oil-low sulphur(< 1%)
IMPOILKER1	Import of Kerosene (1000 tonnes)
IMPOILLPG1	Import of Liquefied Petroleum Gases (1000 tonnes)
IMPOILLUB1	Import of Lubricants (1000 tonnes)
IMPOILOTH1	Import of Heating andother gas oil (1000 tonnes)
IMPOILBIT1	Import of Bitumen (1000 tonnes)
IMPOILWAX1	Import of Paraffin Waxes (1000 tonnes)
IMPOILNON1	Import of Non-specified Petroleum Prods. (1000 tonnes)
IMPGASNGS1	Import of Natural Gas - social price
IMPGASNGC2	Import of Natural Gas - commercial price

Table 3. Mining technologies in MARKAL-Georgia

MINBIOWOO1	Production of Biomass
MINCOALIG1	Production of Lignite Coal
MINGASNAC1	Production of Natural Gas – Commercial
MINOILCRD1	Production of Crude Oil

Table 4. Export technologies in MARKAL-Georgia

EXPCOALIG1	Export of Lignite/Brown Coal (1000 tonnes)
EXPOILCRD1	Export of Crude Oil (1000 tonnes)
EXPOILDST1	Export of Road diesel (1000 tonnes)
EXPOILGSL1	Export of Motor Gasoline (1000 tonnes)
EXPOILHFO1	Export of Fuel oil-low sulphur (< 1%)
EXPOILLUB1	Export of Lubricants (1000 tonnes)
EXPOILWAX1	Export of Paraffin Waxes (1000 tonnes)

Table 5. Electricity export and import technologies

EXPELC11	Russia - Export of Electricity - Fall Day
EXPELC12	Russia - Export of Electricity - Fall Night
EXPELC13	Russia - Export of Electricity - Fall Peak
EXPELC14	Russia - Export of Electricity - Spring Day
EXPELC15	Russia - Export of Electricity – Spring Night
EXPELC16	Russia - Export of Electricity - Spring Peak
EXPELC17	Russia - Export of Electricity - Summer Day
EXPELC18	Russia - Export of Electricity - Summer Night
EXPELC19	Russia - Export of Electricity - Summer Peak
EXPELC1A	Russia - Export of Electricity - Winter Day
EXPELC1B	Russia - Export of Electricity - Winter Night
EXPELC1C	Russia - Export of Electricity - Winter Peak
EXPELC21	Turkey - Export of Electricity - Fall Day
EXPELC22	Turkey - Export of Electricity - Fall Night
EXPELC23	Turkey - Export of Electricity - Fall Peak
EXPELC24	Turkey - Export of Electricity - Spring Day
EXPELC25	Turkey - Export of Electricity - SpringNight
EXPELC26	Turkey - Export of Electricity - Spring Peak
EXPELC27	Turkey - Export of Electricity - Summer Day
EXPELC28	Turkey - Export of Electricity - Summer Night
EXPELC29	Turkey - Export of Electricity - Summer Peak
EXPELC2A	Turkey - Export of Electricity - Winter Day
EXPELC2B	Turkey - Export of Electricity - Winter Night
EXPELC2C	Turkey - Export of Electricity - Winter Peak
EXPELC31	Azerbaijan - Export of Electricity - Fall Day

EXPELC32	Azerbaijan - Export of Electricity - Fall Night
EXPELC33	Azerbaijan - Export of Electricity - Fall Peak
EXPELC34	Azerbaijan - Export of Electricity - Spring Day
EXPELC35	Azerbaijan - Export of Electricity - SpringNight
EXPELC36	Azerbaijan - Export of Electricity - Spring Peak
EXPELC37	Azerbaijan - Export of Electricity - Summer Day
EXPELC38	Azerbaijan - Export of Electricity - Summer Night
EXPELC39	Azerbaijan - Export of Electricity - Summer Peak
EXPELC3A	Azerbaijan - Export of Electricity - Winter Day
EXPELC3B	Azerbaijan - Export of Electricity - Winter Night
EXPELC3C	Azerbaijan - Export of Electricity - Winter Peak
EXPELC41	Armenia - Export of Electricity - Fall Day
EXPELC42	Armenia - Export of Electricity - Fall Night
EXPELC43	Armenia - Export of Electricity - Fall Peak
EXPELC44	Armenia - Export of Electricity - Spring Day
EXPELC45	Armenia - Export of Electricity - SpringNight
EXPELC46	Armenia - Export of Electricity - Spring Peak
EXPELC47	Armenia - Export of Electricity - Summer Day
EXPELC48	Armenia - Export of Electricity - Summer Night
EXPELC49	Armenia - Export of Electricity - Summer Peak
EXPELC4A	Armenia - Export of Electricity - Winter Day
EXPELC4B	Armenia - Export of Electricity - Winter Night
EXPELC4C	Armenia - Export of Electricity - Winter Peak
IMPELC51	Russia - Import of Electricity - Fall Day
IMPELC52	Russia - Import of Electricity - Fall Night
IMPELC53	Russia - Import of Electricity - Fall Peak
IMPELC54	Russia - Import of Electricity - Spring Day
IMPELC55	Russia - Import of Electricity - Spring Night
IMPELC56	Russia - Import of Electricity - Spring Peak
IMPELC57	Russia - Import of Electricity - Summer Day
IMPELC58	Russia - Import of Electricity - Summer Night
IMPELC59	Russia - Import of Electricity - Summer Peak
IMPELC5A	Russia - Import of Electricity - Winter Day
IMPELC5B	Russia - Import of Electricity - Winter Night
IMPELC5C	Russia - Import of Electricity - Winter Peak
IMPELC61	Turkey - Import of Electricity - Fall Day
IMPELC62	Turkey - Import of Electricity - Fall Night
IMPELC63	Turkey - Import of Electricity - Fall Peak
IMPELC64	Turkey - Import of Electricity - Spring Day
IMPELC65	Turkey - Import of Electricity - Spring Night
IMPELC66	Turkey - Import of Electricity - Spring Peak
IMPELC67	Turkey - Import of Electricity - Summer Day
IMPELC68	Turkey - Import of Electricity - Summer Night
IMPELC69	Turkey - Import of Electricity - Summer Peak
IMPELC6A	Turkey - Import of Electricity - Winter Day
IMPELC6B	Turkey - Import of Electricity - Winter Night
IMPELC6C	Turkey - Import of Electricity - Winter Peak
IMPELC71	Azerbaijan - Import of Electricity - Fall Day
IMPELC72	Azerbaijan - Import of Electricity - Fall Night
IMPELC73	Azerbaijan - Import of Electricity - Fall Peak

IMPELC74	Azerbaijan - Import of Electricity - Spring Day
IMPELC75	Azerbaijan - Import of Electricity - Spring Night
IMPELC76	Azerbaijan - Import of Electricity - Spring Peak
IMPELC77	Azerbaijan - Import of Electricity - Summer Day
IMPELC78	Azerbaijan - Import of Electricity - Summer Night
IMPELC79	Azerbaijan - Import of Electricity - Summer Peak
IMPELC7A	Azerbaijan - Import of Electricity - Winter Day
IMPELC7B	Azerbaijan - Import of Electricity - Winter Night
IMPELC7C	Azerbaijan - Import of Electricity - Winter Peak
IMPELC81	Armenia - Import of Electricity - Fall Day
IMPELC82	Armenia - Import of Electricity - Fall Night
IMPELC83	Armenia - Import of Electricity - Fall Peak
IMPELC84	Armenia - Import of Electricity - Spring Day
IMPELC85	Armenia - Import of Electricity - Spring Night
IMPELC86	Armenia - Import of Electricity - Spring Peak
IMPELC87	Armenia - Import of Electricity - Summer Day
IMPELC88	Armenia - Import of Electricity - Summer Night
IMPELC89	Armenia - Import of Electricity - Summer Peak
IMPELC8A	Armenia - Import of Electricity - Winter Day
IMPELC8B	Armenia - Import of Electricity - Winter Night
IMPELC8C	Armenia - Import of Electricity - Winter Peak

Note that modeling export for commodities other than electricity doesn't make sense for Georgia, since they are not produced domestically. They are imported and then exported so don't really affect the energy system. Thus exports are modeled only in Base year to replicate BY energy Balance, but in future year's only NET imports are modeled (import-export). Although, if there is a need to model exports it can be easily achieved with current model setup, but the demand projections for export and/or the export prices and their projections will need to be entered.

3.2.2 The Electricity and Natural Gas Supply Sub-systems

Electricity Supply

The electricity supply sub-system consists of all technologies that transform fuels into electricity and deliver that energy carrier to the end use sectors. This includes electricity generating plants and the electricity transmission and distribution networks. In MARKAL-Georgia the electric sector consists of three parts:

- Production of electricity from electric-only power plants (MARKAL set ELE);
- The transmission and distribution networks, which are split into centralized electricity (ELCC) subject to transmission losses and perhaps costs, decentralized electricity (ELCD) subject to distribution losses and perhaps costs, and finally electricity (ELC) which feeds the various consumption sectors (<sect>ELC); and
- Electricity import and export.

The electricity generating plants are named as follows:

- First 3 letters describe the plant type (EPP for electric-only power plant);
- Following 3 letters describe the fuel type;
- Next 3 letters indicates name of plant.

For example EPPHYDEAV stands for the Enguri and Vardnili (EAV) Hydro (HYD) Electric only power plant (EPP).

As in the demand sectors, the power plants get their <fuel> from "dummy" supply processes, named XCON<fuel>, where CON stands for CONversion sector.

As already noted, Imports and exports of electricity are modeled from 4 sources and each is modelled for each time-slice to allow timing flexibility. So in total we have 48 technologies (4 sources x 12 time-slice). They are modeled as resources <IMP/EXP>ELCCxy, where x stands for source and y represents the time-slice.

These imports/exports produce/consume electricity ELCx (x representing the source), which are then gathered together by corresponding X<IMP/EXP>ELCx technologies to produce ELC or consume ELCD.

Electricity transmission and distribution are represented separately as interconnection (LNK) technologies (ELNKCEN<year> and ELNKDCN<year>), each with its efficiency. The transmission and distribution losses (efficiency) are calculated from the base year energy balance data. These losses may be changed over time by the analyst.

A simplified representation of the MARKAL-Georgia electricity supply and upstream RES is shown in Figure 11.

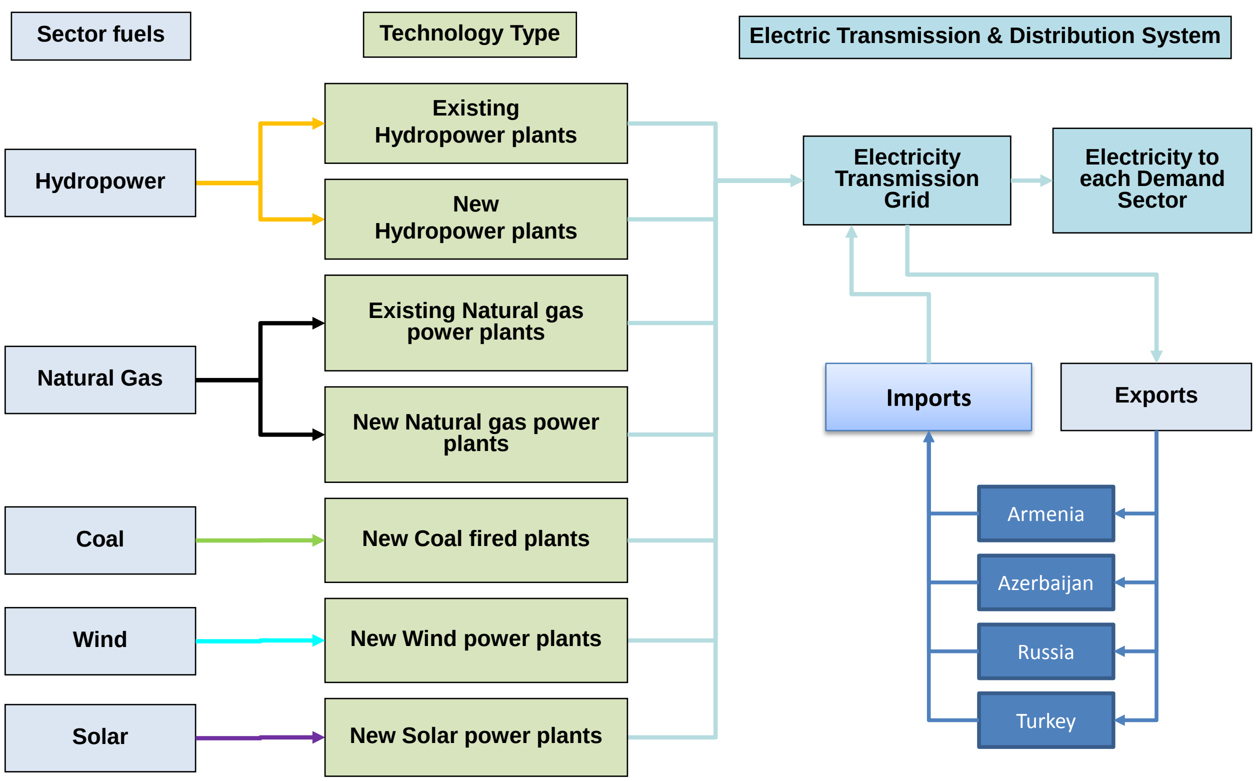


Figure 11. MARKAL-Georgia Electricity Supply RES (Simplified)

Natural Gas Supply

The natural gas supply sub-system consists of all technologies that produce and deliver natural gas to customers, including transmission and distribution pipelines, as well as processing and storage facilities.

MARKAL-Georgia models two types of natural gas, social gas and commercial gas. Social gas is cheaper gas that can be delivered only to households and the power sector. The amount of social gas is limited and varies over time. Commercial gas is available with commercial price. Currently it is modeled as unlimited in MARKAL-Georgia, but can be limited to represent the overall pipeline capacity. Commercial gas is delivered to all sectors including the residential and power sector so that these sectors can also use it if social gas is not enough. To model the two types of gas there are two import processes modeled and one mining process, which produces commercial gas. Each type of gas is than transmitted by separate pipeline processes PNGAPIPE01 for social gas and PNGAPIPE02 for commercial gas. PNGAPIPE09 process represents the future option to permit expanding of the commercial pipeline capacity if necessary. Existing distribution networks are represented at the sectorial level by the X<sector>GAS00 processes, although all losses (both transmission and distribution losses are accounted in the pipeline processes.

A simplified representation of the MARKAL-Georgia natural gas supply and upstream RES is shown Figure 12.

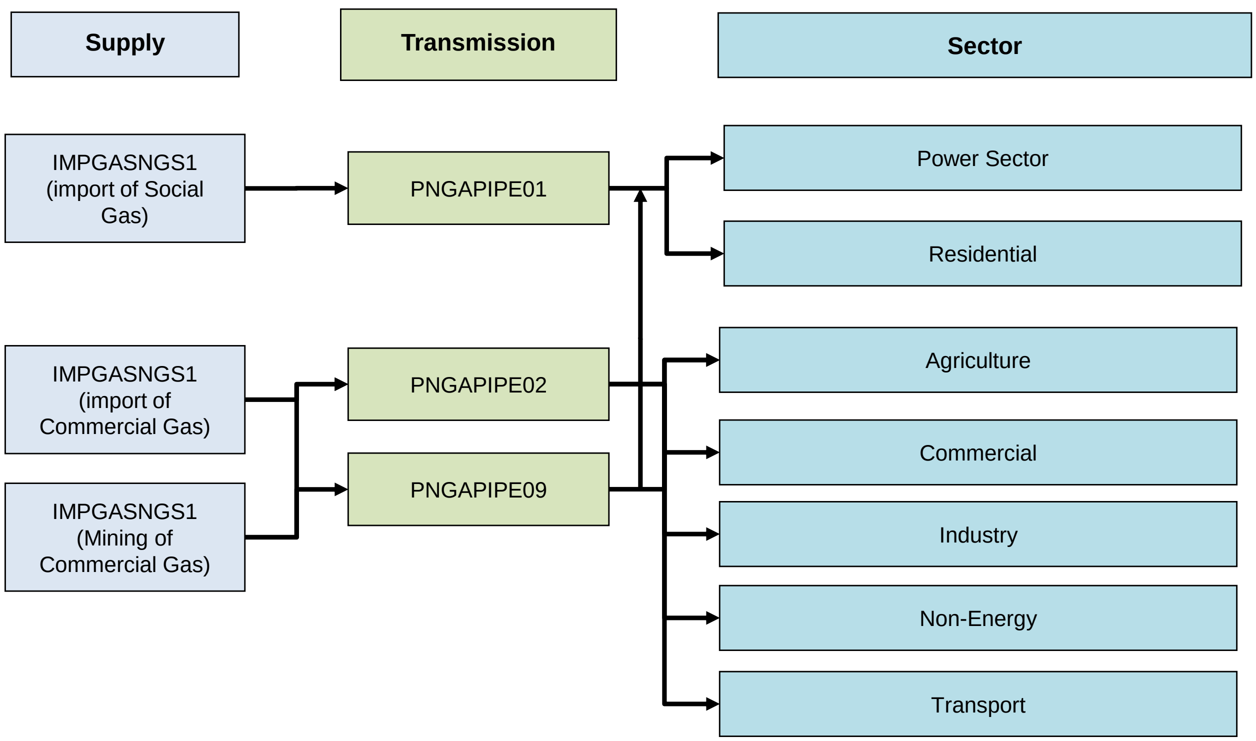


Figure 12. MARKAL-Georgia Natural Gas Supply RES (Simplified)

3.3 Emission Accounting

Current version of MARKAL-Georgia accounts for CO_2, CH_4 and N_2O emissions in energy sector, which includes emissions from fuel combustion and fugitive emissions. CO2 emissions are tracked both at sector level as well as at technology level. The methane and N_2O emissions from incomplete combustion are tracked only at sectoral level. Different types of emissions then are aggregated into aggregate emissions (for example all sub-sectoral CO_2 emissions are aggregated into energy sector CO_2 emissions, etc.). Similarly to energy carriers, different names of emissions are used to indicate the emission at different level of RES or at different level of aggregation.

Table 6 lists the emission names used in MARKAL-Georgia:

Table 6. Emission commodities in MARKAL-Georgia

MARKAL name	Description
Energy Sector fugitive Methane (CH4) Emissions	
MTHMC	Methane emissions from Coal Mining
MTHMO	Methane emissions from Oil Production
MTHMN	Methane emissions from Natural gas Production
MTHPT	Methane emissions from Natural gas Pipelines
Agriculture Sector Emissions from fuel combustion	
COA	Agriculture Carbon Dioxide
MTHICA	Methane emissions from Incomplete Combustion in agriculture
N2OICA	N2O emissions from Incomplete Combustion in agriculture
CO2-A	CO2 at technology level in Agriculture
Commercial Sector Emissions from fuel combustion	
COC	Commercial Carbon Dioxide
MTHICC	Methane emissions from Incomplete Combustion in commercial
N2OICC	N2O emissions from Incomplete Combustion in commercial
CO2-C	CO2 at technology level in Commercial
Industry Sector Emissions from fuel combustion	
COI	Industry Carbon Dioxide
MTHICI	Methane emissions from Incomplete Combustion in Industry
N2OICI	N2O emissions from Incomplete Combustion in Industry
CO2-I	CO2 at technology level in Industry
Power Sector Emissions from fuel combustion	
COP	Power Sector Carbon Dioxide
MTHICP	Methane emissions from Incomplete Combustion in Power sector
N2OICP	N2O emissions from Incomplete Combustion in Power sector
CO2-P	CO2 at technology level in Power sector
Residential Sector Emissions from fuel combustion	
COR	Residential Carbon Dioxide
MTHICR	Methane emissions from Incomplete Combustion in Residential
N2OICR	N2O emissions from Incomplete Combustion in Residential
CO2-R	CO2 at technology level in residential
Transport Sector Emissions from fuel combustion	
COT	Carbon Dioxide Transport
COB	Bunker fuel Carbon Dioxide
MTHICT	Methane emissions from Incomplete Combustion in Transport
N2OICT	N2O emissions from Incomplete Combustion in Transport
CO2-T	CO2 at technology level in Transport
Non-energy carbon emissions from stored products	
CON	Carbon Dioxide from stored products
Aggregated Emissions	
GHGTOT*	Total GHG Emissions in CO2 Equivalent
GHGNRG	Total Energy Sector GHG Emissions

CO2*	Total CO2 Emissions
CO2NRG	Total Energy Sector CO2 Emissions
MTH*	Total Methane Emissions
MTHNRG	Total Energy Sector Methane Emissions
N2O*	Total N2O Emissions
N2ONRG	Total Energy Sector N2O Emissions
MTHCEQ*	CO2 eq Methane Emissions
MTHENCEQ	CO2 eq Methane Emissions -Energy use
N2OCEQ*	CO2 eq N2O Emissions
N2OENCEQ	CO2 eq N2O Emissions - Energy use
MTHIC	Methane emissions from Incomplete Combustion
N2OIC	N2O emissions from Incomplete Combustion

Please note that some aggregated emissions (denoted with *) are not currently used in MARKAL Georgia, since for given setup they are equal to their energy sector counterparts. They will be used when MARKAL-Georgia is extended to cover non-energy sector emissions to represent the sum of emissions from all sectors.

The main emission commodities used for emission accounting from fuel combustion in MARKAL-Georgia are CO<sect>, MTHIC<sect> and N2OIC<sect> emissions where <sect> stands for sector (I=Industry, R=Residential, P=Power, C=Commercial, A=Agriculture, T=Transport, B=Bunker). Bunker emissions account for emissions from fuel used for international air and ship transport that are not counted in the countries national GHG account, but calculated in the model These emissions are produced by corresponding X<sect><fuel> processes, using the activity of the process (i.e. the use of that particular fuel in that particular sector) and corresponding emission factor. Figure 13 shows the emissions as output of X-processes for Agriculture as an example.

Please note that in case of double X-processes as in case shown in Figure 10, emissions are accounted at individual X-processes (left hand side) and not at "combination" X-process, because of the use of emission factor which depends on particular fuel consumed.

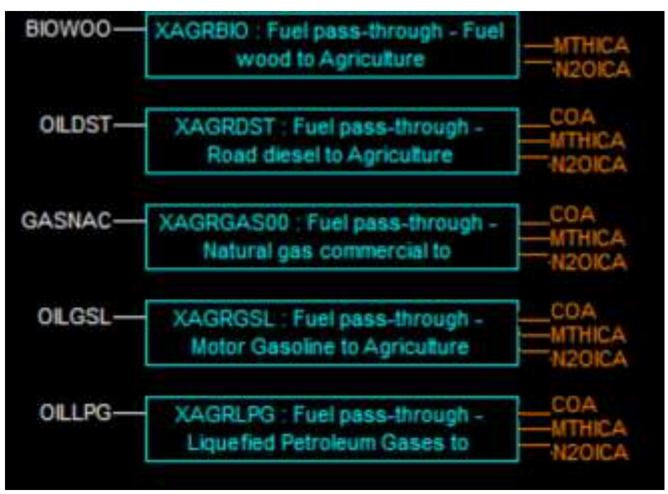


Figure 13. Screen shot from RES showing Emissions from fuel combustion in Agriculture

The fugitive emissions from mining are produced by the corresponding mining technologies and fugitive emissions from natural gas losses are produced by the gas pipelines.

4 MARKAL-Georgia Templates and data

This section describes the data needed to populate the model, and documents the data sources used and assumptions made in MARKAL-Georgia. ANSWER "Smart" Excel spreadsheet templates are the basic mechanisms used for the data collecting and organizing all parts of the model. These templates are then uploaded into the associated database. Table 7 lists templates necessary to run MARKAL-Georgia BAU scenario. All MARKAL-Georgia template names start with "LEDS-Georgia".

Table 7. MARKAL-Georgia Templates

MARKAL-Georgia template	Data Contained
Supply	Base-year Energy Balance, resource supply technologies, and fuel prices. All conversion factors and emission factors are also here.
BY-AGR/COM/IND/RSD/TRN/ TED+NON	Base-year demand sectors, by sector (TED and NON combined in one template) – six workbooks total
BY-PP	Existing power generation plants
NEWTCH-PP	New power generation plants
NEWTCH-DMD NEWTCH-TRN	New Demand technologies. Transport new demand technologies are in separate template
Demand_ Projections-REF Demand_ Projections-TRN	Demand projection parameters. Transport demand projections are in separate template
UC10	BAU user constraints on fuel and technology groups limiting to 10% fuel switch and 10% advanced technology penetration for each end-use.
UC_GAS	User constraints setting limits on gasification
UC- ThermalPP	User Constraint ensuring that 20% (for BAU case) of energy consumed in the country is generated from thermal plants.
BAU-AGG_ Emissions	Defining aggregate emission commodities
BAU-BOUNDLO	Setting lower bounds on base year technologies to make sure they don't retire before the end of their lifetime
BAU- Global	Setting time-slice durations
BAU- POT_LIM	Setting the potential limits on renewable resources

In addition there are Excel files which include data that is used in the templates. Names of all of these start with "DataSource". Currently there are three data files.

Table 8. MARKAL-Georgia DataSource files

File Name	Data Contained
Georgia_LoadCalibration	Includes daily load of Georgian power sector in 2014 and calibration of Time Slices and end-use demand splits by Time Slice.
NewPPs	Includes lists of New power plants of different types and their characteristics used to populate NEWTCH-PP template
Survey_Calculations	Includes information from EC-LEDS residential survey use for calibration of residential sector

Each MARKAL-Georgia template is organized similarly in terms of the basic types of sheets found in each, as tabulated below, with indications of applicable workbooks in [brackets]. The MARKAL input sheets are un-colored, whereas the data input sheets are colored in pink.

Table 9. Common Worksheet Types in Templates

Worksheet Name	Description
Energy_ Balance or Energy Supply Data	National or Sector Energy Balance [for base year SUP, sector, and PP workbooks]
Commodities	The list of all commodities (demands, energy carriers, and emissions) with their descriptions, units and set membership that appear any place in the workbook.
Technologies	The list of all technologies with their descriptions, capacity and activity units and set membership, that appear anyplace in the workbook.
Constraints	List of all user-defined constraints appearing in the workbook.
Demand_ Data	The calculated useful energy demands, and the time of use profile where appropriate. [Sector and demand projection workbooks]
Calibration_<end-use>	Calculation sheets for determining end use technology stocks. [Sector and PP workbooks]
Technology Data_<sub-sector>	Load sheets that organize model data to be read by ANSWER.
FuelPRC	The 'DUMmy' technologies passing the upstream energy carriers to each sector. [SUP, PP, and Sector workbooks]
DM_DUM	The 'DUMmy' technologies used to avoid infeasibilities in the model. [SUP, PP, and Sector workbooks]

Constraint_ Data	Load sheets and data for each user-defined constraint appearing in the workbook. [SUP, UC, and POT_LIM workbooks]
Other	Other data entry and calculation sheets as needed

Sector templates are organized and formatted to facilitate calibration of the first year of the model in the workbook, as well as for easy and automatic data importing into the MARKAL data handling system (ANSWER).

The templates are linked with each other. When one template is changed it is important to make sure that all linked templates get updated. The table below describes the dependencies of each template. These dependencies are saved in the LEDS_Georgia_Dependency Table, and ANSWER checks against this file whether all dependencies have been updated when a changed template is imported.

Table 10. Template Dependencies in MARKAL-Georgia

Dependent Template Name	Linked Data Source Templates
DataSource_DataSource_LoadCalibration	LEDS_Georgia_BY-COM.xls
	LEDS_Georgia_BY-RSD.xls
	LEDS_Georgia_Supply
DataSource_NewPPs	DataSource_DataSource_LoadCalibration
DataSource_Survey_Calculations	none
LEDS_Georgia_Supply	none
BAU-Globals	DataSource_DataSource_LoadCalibration
LEDS_Georgia_BY-AGR.xls	LEDS_Georgia_Supply
	DataSource_LoadCalibration
LEDS_Georgia_BY-COM.xls	LEDS_Georgia_Supply
	DataSource_LoadCalibration
LEDS_Georgia_BY-IND.xls	LEDS_Georgia_Supply
	DataSource_LoadCalibration
LEDS_Georgia_BY-RSD.xls	LEDS_Georgia_Supply
	LEDS_Georgia_DataSource_LoadCalibration
	DataSource_Survey_Calculations
LEDS_Georgia_BY-TED+NON.xls	LEDS_Georgia_Supply
	DataSource_LoadCalibration
LEDS_Georgia_BY-TRN.xls	LEDS_Georgia_Supply
	LEDS_Georgia_DataSource_LoadCalibration
LEDS_Georgia_BY-PP.xls	LEDS_Georgia_Supply
	LEDS_Georgia_DataSource_LoadCalibration
LEDS_ Georgia_ BAU-BOUNDLO	LEDS_Georgia_BY-AGR.xls
	LEDS_Georgia_BY-COM.xls
	LEDS_Georgia_BY-IND.xls
	LEDS_Georgia_BY-RSD.xls
	LEDS_Georgia_BY-TED+NON.xls

	LEDS_Georgia_BY-TRN.xls
LEDS_ Georgia_ NEWTCH-DMD	LEDS_Georgia_BY-AGR.xls
	LEDS_Georgia_BY-COM.xls
	LEDS_Georgia_BY-IND.xls
	LEDS_Georgia_BY-RSD.xls
	LEDS_Georgia_BY-TED+NON.xls
LEDS_Georgia_UC10	LEDS_Georgia_Demand_Projections-REF
	LEDS_Georgia_BY-AGR.xls
	LEDS_Georgia_BY-COM.xls
	LEDS_Georgia_BY-IND.xls
	LEDS_Georgia_BY-RSD.xls
LEDS_Georgia_UC_GAS	LEDS_Georgia_BY-AGR.xls
	LEDS_Georgia_BY-COM.xls
	LEDS_Georgia_BY-IND.xls
	LEDS_Georgia_BY-RSD.xls
LEDS_Georgia_UC-ThermalPP	none
LEDS_Georgia_NEWTCH-TRN	LEDS_Georgia_TRN_Demand_Projections
	LEDS_Georgia_BY-TRN.xls
LEDS_Georgia_Demand_Projections-REF	LEDS_Georgia_BY-AGR.xls
	LEDS_Georgia_BY-COM.xls
	LEDS_Georgia_BY-IND.xls
	LEDS_Georgia_BY-RSD.xls
	LEDS_Georgia_BY-TED+NON.xls
LEDS_Georgia_Demand_Projections-TRN	LEDS_Georgia_Demand_Projections-REF
	LEDS_Georgia_BY-TRN.xls
LEDS_Georgia_NEWTCH-DMD	LEDS_Georgia_BY-AGR.xls
	LEDS_Georgia_BY-COM.xls
	LEDS_Georgia_BY-IND.xls
	LEDS_Georgia_BY-RSD.xls
	LEDS_Georgia_BY-TED+NON.xls
LEDS_Georgia_NEWTCH-PP	LEDS_Georgia_PP_Data
	DataSource_NewPPs
	LEDS_Georgia_Supply
LEDS_Georgia_BAU-AGG_Emissions	none

A more detailed description of each of the templates, providing key information from the templates is given below. Since the information contained in MARKAL-Georgia is very extensive, not everything can be carried over to these guidelines. So only key information and assumptions are provided here, together with guidance on other information in the MARKAL-Georgia templates, which can be viewed in the templates themselves.

4.1 Supply Template

Supply Template *LEDS_Georgia_Supply* is a main MARKAL-Georgia template and includes the following information:

- Base year Energy Balance
- Modification of Supply data for future model years
- Fuel prices
- Other information that is common to all templates like fuel conversion factors and emission factors.

Each are described in detail bellow.

4.1.1 Base-year Energy Balance

The base-year Energy Balance, along with base-year cost data, forms the starting point for model development. The Energy Balance provides a comprehensive picture of the supply of all energy carriers (fuels and electricity) and the sectors where they are consumed. All entries have units of Petajoules (PJ). This energy balance is used to calculate base-year import, domestic production, and export limits, and base-year gas and electricity transmission and distribution capacity and losses. These base-year limits and levels are used to calibrate model for base year. Other sheets in the workbook, described below, provide the option to modify these values in future years.

Figure 14 shows the base year energy balance as used in MARKAL-Georgia for RES setup and base year calibration. The sheet "Energy Supply Data" is the first sheet in the Supply workbook, .where the columns of the *Energy Supply Data* sheet identify all of the supply-side energy carriers to be tracked in the model, with the rows then providing for each sector the production and consumption of each fuel. Each sector BY workbook has a link to the relevant rows of the Energy Balance in its associated worksheet. The source of 2014 energy balance in MARKAL-Georgia is Geostat's 2014 energy balance[5].

[5] With modification of gas consumption for energy and non-energy purposes in chemical industry based on information from Rustavi Azoti industrial plant.

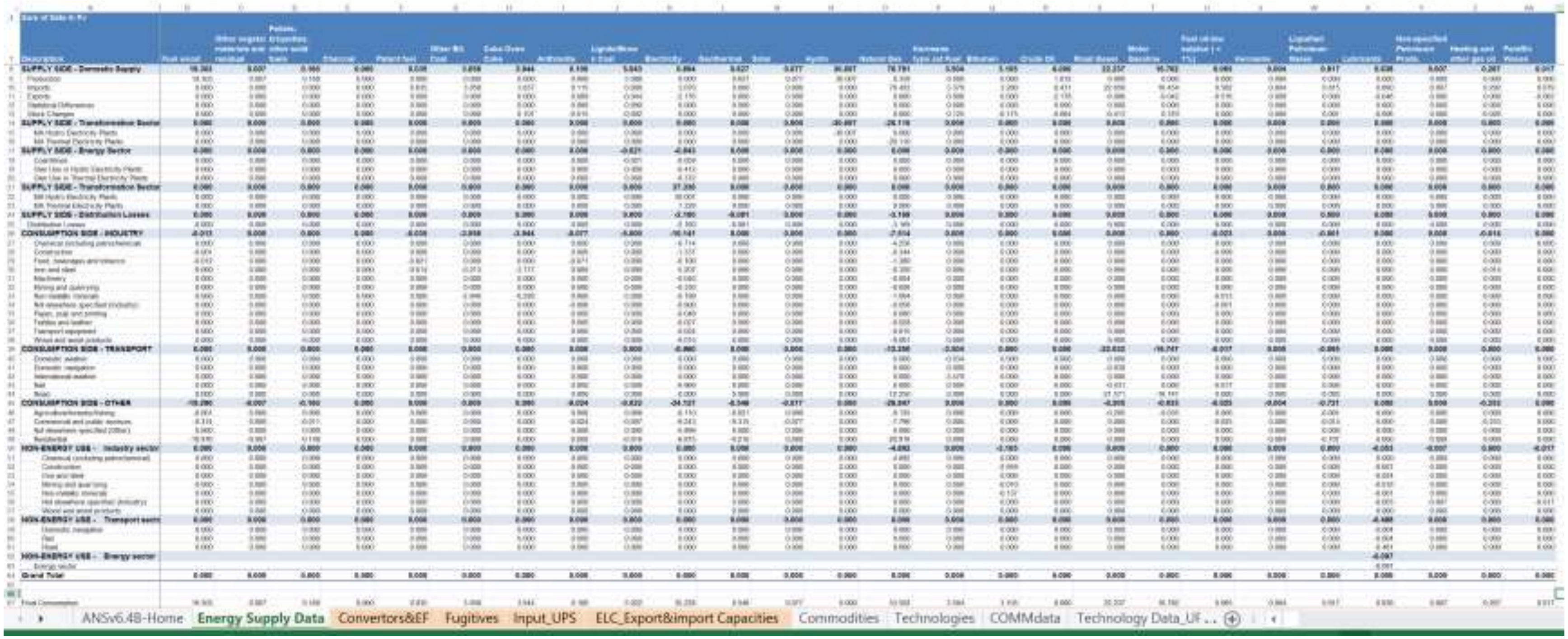


Figure 14. MARKAL-Georgia Base Year Energy Balance

4.1.2 Modification of Supply Data for Future Model Years

Several sheets in Supply workbook permit the user to review the data calculated for the base year from the energy balance and modify the default projections for the following parameters:

- Future import and production limits – data is directly entered in MARKAL smart sheet "Technology Data_SUP" for production and import levels for biomass and fossil fuels. For electricity it links to the ELC_Export&import Capacities and for gas to sheet "Import prices";
- Electricity import and export limits – capacity limits are given on data sheet "ELC_Export&import Capacities", contractual limits are entered in the sheet "Constraint Data".
- Present and future T&D losses, as well as distribution grid capacity and expansion costs (if available) – are entered into data sheet "Input_UPS" and MARKAL smart sheet "Technology Data_UPS" takes values from there.

"Data" specified for future years is always an assumption. In some cases, these may be based on national plans (e.g., to expand or contract mining operations, to improve transmission and distribution losses), in others they may be based on extrapolation of past trends. Table 11 documents the data sources and/or assumptions made for the MARKAL-Georgia supply sector.

Table 11. Summary of Data Sources for Supply Limits

Data Type	Data Source/Assumptions
Future import and production limits	Fossil fuel import limits: The upper limit on social gas is imposed based on availability of social gas post 2014. (Up to 1400 mcm before 2020, then 1600 mcm before 2026 and 1200 mcm afterwards). Commercial gas and other fossil fuels can be imported in unlimited quantities. Production limits: Bound on Biomass and gas production is 5% above 2014 level, there is no limit on coal production and no increase in crude oil production.
Electricity import and export limits	Capacity limits: Export/Import Capacity limits are based on extension plans for expansion of Georgia's electricity transmission system. Source: Ministry of Energy, Analytic Department Contractual Limits: No contractual limits post 2014.
Electricity and gas T&D losses	Electricity and gas T&D losses are based on 2014 EB. For following years the losses are maintained at 2014 levels.
Electricity, gas distribution extensions	The possibility of extending electricity distribution network is not modeled. It is assumed that distribution network is enough to meet any future demand. Gas pipeline extension is not modeled either. Extension of the gas distribution network is modeled through user constraints discussed in Chapter 4.3.1.

4.1.3 Fuel Prices

The four Fuel Prices sheets in the Supply template develop the sector fuel markups and fuel price projection for future model years from country-specific base year values. The parameters that need to be specified relate to the following aspects of the energy system.

1. **Domestic and imported fuel prices (Eur/GJ)**: current and projected prices of locally produced (except electricity), and imported energy carriers. These are input in the template on the sheet "Import_Prices". MARKAL smart sheet "TechData_FuelPrices" then reads these projections as input for the model.

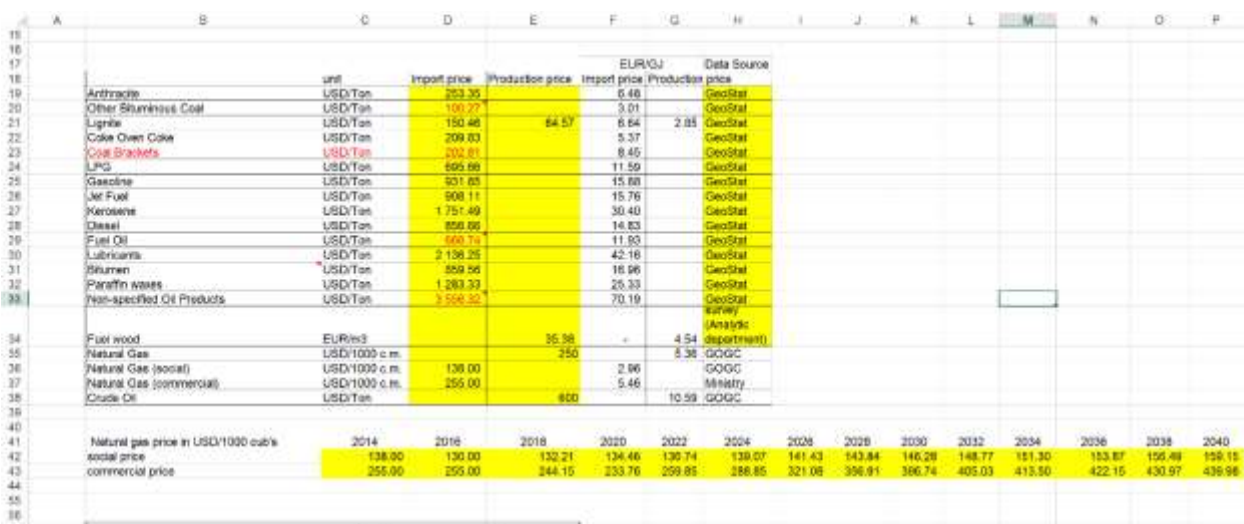
2. **Sector fuel Prices (Eur/GJ)**: the actual/current prices paid by the different sectors for different energy carriers are input in the sheet "Delivery_costs". The difference between the imported and sector fuel prices are used to compute sector price markups for different sectors.

Table 12 documents the data sources and/or assumptions for fuel prices made for MARKAL-Georgia.

Table 12. Summary of Data Sources for Fuel Prices

Data Type	Data Source/Assumptions
Domestic and imported fuel prices & projections	Geostat information for 2014 prices and IEA WEO "current prices scenario" for price projections (Europe), Social gas price projection – Ministry of Energy
Electricity export/import prices & projections	Ministry of Energy
Sector fuel prices	Geostat, GNERC, oil companies, publications. Sectoral BY templates link to this sheet to define sectoral markups for each commodity.

Figure 15 is a screenshot from the Import_prices tab of the Supply template showing the fuel prices used in MARKAL-Georgia. Figure 16 is another screenshot from the same tab showing the price growth coefficients used for the different resources, and the Figure 17 screenshot shows the sector fuel process from the Delivery_costs tab.



	unit	Import price	Production price	EUR/GJ Import price	EUR/GJ Production	Data Source price
Anthracite	USD/Ton	253.35		6.48		GeoStat
Other Bituminous Coal	USD/Ton	100.27		3.01		GeoStat
Lignite	USD/Ton	150.46	84.57	6.64	2.85	GeoStat
Coke Oven Coke	USD/Ton	209.83		5.37		GeoStat
Coal Brackets	USD/Ton	202.81		8.45		GeoStat
LPG	USD/Ton	695.66		11.59		GeoStat
Gasoline	USD/Ton	931.65		15.88		GeoStat
Jet Fuel	USD/Ton	908.11		15.76		GeoStat
Kerosene	USD/Ton	1 751.49		30.40		GeoStat
Diesel	USD/Ton	856.66		14.83		GeoStat
Fuel Oil	USD/Ton	660.74		11.93		GeoStat
Lubricants	USD/Ton	2 138.25		42.16		GeoStat
Bitumen	USD/Ton	859.56		16.96		GeoStat
Paraffin waxes	USD/Ton	1 283.33		25.33		GeoStat
Non-specified Oil Products	USD/Ton	3 556.32		70.19		GeoStat
Fuel wood	EUR/m3		35.38	-	4.54	survey (Analytic department)
Natural Gas	USD/1000 c.m.		250		5.38	GOGC
Natural Gas (social)	USD/1000 c.m.	138.00		2.96		GOGC
Natural Gas (commercial)	USD/1000 c.m.	255.00		5.46		Ministry
Crude Oil	USD/Ton		600		10.59	GOGC

Natural gas price in USD/1000 cub's	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
social price	138.00	130.00	132.21	134.46	136.74	139.07	141.43	143.84	146.28	148.77	151.30	153.87	156.49	159.15
commercial price	255.00	255.00	244.15	233.76	259.85	288.85	321.08	356.91	386.74	405.03	413.50	422.15	430.97	439.98

Figure 15. Fuel prices input template

		outlook 2014	2020	2030	2040	6	10	10	1 year growth 2020	2030	2040
oil	($/boe)	97	83	130	150	-14.4%	56.6%	15.4%	-2.4%	5.7%	1.5%
gas	($/MBTU)	9.3	8.1	12.5	13.8	-12.9%	54.3%	10.4%	-2.2%	5.4%	1.0%
coal	($/ton)	78	99	115	123	26.9%	16.2%	7.0%	4.5%	1.6%	0.7%

		2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
oil	(EUR/GJ)	1.00	0.95	0.91	0.86	0.96	1.08	1.20	1.34	1.50	1.55	1.59	1.64	1.69	1.75
gas	($/1000 c.m)	1.00	1.00	0.96	0.92	1.02	1.13	1.26	1.40	1.56	1.59	1.62	1.66	1.69	1.73
coal	(EUR/GJ)	1.00	1.09	1.19	1.30	1.37	1.43	1.50	1.58	1.66	1.69	1.73	1.76	1.80	1.84

Figure 16. Fuel price growth coefficients

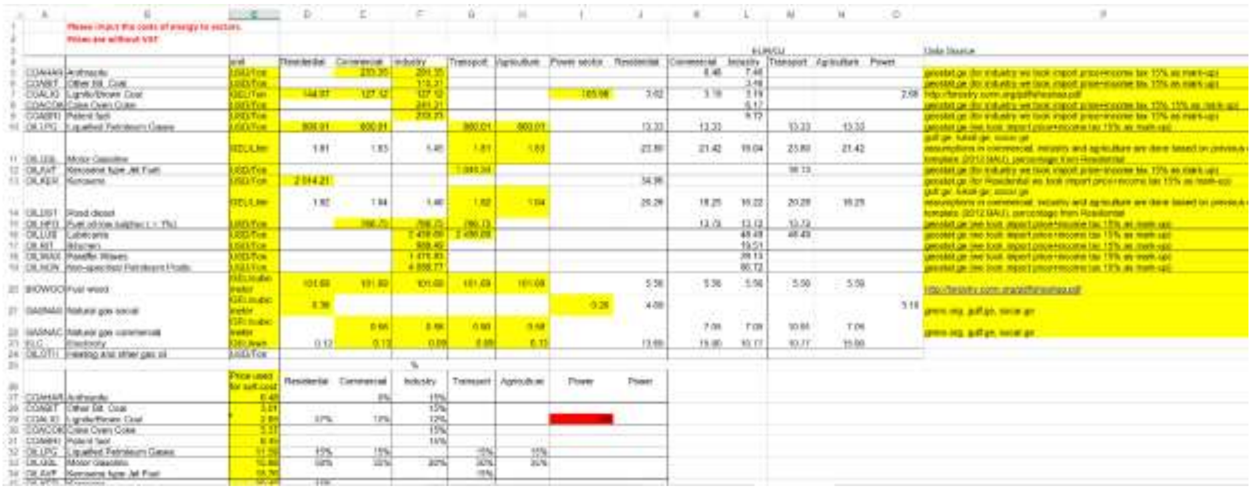


Figure 17. Sector Fuel prices

4.1.4 Other information in supply template

Other information located in the supply template include unit conversions factors and emission factors used throughout MARKAL-Georgia templates. All templates that need these values link to this workbook. All conversion units and fuel combustion emission factors are entered in the sheet "Convertors&EF", whereas fugitive emissions and intensities are given in the sheet "fugitives"

Table 13 documents the data sources and/or assumptions made for MARKAL-Georgia and show Key information from corresponding sheets. Figure 18 and Figure 19 are screenshots showing the conversion factors and fugitive emission factors used in MARKAL-Georgia.

Table 13. Summary of Data Sources for other information in Supply template

Data Type	Data Source/Assumptions
Conversion factors	Geostat (values used for EB). Note that Conversion factors are given for the user only for necessary conversions in templates. MARKAL-Georgia actually reads values in PJ.
Emission factors for fuel combustion	1996 revised IPPC guidelines
Emission factors for fugitive emissions	2014 fugitive emissions are taken from inventory software used for national inventory compilation. These fugitive emissions are used to define fugitive emission intensity factors.

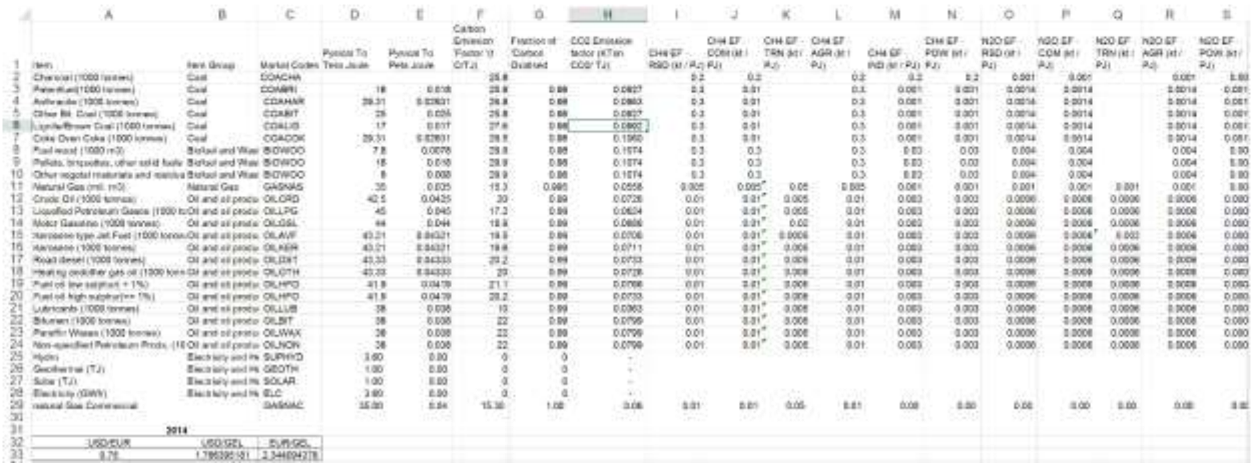


Figure 18. Conversion factors and emission factors used in MARKAL-Georgia

	Activity (PJ)	Emissions (Kt Ch4)	Emission intensity	source
CH4 from coal mining	5.09	4.00	0.79	Calulations from IPCC software
CH4 from oil mining	1.81	0.00	0.00	Calulations from IPCC software
CH4 from gas mining	0.36	0.08	0.23	Calulations from IPCC software
CH4 from gas T&D	76.42	58.38	0.76	Calulations from IPCC software

Figure 19. Fugitive Emissions and Emission intensity factors

4.2 Base-year Calibration of model

The sectors defined in MARKAl-Georgia are agricultural, commercial, industrial, residential, transportation, TED and non-energy. As noted earlier, each sector has its own set of sheets organized in similar fashion, and kept in a separate BY template (named LEDS_Georgia_BY-<sect>, where <sect> is the three character sector identifier). Each sector begins with the sector's base-year fuel consumption data from the energy balance, extracted by automatic link from the Supply template. Depending on the sector, a series of splits are then applied to these consumption values, as follows:

1. Split each fuel's consumption into various end uses (COM+IND+RSD)
2. Split end use consumption into building types (cooling, heating, and hot water for RSD)
3. Split final consumption among devices using the same fuel (e.g., window vs central AC)

The resulting apportioned consumption values are used to calculate base year useful energy service demand, using default efficiencies for existing equipment (revised where local information is available).

The simplified versions of main formulas used by MARKAL are the following:

$$FEC_i = \sum_{t=1}^{n_i} FEC_t, \quad (1)$$

$$FEC_t = UE_t / EFF_t, \quad (2)$$

$$UE_t = CAP_t * CF_t. \quad (3)$$

For each fuel *i*, from the Energy balance, the total final energy consumption (FEC_t), equals to the sum of FECs of each technology that consumes this fuel (FEC_{ti}). For technologies themselves the FEC_t equals to the useful energy UE_t divided by the efficiency of technology, EFF_t. The useful energy is obtained by multiplying the capacity of the technology CAP_t with its capacity factor CF_t.

4.2.1 Residential

As discussed above, the energy consumption in the residential sector is attributed to the following end-uses:

- space heating (H);
- water heating (W);
- space cooling (C);
- cooking (FOD);
- lighting (LIT),
- refrigeration and freezing (REF);
- clothes washing (WSH);
- clothes drying (DRY);
- dish washing (DSH)
- consumption of other electricity in households (OTH)

Space heating (H), water heating (W) and space cooling (C) is handled separately for the following types of residential buildings: *Apartments, Single House Urban Central, Single House Urban Local* and *Single House Rural Local*.

MARKAL-Georgia is a technology-based model and thus needs information on the technologies that are existing in the Base Year and satisfy different types of demand. For each technology the following data is needed:

1. **Base-year efficiency** (%): for each of the existing devices, the conversion efficiency to meet the end-use demands should be entered;
2. **Capacity factor:** number of months that technology operates divided by number of month in a year (12).
3. **Other technology parameters:** such as running costs and remaining lifetime of existing demand devices.
4. **Installed capacity:** The installed capacity of technology (PJ/a)

These parameters should be calibrated in such way that the final energy consumption of all devices and all end-uses sum up to the Final Energy Consumption given in Residential sector in Energy Balance for each fuel.

Data for populating the residential (or other demand sector) template is best gathered through extensive surveys, and in 2014 two projects, EC-LEDS and G4G carried out residential surveys which are the basis for information entered for the residential sector in MARKAL Georgia. Most of the information comes from EC-LEDS residential survey and this information is presented in a separate data file called. DataSource_Survey_Calculations. The Main MARKAL residential template is LEDS_Georgia_BY-RSD, which links to DataSource_Survey_Calculations to obtain necessary data. It also links to Supply template to obtain base year energy consumption values in residential sector as well as conversion and emission factors.

Calculations of fuel consumption for different end uses by different technologies based on survey data is performed in Calibration-<service> sheets. There are separate sheets for heating, cooling, hot water, cooking, lighting and other electricity used. In the sheets themselves there is some data that comes from the surveys and some that are based on expert estimations. Each is colored in different ways to identify the source. Pink are survey data and blue are expert estimations. Everything else are formulas used to calculate energy consumption.

Figure 20 shows screen shot from the Calibration_Heating sheet. The upper rows show the number of households in different types of categories and penetration of heating as well as of different fuels within each category. Middle rows show the areas that are heated within each category and average heating periods. The last rows show technological split for apartments and fuel consumption, end-use demand and capacity calculations for each technology. Formulas 1-3 are used for these calculations. Similar calculations follow this one (not shown on the Figure) for the other three types of dwellings.

type of dwelling	No of households in Georgia (thousand)	share of households without heating (%)	Number of households with heating (thousand)	share of households with heating on gas	Number of households with gas heating (thousand)	share of households with heating on wood	Number of households with wood heating (thousand)	share of households with heating on electricity	Number of households with electric heating (thousand)	households with heating on coal	households with coal heating (thousand)	share of households with heating on LPG	households with LPG heating (thousand)
Apartments	379.2	4.1	363.5	71.98	261.7	13.90	50.5	14.12	51.3	0.00	0.0	0.00	0.0
Single House - central heating system	34.5	0.9	32.7	59.74	19.6	41.86	14.1	0.80	0.6	0.00	0.0	0.00	0.0
Single House - Urban - Local	147.8	1.9	144.8	46.67	67.6	52.22	75.6	1.11	1.6	0.10	0.2	0.00	0.0
Single House - Rural - Local	394.2	0.8	391.9	2.73	10.7	96.29	377.4	0.39	1.5	0.00	0.0	0.38	1.5
Total	955.1	8.8	955.1		359.6		517.6		54.5		0.2		1.5

type of dwelling	average sq.m	% of dwelling heated	Average hours heating system is on (hours per day)	Average duration when the heating is on (months per year)
Apartments	70.1	57.2	8.7	5.8
Single House - central heating system	112.1	58.5	11.3	6.6
Single House - Urban - Local	106.3	34.3	10.0	6.1
Single House - Rural - Local	124.6	26.4	11.3	6.8

capacity (MW /sq.m) 0.0001
GWh to PJ 0.0036
TJ/thousand cubm 7.80

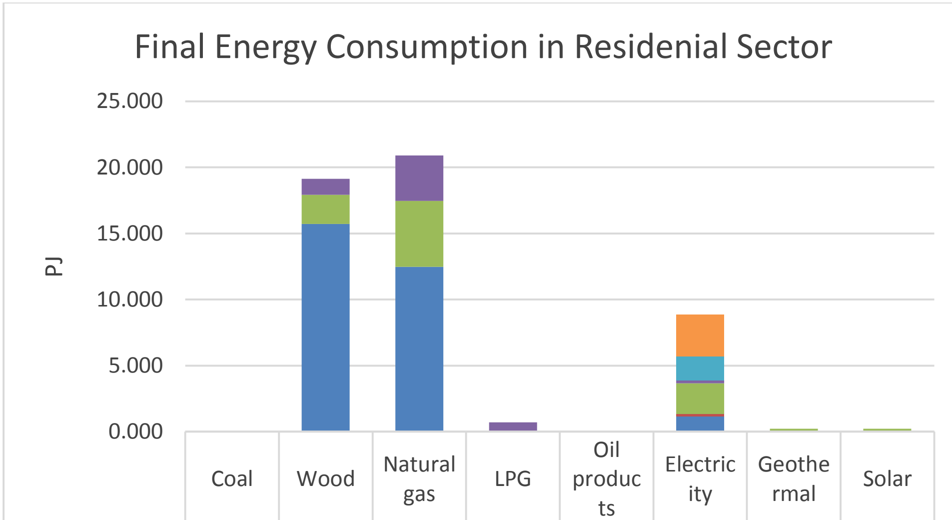
RHAE Residential Heating Apartments All Existing

Technology		FUEL	share (%)	number od households (thousand)	average area heated (sq.m)	useful energy capacity (MW /sq.m)	Efficiency	average operation hours	average operation months	consumption (PJ/ thousand household)	fuel consumption (PJ)	Model CF	useful energy demand (RHAE)	Installed capacity
RHAEGAS300	Rad.Space Heat.Apt.All.GAS.06 Furnace	RSDGAS	22.15	57.96	70.1	0.00010	0.8500	11.3333	5.83	0.06	3.35	0.47	2.85	6.07
RHAEGAS200	Rad.Space Heat.Apt.All.GAS.06 Stove<I	RSDGAS	77.85	203.70	40.1	0.00010	0.8	8.6537	5.83	0.03	5.48	0.47	4.37	9.32
RHAEBIO200	Rad.Space Heat.Apt.All.BIO.50 Stove<H	RSDBIO	100.00	50.51			0.51		5.83	0.0286553	1.45	0.47	0.74	1.57
RHAEELC200	Rad.Space Heat.Apt.All.ELC.00.Stove<F	RSDELC	85.37	43.83	40.1	0.00010	0.95	8.6537	5.83	0.02	0.09	0.47	0.94	2.00
RHAEELC300	Rad.Space Heat.Apt.All.ELC.00 Heat Pu	RSDELC	14.63	7.51	40.1	0.00010	1.8	8.6537	5.83	0.01	0.08	0.47	0.16	0.34
TOTAL:											11.34		9.06	

Figure 20. Example calculation of fuel consumption for apartment heating by different end uses, fuels and technologies

Similar logic is followed for calculation of end use demands and technology fuel consumption and capacity for other end-use services, which are contained in the corresponding calibration sheets.

Fuel consumption values by different fuels and end uses is then summed up in the Energy Balance sheet and compared to the total energy consumption values in the Residential sector from the national Energy balance in the Supply template. Figure 21 shows final energy consumption splits in the residential sector by different fuels and services in MARKAL-Georgia.



	Coal	Wood	Natural gas	LPG	Oil products	Electricity	Geothermal	Solar
Other						3.180		
Lighting						1.811		
Cooking	0.000	1.205	3.453	0.647	0.000	0.213	0.000	0.000
Hot Water	0.000	2.194	4.985	0.000	0.000	2.325	0.210	0.217
Cooling						0.180		
Heating	0.016	15.733	12.478	0.060	0.004	1.165	0.000	0.000

Figure 21. Final Energy Consumption by different fuels and services in residential sector

The Technology_Data sheets in the Residential workbook represent MARKAL input smart sheets. They take values from data sheets and transform into the format that is readable by ANSWER software.

Table 14. Summary of Data Sources for the Residential Sector

Data Type	Data Source/Assumptions
Technology stocks	EC-LEDS and HPEP[6] residential surveys
Technology operational characteristics (i.e. operation hours)	EC-LEDS and HPEP[3] residential surveys
Technology Efficiencies	Expert estimations
Technology remaining lifetime	MARKAL default values, with custom modifications for lighting technologies (1 year incandescent, 3 halogen, 5 LED and compact fluorescent)

4.2.2 Commercial

As discussed above, the energy consumption in the commercial sector is attributed to the following end-uses:

[6] Data from HPEP residential survey extracted and provided by World Experience Georgia (WEG) in the previous version of MARKAL-Georgia

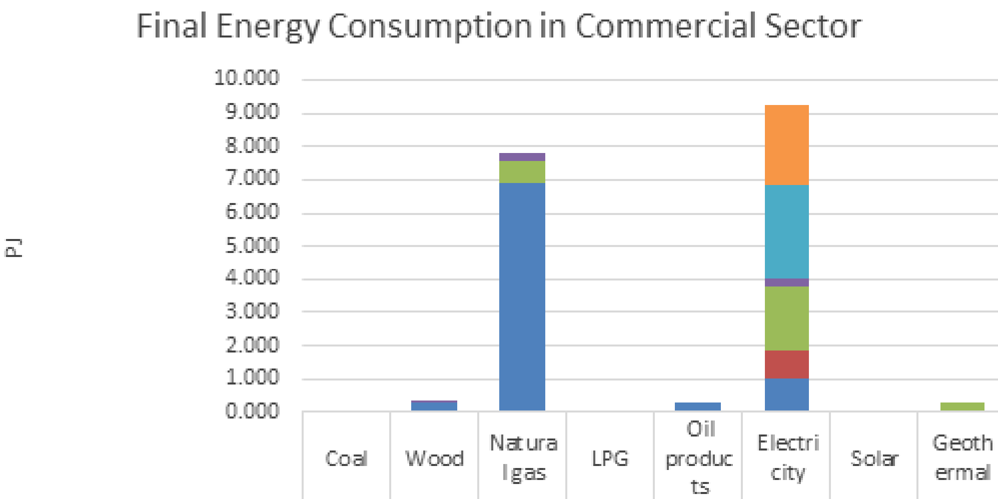
- Space Heating (H)
- Water Heating (W)
- Space Cooling (C)
- Lighting (LIT)
- Cooking (FOD)
- Public Lighting (PLI)
- Other ELC (OTH)

The data that is needed by MARKAL-Georgia for commercial sector is similar to Residential sectors (i.e. technology characteristics for different end-uses, end use demands), but because there was no detailed commercial survey available for the moment of creation of this version of MARKAL_Georgia, the sector is based on a single building type (SE) with characteristics that are calculated based on a top-down approach, by splitting the final energy consumption in commercial sector, taken from EB, by different end uses and technologies. Thus the data used for the commercial sector includes:

1. **Total base-year consumption by fuel (PJ)**: taken from the energy balance;
2. **Base-year end-use split by each fuel (%):** how much of each fuel's consumption can be attributed to each of the end-uses; which is based on average values of fuel consumption splits from different energy audits performed in commercial and state owned buildings by EC-LEDS and other projects.
3. **Technology split (%):** end-uses HSE, WSE, CSE, LIT, REF can be met by different fuels and technologies; when the same fuel feeds more than one technology the split of final energy between these needs are specified. Assumptions are also based on energy audits.

The template for base year commercial sector calibration and RES setup is LEDS_Georgia_BY-COM. The data sheet "Information" includes information from different energy audits that are used to calculate fuel consumption splits by different end uses. The Energy_Balance sheet then uses this information to split the commercial sector FEC (from on Supply template Energy Balance) into different end uses. The Calibration<service> sheets then split the final energy consumption of different end use services by different technologies. Other sheets in Commercial workbook represent MARKAL input smart sheets. They take values from data sheets and transform into the format that is readable by ANSWER software.

Figure 22 shows the decomposition of the sector final energy to the various end-uses and fuels, while Figure 23 provides screen shot from "Calibration_Heating" sheet showing the splits and efficiency for heating devices, as an example of Calibration sheets. Table 7 documents the data sources and assumptions in the commercial sector.



	Coal	Wood	Natural gas	LPG	Oil products	Electricity	Solar	Geothermal
Other						2.4		
Lighting and public lighting						2.8		
Cooking	0.000	0.006	0.234	0.014	0.000	0.283	0.000	0.000
Hot Water	0.000	0.000	0.636	0.000	0.000	1.904	0.077	0.315
Cooling						0.9		
Heating	0.030	0.318	6.926	0.000	0.278	1.007	0.000	0.000

Figure 22. Final Energy Consumption by different fuels and services in commercial sector

CHSE	Commercial Heating	EFF	CF	Final energy (PJ)	useful energy demand (PJ/a)	Installed capaicty (PJ/a)
CHSEBIO100	Com.Space Heat.BIO.00.Stove.	0.50	0.833	0.31833	0.1592	0
CHSECOA100	Com.Space Heat.COA.00.Stove.	0.50	0.833	0.03034	0.0152	0
CHSEELC200	Com.Space Heat.ELC.00.Stove.	0.90	0.833	1.00697	0.9063	1
CHSEGAS200	Com.Space Heat.GAS.00.Stove.	0.80	0.833	6.92578	5.5408	7
CHSELPG200	Com.Space Heat.LPG.00.Stove.	0.70	0.833	0.00000	0.0000	0
CHSEOIL200	Com.Space Heat.OIL.00.Stove.	0.65	0.833	0.27785	0.1806	0
				8.55928	6.80184	8.16645

Figure 23. Commercial space-heating techs/fuel splits

Table 15. Summary of Data Sources for the Commercial Sector

Data Type	Data Source/Assumptions
Consumption shares	
Fuels by end-use	Energy audits from EC-LEDS project, Energy Efficiency Centre
Device shares	Single devices are assumed per each fuel and end-use
Technology operational characteristics (i.e. operation hours)	Assumptions on operational months

Technology Efficiencies	MARKAL default values
Technology remaining lifetime	MARKAL default values, with custom modifications for lighting technologies (1 year incandescent, 3 halogen, 5 LED and compact fluorescent)

4.2.3 Industry

As discussed above, the industry sector is split into the following sub-sectors:

- chemical industry;
- food, beverages and tobacco industry;
- iron and steel industry;
- non-metallic minerals industry;
- construction and
- other manufacturing industry, which combines all industries that are not part of above categories

The energy consumption in each sub-sector (other than construction) is attributed to the following end-uses:

- Process heat; and
- Machine drive.

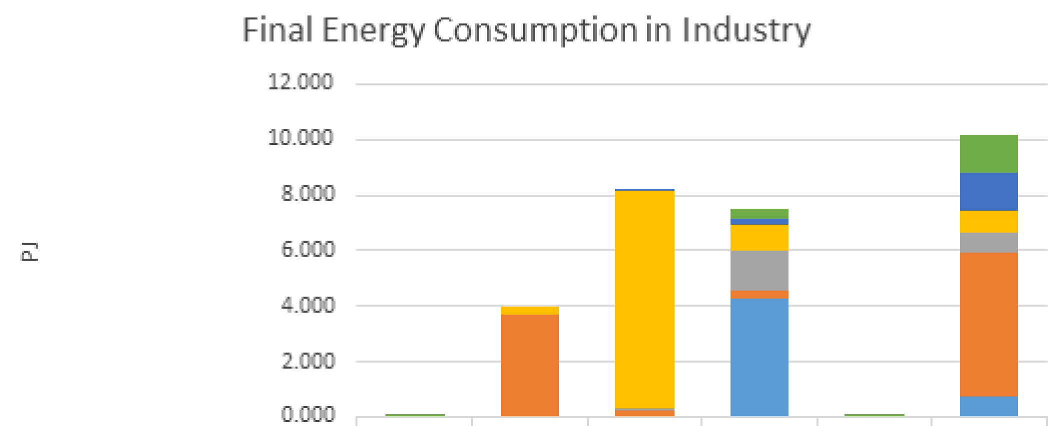
Construction sector is presented by a single"generic" end use technology that consumes different energy carriers.

The data needed for the industry sector includes:

1. **Base-year Energy Consumption (PJ)**: energy consumption for each fuel type, allocated to each sub-sector. The sum of these rows must match the total industrial energy consumption reported in the energy balance; the current split of final energy consumption by fuel and sub-sector is given in Figure 24.
2. **Base-year end-use split (%)**: how much of industrial consumption of each fuel can be allocated in each subsector to each end-use as shown on Figure 25;
3. **Base-year efficiency** (%): for each of the fuels/demand technologies, the conversion efficiency to meet the end-use demands should be reviewed as shown in Figure 26.

The template for base year industry sector calibration and RES setup is LEDS_Georgia_BY-IND. The data sheet "Energy Balance" includes information on base year energy consumption by fuels, sub-sectors and end-uses. The Calibration<service> sheets then split the final energy consumption of different end-uses by different technologies. Industry sector is modeled in simplistic way in MARKAL-Georgia (can be extended in future) and it is assumed that each fuel type has only one "generic technology" for each end-use. The conversion efficiency of final technologies can be also reviewed/modified here. Other sheets in Industry workbook represent MARKAL input smart sheets. They take values from data sheets and transform into the format that is readable by ANSWER software.

Figure 24 shows the decomposition of the sector final energy to the various end-uses and fuels, while Figure 25 provides screen shot from "Energy Balance" sheet showing the splits of energy consumption in each sub-sector by end-use. Figure 26 provides the screen shot from "Calibration_IHT sheet showing the list of end-use technologies for process heat in each sub-sector. Table 16 documents the data sources and assumptions for industry sector.



	Wood	Coke	Coal	Natural Gas	Oil Products	Electricity
Construction	0.001	0.00	0.00	0.34	0.01	1.34
Other manufacturing industry	0.000	0.00	0.01	0.21	0.00	1.38
Non-metallic minerals industry	0.000	0.23	7.85	1.00	0.01	0.80
Food, Beverages and Tobaco industry	0.012	0.00	0.09	1.38	0.00	0.70
Iron and steel industry	0.000	3.72	0.23	0.32	0.01	5.21
Chemical industry	0.000	0.00	0.00	4.26	0.00	0.71

Figure 24. Final Energy Consumption by different fuels and sub-sectors in industry sector

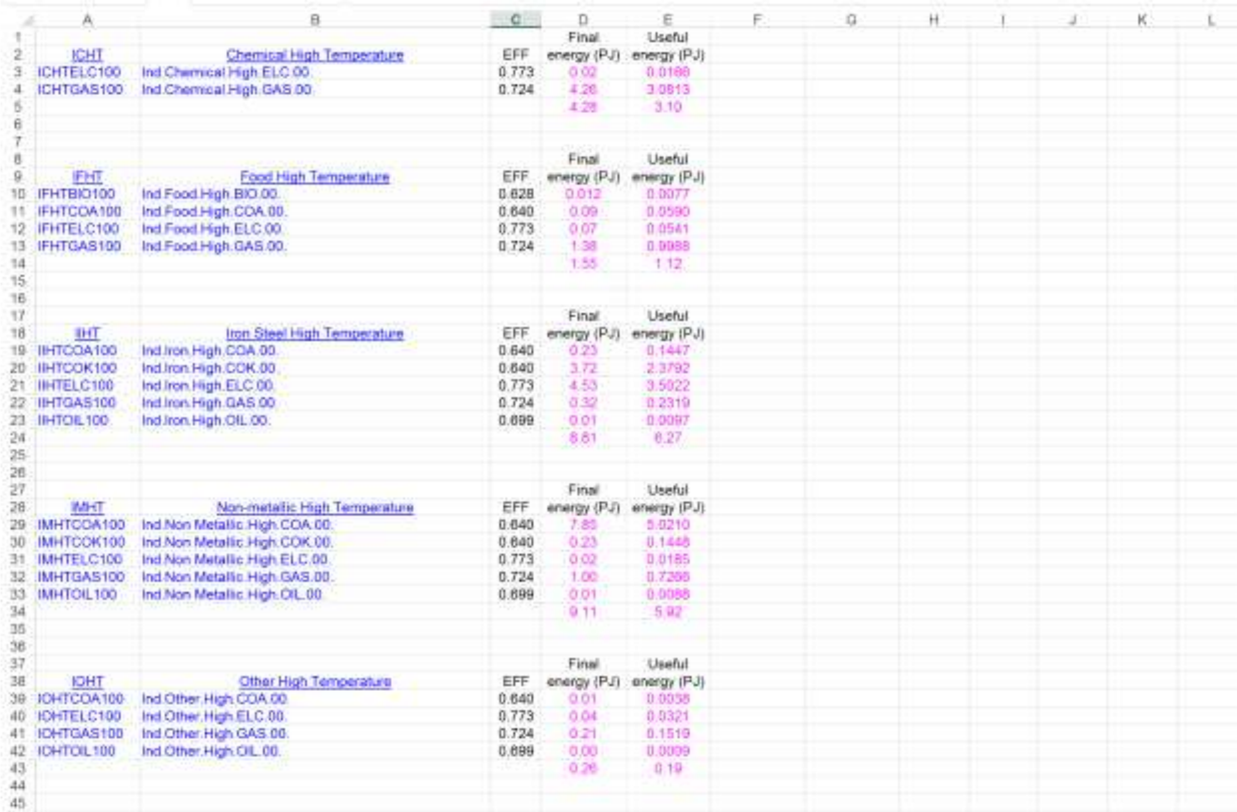
Breakout by Energy Service (Fractional Shares)

End-use description		INDBIO	INDCOK	INDCOA	INDGAS	INDOIL	INDELC
Chemical High Temperature	ICHT	1.00	1.00	1.00	1.00	1.00	0.03
Chemical Mechanical	ICMD	0.00	0.00	0.00	0.00	0.00	0.97
		1.00	1.00	1.00	1.00	1.00	1.00
Iron Steel High Temperature	IIHT	1.00	1.00	1.00	1.00	1.00	0.87
Iron Steel Mechanical	IIMD	0.00	0.00	0.00	0.00	0.00	0.13
		1.00	1.00	1.00	1.00	1.00	1.00
Food High Temperature	IFHT	1.00	1.00	1.00	1.00	1.00	0.10
Food Mechanical	IFMD	0.00	0.00	0.00	0.00	0.00	0.90
		1.00	1.00	1.00	1.00	1.00	1.00
Non-metallic High Temperature	IMHT	1.00	1.00	1.00	1.00	1.00	0.03
Non-metallic Mechanical	IMMD	0.00	0.00	0.00	0.00	0.00	0.97
		1.00	1.00	1.00	1.00	1.00	1.00
Other High Temperature	IOHT	1.00	1.00	1.00	1.00	1.00	0.03
Other Mechanical	IOMD	0.00	0.00	0.00	0.00	0.00	0.97
		1.00	1.00	1.00	1.00	1.00	1.00
Construction Generic	INHT	1.00	1.00	1.00	1.00	1.00	1.00
		1.00	1.00	1.00	1.00	1.00	1.00

Final Energy Consumption by End-Use and Sector Type (PJ)

Final end-use description	Demand	INDBIO	INDCOK	INDCOA	INDGAS	INDOIL	INDELC	TOTAL
Chemical High Temperature	ICHT	0.00	0.00	0.00	4.26	0.00	0.02	4.28
Chemical Mechanical	ICMD	0.00	0.00	0.00	0.00	0.00	0.69	0.69
Total Chemical		0.00	0.00	0.00	4.26	0.00	0.71	4.97
Iron Steel High Temperature	IIHT	0.00	3.72	0.23	0.32	0.01	4.53	8.81
Iron Steel Mechanical	IIMD	0.00	0.00	0.00	0.00	0.00	0.68	0.68
Total Iron and Steel		0.00	3.72	0.23	0.32	0.01	5.21	9.48
Food High Temperature	IFHT	0.0123	0.00	0.09	1.38	0.00	0.07	1.55
Food Mechanical	IFMD	0.00	0.00	0.00	0.00	0.00	0.63	0.63
Total Food		0.01	0.00	0.09	1.38	0.00	0.70	2.18
Non-metallic High Temperature	IMHT	0.00	0.23	7.85	1.00	0.01	0.02	9.11
Non-metallic Mechanical	IMMD	0.00	0.00	0.00	0.00	0.00	0.77	0.77
Total Non-metallic		0.00	0.23	7.85	1.00	0.01	0.80	9.89
Other High Temperature	IOHT	0.00	0.00	0.01	0.21	0.00	0.04	0.26
Other Mechanical	IOMD	0.00	0.00	0.00	0.00	0.00	1.34	1.34
Total Other		0.00	0.00	0.01	0.21	0.00	1.38	1.60
Construction Generic	INHT	0.00	0.00	0.00	0.34	0.01	1.34	1.69
Total Paper		0.00	0.00	0.00	0.34	0.01	1.34	1.69
Total-After Share Assumptions		0.01	3.94	8.17	7.51	0.04	10.14	29.82
Total-Before Share Assumptions		0.01	3.94	8.17	7.51	0.04	10.14	29.82

Figure 25. Industry end-use splits



Row	A	B	C	D	E
1				Final	Useful
2	ICHT	Chemical High Temperature	EFF	energy (PJ)	energy (PJ)
3	ICHTELC100	Ind.Chemical.High.ELC.00.	0.773	0.02	0.0166
4	ICHTGAS100	Ind.Chemical.High.GAS.00.	0.724	4.26	3.0813
5				4.28	3.10
8				Final	Useful
9	IFHT	Food High Temperature	EFF	energy (PJ)	energy (PJ)
10	IFHTBIO100	Ind.Food.High.BIO.00.	0.628	0.012	0.0077
11	IFHTCOA100	Ind.Food.High.COA.00.	0.640	0.09	0.0590
12	IFHTELC100	Ind.Food.High.ELC.00.	0.773	0.07	0.0541
13	IFHTGAS100	Ind.Food.High.GAS.00.	0.724	1.38	0.9988
14				1.55	1.12
17				Final	Useful
18	IIHT	Iron Steel High Temperature	EFF	energy (PJ)	energy (PJ)
19	IIHTCOA100	Ind.Iron.High.COA.00.	0.640	0.23	0.1447
20	IIHTCOK100	Ind.Iron.High.COK.00.	0.640	3.72	2.3792
21	IIHTELC100	Ind.Iron.High.ELC.00.	0.773	4.53	3.5022
22	IIHTGAS100	Ind.Iron.High.GAS.00.	0.724	0.32	0.2319
23	IIHTOIL100	Ind.Iron.High.OIL.00.	0.699	0.01	0.0097
24				8.81	6.27
27				Final	Useful
28	IMHT	Non-metallic High Temperature	EFF	energy (PJ)	energy (PJ)
29	IMHTCOA100	Ind.Non Metallic.High.COA.00.	0.640	7.85	5.0210
30	IMHTCOK100	Ind.Non Metallic.High.COK.00.	0.640	0.23	0.1446
31	IMHTELC100	Ind.Non Metallic.High.ELC.00.	0.773	0.02	0.0185
32	IMHTGAS100	Ind.Non Metallic.High.GAS.00.	0.724	1.00	0.7266
33	IMHTOIL100	Ind.Non Metallic.High.OIL.00	0.699	0.01	0.0086
34				9.11	5.92
37				Final	Useful
38	IOHT	Other High Temperature	EFF	energy (PJ)	energy (PJ)
39	IOHTCOA100	Ind.Other.High.COA.00	0.640	0.01	0.0056
40	IOHTELC100	Ind.Other.High.ELC.00.	0.773	0.04	0.0321
41	IOHTGAS100	Ind.Other.High.GAS.00.	0.724	0.21	0.1519
42	IOHTOIL100	Ind.Other.High.OIL.00.	0.699	0.00	0.0009
43				0.26	0.19

Figure 26. Industrial process heat techs/fuel splits

Table 16. Summary of Data Sources for the Industrial Sector

Data Type	Data Source/Assumptions
Fuel consumption by subsector	Geostat 2014 Energy Balance. The natural gas consumption in chemical industry for energy purposes has been corrected using data form Georgia's largest chemical plant, Rustavi Azoti.
Share of consumption to each end-use	It was assumed that only electricity is used for mechanical drive. All other fuels are used for process heat. The split of electricity consumption between process heat and mechanical drive in each subsector is based on the information from EC-LEDS survey of large industrial plants.
Efficiencies of base year technologies	MARKAL default values.

4.2.4 Agriculture

As mentioned previously, this sector has only one end-use, overall agricultural energy consumption, so no sub-sectorial or end-use demand splitting is required.

The data needed for agriculture includes:

1. **Base-year consumption by fuel (PJ)**, taken directly from the energy balance; and
2. **Base-year efficiency** (%): for each of the fuels, the conversion efficiency from final to useful demand must be specified.

With respect to the efficiency, since agriculture demand is not distinguished by activity (e.g., irrigation, tractors, drying crops, heating greenhouses), or actual devices, this parameter is quite abstract. Efficiency for the different energy carriers can for the most part be directly associated with the activities just noted (e.g., almost all the electricity goes for irrigation, while the diesel is used mainly for tractors but some is also used for irrigation, and LPG is used for heating greenhouse). As a result, efficiency can be estimated by fuel-type and purpose to represent typical devices. Because this parameter is abstract and arbitrary, the important values to review and note are the ratios between efficiencies of existing devices and new devices defined in NEWTCH-DMD. These have been established for the general regional situation, but may be adjusted if needed for country-specific conditions.

The template for base year agriculture sector calibration and RES setup is LEDS_Georgia_BY-AGR. The Energy Balance data sheet includes information on base year energy consumption by fuels, and is linked to Supply template to take values from national energy balance. The DM_Calib_AGR sheet then assigns different technologies to different fuels consumed in agriculture sector. The conversion efficiency of final technologies can be reviewed and modified here. Other sheets in agriculture workbook represent MARKAL input smart sheets. They take values from data sheets and transform into the format that is readable by ANSWER software.

The MARKAL-Georgia Agriculture workbook, DM_Calib_AGR sheet, is shown in Figure 27. Table 17 documents any data or assumptions used in the agriculture sector.

AGR	Agriculture Enduse	EFF	CF	Final Energy (PJ)	useful energy demand (PJ/a)	Installed capaicty (PJ/a)
AGRBIO100	Agr.ENDUSE.BIO.00.Generic.	0.6	0.501	0.000768	0.000461	0.00092
AGRELC100	Agr.ENDUSE.ELC.00.Generic.	0.85	0.501	0.1097	0.0932	0.186
AGRGEO100	Agr.ENDUSE.GEO.00.Generic.	0.7	0.501	0.0213	0.0149	0.030
AGRGAS100	Agr.ENDUSE.GAS.00.Generic.	0.7	0.501	0.1352	0.0947	0.189
AGRLPG100	Agr.ENDUSE.LPG.00.Generic.	0.7	0.501	0.0006	0.0004	0.001
AGROIL100	Agr.ENDUSE.OIL.00.Generic.	0.76	0.501	0.2403	0.1826	0.364
				0.5079	0.3063	0.7706

Figure 27: Agriculture sector Base-year generic technology characterization

Table 17. Summary of Data Sources for the Agriculture Sector

Data Type	Data Source/Assumptions
Fuel Consumption in agriculture	National energy balance 2014
Efficiencies of end-use technologies	MARKAL default values
Capacity factors of end use technologies	It was assumed that end-use technologies in agriculture operate have of the time in year.

4.2.5 Transportation

As discussed above, the energy consumption in the transport sector is attributed to the following end-uses, which are grouped into passenger transport and freight transport categories:

- Light duty vehicles (TLDV)
- Buses (TBUS)
- Mini-Buses (TMBS)
- Two wheelers (TTWO)
- Heavy goods vehicles (THGV)
- Light commercial vehicles (TLCV)
- Rail passenger (TPRL)
- Rail freight (TFRL)
- International aviation (bunker) (TIAV)
- Domestic aviation (TDAV)
- International shipping (bunker) (TISH)
- Domestic shipping (TDSH)
- Off-road (TOFF)

MARKAL-Georgia is a technology-based model and, as for other sectors, it needs information on the technologies that are existing in the Base Year and satisfy different types of end use demands. Technologies are characterized by efficiencies, capacity factors (equal to 1 in case of transport) and installed capacity (amount of demand that this technology has satisfied in base year). To calculate efficiencies and installed capacity, as well as total demand of each end use, the following information is needed:

1. **Transport stock and characteristics in base year**: This includes number of vehicles per each category, average efficiency factors and annual mileage. These parameters are required only for road transport.
2. **Final Energy consumption by each end use and fuel:** For road transport, this is calculated based on transport stock and characteristics discussed above, whereas for rail data is needed to split passenger and freight energy use, while aviation and navigation data are taken directly from the energy balance sheet.
3. **Useful energy demand:** Useful energy demand for road passenger transport is estimated in million passenger-kms (mpkm) and for freight transport in million tonnes-km (mtkm). These values can be input directly if known, otherwise can be calculated using stock data and average load factors for each transport type. For rail, aviation and navigation, the useful energy demand is estimated in PJ and equals to final energy consumption in the corresponding end use category.

These parameters should be calibrated in such way that the final energy consumption of all devices and all end-uses sum up to the Final Energy Consumption given for Transport in the Energy Balance for each fuel.

The base year MARKAL-Georgia transport template is LEDS_Georgia_BY-TRN, which links to the Supply template to obtain base year energy consumption values in transport sector as well as Conversion and emission factors.

To populate this template with the necessary information on transport stock and characteristics, detailed statistical information and extensive transport surveys are needed. The list of data sources used for calibration of the transport sector is given in Table 18. There are several data sheets that hold the information used for data input. The main sheet for road transport is sheet "Transport_data", which holds information on road transport stock, their characteristics and calculations of fuel consumption by each type of road transport and for each fuel. The screen shot of this sheet is presented on Figure 28.

There are several other sheets which hold the background information for this sheet. These are "Survey data" holding information from Residential surveys used to evaluate characteristics of LDVs, "PT data" holding information on stocks and characteristics of buses, mini buses and freight transport and "International Freight transport" holding information on international trucks moving on Georgian territory.

The data sheet "Rail_data" contains information on passenger (including Tbilisi Metro) and freight rail, such as fuel consumption by each mode and annual activity.

The data sheet "Energy Balance" gathers information from road transport calibration and rail calibration and compares them with the National Energy balance from Supply template. It also takes fuel consumption values for navigation and aviation from national energy balance to be used for calibration of these services. The finals split of each fuel consumption by services is presented by chart in Figure 29.

The efficiency of each type of transport then equals to the useful energy satisfied by that transport divided by final energy consumption (based on Eq.2). Based on Eq. 3, the installed capacity of each technology equals to the useful energy satisfied by that particular technology (since CF=1). The calculation of efficiencies is done on "Calibration_passenger", "Calibration_freight" and "Calibration_other" sheets.

Figure 29 shows screen shot from the Calibration_passenger sheet, as an example. Similar calculations are performed (not shown on the Figure) at other two calibration sheets as well.

Other sheets in Transport workbook represent MARKAL input smart sheets. They take values from data sheets and transform into the format that is readable by ANSWER software.

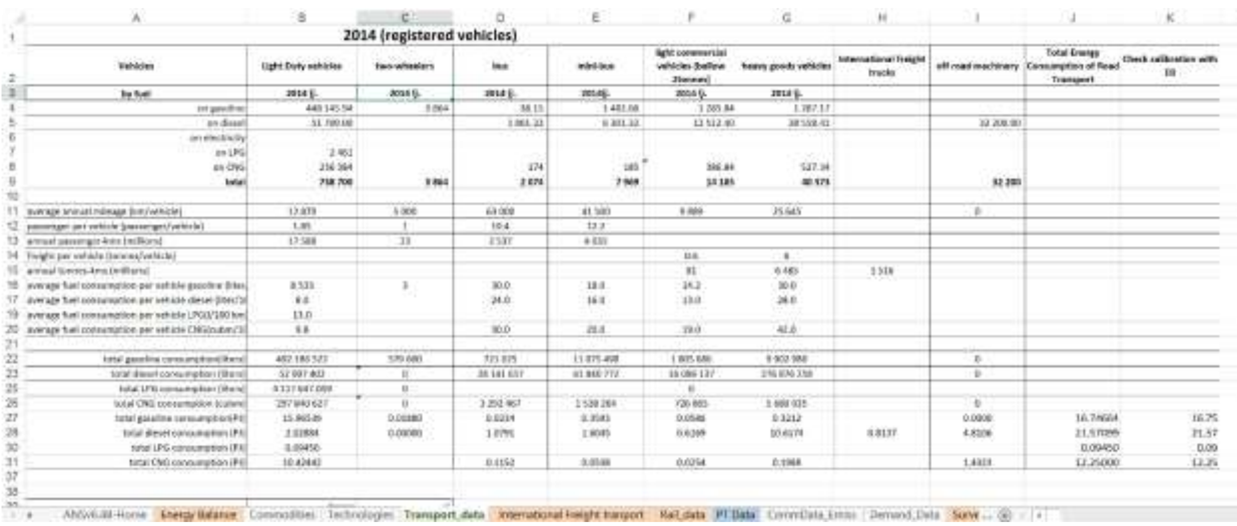
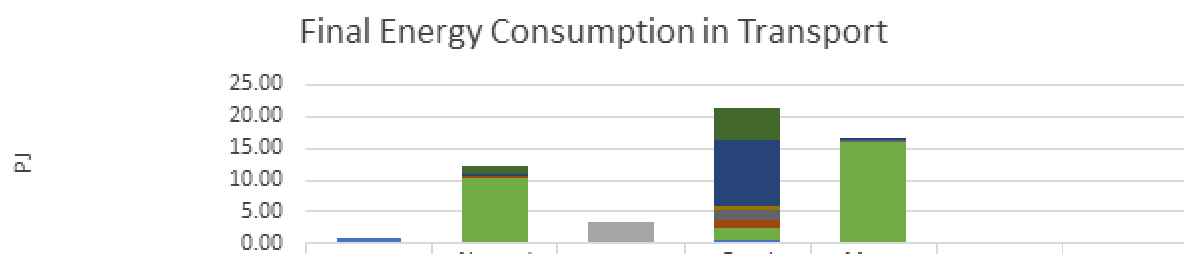


Figure 28. Road transport stock and characteristics used for calibrating MARKAL-Georgia Transport sector



	Electricity	Natural gas	Jet Fuel	Road diesel	Motor Gasoline	Fuel oil	LPG
Off-road and other		1.43		4.81			
Heavy Goods Vehicles		0.20		10.62	0.32		
Light Commercail Vehicles		0.03		0.62	0.06		
Mini-busses		0.05		1.60	0.36		
Busses		0.12		1.08	0.02		
Two-wheelers					0.02		
Light Duty Vehicles		10.42		2.03	15.97		0.09
Rail freight	0.67			0.42		0.02	
Rail Passenger	0.29			0.01			
International aviation	0.00	0.00	3.47	0.00	0.00	0.00	0.00
Domestic navigation	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Domestic aviation	0.00	0.00	0.03	0.00	0.00	0.00	0.00

Figure 29. Final Energy Consumption by different fuels and services in transport sector

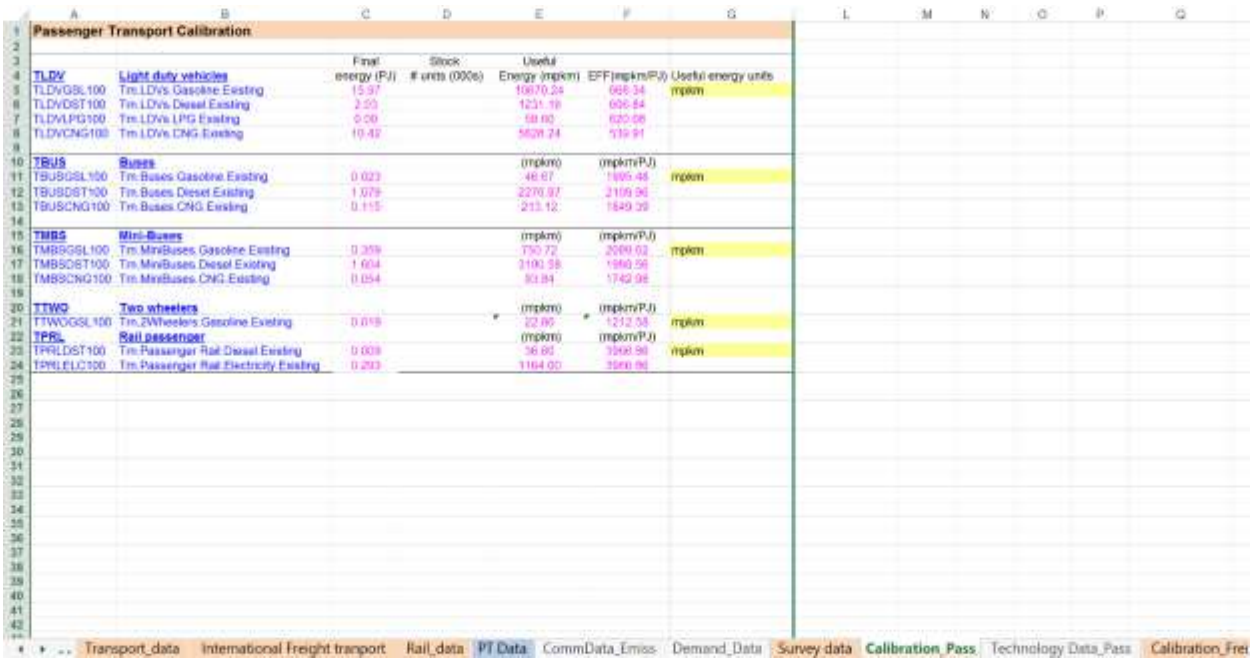


Figure 30. Calibration of Passenger transport efficiencies

Table 18. Summary of Data Sources for the Transport Sector

Data Type	Data Source/Assumptions
Technology stocks	Registered car fleet, bus (also minibus) - Statistical Yearbook of Georgia - 2015; Average number of “active” (used for freight or passenger transportation) buses, microbuses and freight trucks — 2006 surveys by GeoStat (not official); Number of nonresident (incl. transit) trucks that enter Georgia in freight-loaded state — Revenue Service of Georgia[7].
Technology characteristics (i.e. mileages, load factors, fuel intensities)	Private LDV numbers by fuel types, annual distance covered by private cars, average consumption of fuel by LDVs — EC-LEDS and HPEP[8] Residential End-Use Surveys; LDV load factor — Road Map of Georgian Sustainable Urban Transport Project[9];

[7] Loading factor and distance traveled through Georgia for these cars were derived according to some assumptions. Additional assumption is that these cars fill fuel tanks only on one direction.

[8] Data from HPEP residential survey extracted and provided by World Experience Georgia (WEG) in the previous version of MARKAL-Georgia

	load factors, and annual mileages of public transport and freight transport — 2006 surveys by GeoStat (not official); Fuel intensities of buses, microbuses and trucks — Urban Sustainable Energy Development Plans, International transportation models;
Final Energy Consumption	For Road transport – calculated based on stock data and calibrated against values in Energy Balance. For aviation and navigation – National Energy balance. Distribution of electricity and diesel consumption by passenger and freight transport in railway — Georgian Railway; Energy consumption in Tbilisi Metro — Monitoring Report of Tbilisi Sustainable Energy Development Plan;
Demand	For Road transport – calculated based on stock data Railway passenger turnover, railway turnover — Statistical Yearbook[10]; Passenger turnover in Tbilisi Metro — Monitoring Report of Tbilisi Sustainable Energy Development Plan;
Technology remaining lifetime	MARKAL default values (15 for LDVs, 12 for busses, mini-busses and LDVs, 10 for two wheelers and HGVs, 30 for generic rail, aviation and navigation technologies).

4.2.6 Non-energy and TED

As already mentioned, TED sector demand represents the electricity delivered to Georgia's occupied territory of Abkhazia. Non energy sector, on the other hand represents non-energy consumption of energy carriers in industry and transport.

There is single demand for transport sector (TED) and three demands for non-energy

- Non Energy - chemical Industry gas demand (NONG)
- Non Energy - Industry other (NONI)
- Non Energy – Transport (NONT)

The data needed for non-energy includes only **Base-year consumption by fuel (PJ)**, taken directly from the energy balance;

Similarly, to agriculture, non-energy sector is modeled by generic technologies with efficiency of 1. For each demand there is only single technology satisfying the demand but consuming several energy carriers, in case of industry demand. The share of each energy carrier is determined by energy balance.

[9] Road Map of Georgian Sustainable Urban Transport Project. SYSTRA. 2010

[10] Statistical Yearbook of Georgia -2015, GeoStat, 2015.

The template for base year calibration and RES setup is LEDS_Georgia_BY-TED+NON. The data sheet "Energy Balance" includes information on base year energy consumption by energy carriers, and is linked to Supply template to take values from the national energy balance. The Calibration_NON_TED sheet then calculates demand and assigns different technologies to different demands. Other sheets in this workbook represent MARKAL input smart sheets. They take values from data sheets and transform into the format that is readable by ANSWER software.

The "energy balance" sheet, is shown in Figure 31. Table 19 documents any data or assumptions used in these sectors.

A	B	C	D	E	F	G	H
Base Year Energy Balance - [2014]			Georgia				
	GASNAC	OILBIT	OILLUB	OILNON	OILWAX	ELC	
	Natural gas commercial	Bitumen	Lubricants	Non-specified Petroleum Prods.	Paraffin Waxes	Electricity	Total
NON-ENERGY USE - Industry sector	4.892	3.105	0.053	0.007	0.017		8.074
NON-ENERGY USE - Transport sector			0.488				0.488
	NONGAS	NONBIT	NONLUB	NONNON	NONWAX		
Final electricity consumption for TED						5.9	
						TEDELC	

Figure 31: Consumption of energy carriers in Non-energy and TED sectors in base year

Table 19: Summary of Data Sources for the TED and Non-energy Sectors

Data Type	Data Source/Assumptions
Consumption of energy carriers for non-energy purposes	National energy balance 2014
Electricity consumption in TED	National energy balance 2014
Capacity factors of end use technologies	Assumed to be 1.

4.2.7 Existing Power Generation Technologies

Georgia's power system in MARKAL-Georgia is represented by electricity only plants of two types:

- Hydro Power Plant
- Natural Gas Power Plants

There are three existing hydropower plant (HPP) technologies represented in MARKAL-Georgia:

- EPPHYDEAV - representing Enguri HPP and Vardnili HPP (Reservoir)

- EPPHYDREG - representing all other reservoir HPPS, aggregated and represented by the sum or average of plant characteristics.
- EPPHYDROR - representing Run of River HPPs, aggregated and represented by the sum/average of plant characteristics.

There are also three natural gas power plants (TPP):

- EPPGASMTK -representing Mtkvari TPP
- EPPGASENE - representing Energy Invest TPP
- EPPGASTBI - representing Tbilsresi TPP

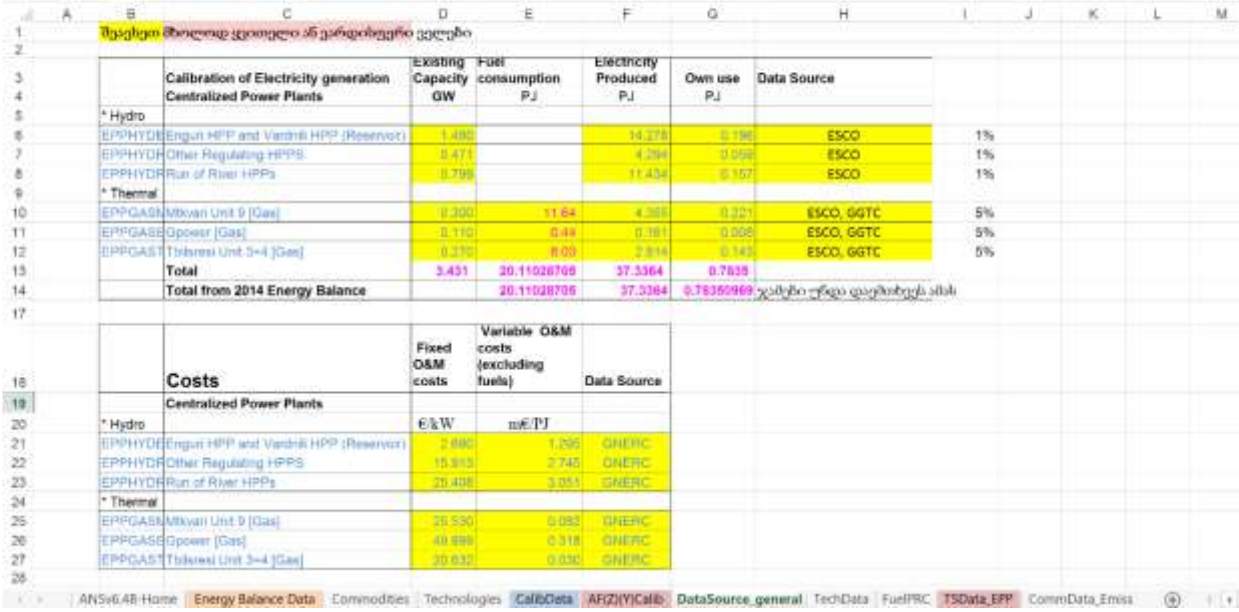
For each of the technologies the following data is entered:

1. **Existing capacity (GW) and** retirement profile whenever the plant has planned retirement during the model horizon;
2. **Base-year energy input and ELC output (PJ);**
3. **Efficiency (%):** annual input and output energy are checked against the conversion efficiency (%).
4. **Contribution to the Peak (%):** representing the upper limit a plant can generate during the peak demand time slice. Introduced in order to prevent unrealistic contribution to the peak demand from variable or intermittent technologies.
5. **Annual availability (%):** specified for thermal plants;
6. **Seasonal availability** (%): specified for hydro plants;
7. **Minimum production (% or PJ/annum):** specific annual/seasonal minimum production constraints;
8. **Running costs:** Fixed (EUR/kW) and variable costs other than fuel costs (mil EUR/PJ);

The template for base year power sector calibration and RES setup is LEDS_Georgia_BY-PP. there are several data sheets in the template. The Energy Balance Data sheet takes information from the national energy balance in the Supply template that is used to check the calibration of individual plants. The DataSource_general sheet is used for inputting plant specific information, such as installed capacity, generation, consumption and cost data. It also has a link to the Energy Balance Data sheet, which checks the calibration of generation and fuel consumption (checking that the sum of energy produced by all hydro and thermal plants equals to the value given in energy balance, also checking that the sum of natural gas consumption by thermal plants equals to the values given in National energy Balance). The screen shot of the DataSource_general sheet is given in Figure 32. The sheet CalibData then takes data from DataSource_general and uses it to calculate base year efficiencies and base year capacity factors. The screen shot of the CalibData sheet is given in Figure 33.

The sheet AF(Z)(Y)Calib is used to calculate seasonal availability factors of hydro plants. It uses 5 year averages of seasonal generation of different types of hydro plants. The screen shot of this sheet is given in Figure 34. Sheet TSData_EPP is used to enter the retirement profile of each plant and its minimum production values. All other sheets represent MARKAL input smart sheets. They take values from data sheets and transform into the format that is readable by ANSWER software. Figure 34. Calculation of Seasonal Availability factors of hydro plants

Table 20 documents any data or assumptions used for power sector setup in MARKAL-Georgia.

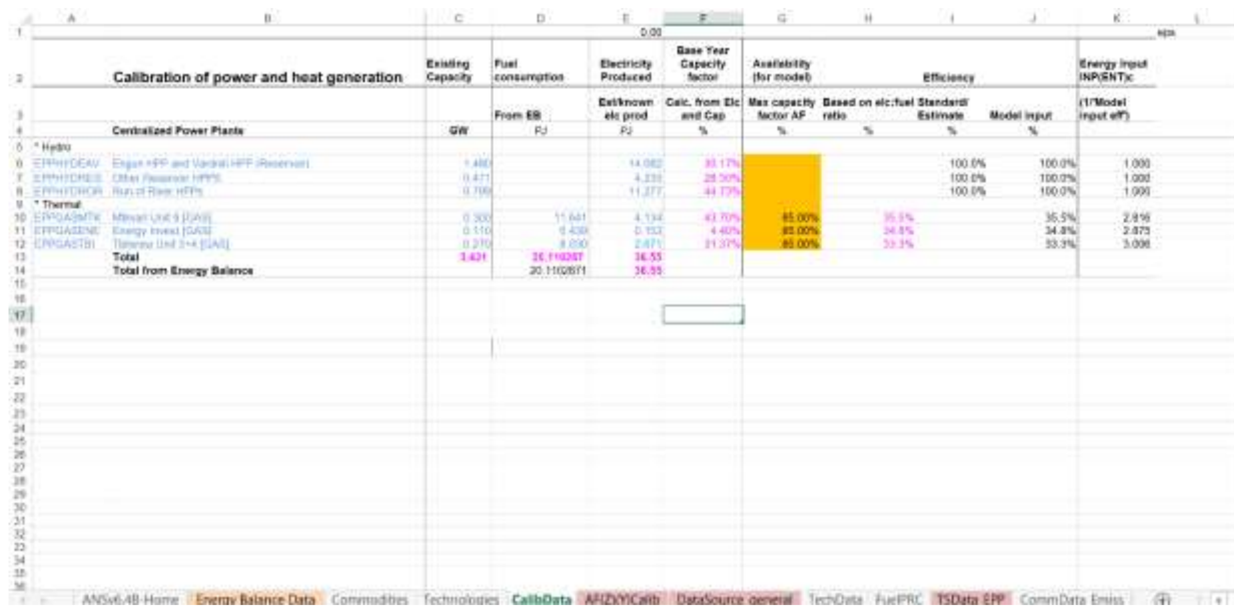


[illegible]

	Calibration of Electricity generation Centralized Power Plants	Existing Capacity GW	Fuel consumption PJ	Electricity Produced PJ	Own use PJ	Data Source	
* Hydro							
EPPHYDE	Enguri HPP and Vardnili HPP (Reservoir)	1.480		14.278	0.196	ESCO	1%
EPPHYDR	Other Regulating HPPS	0.471		4.294	0.059	ESCO	1%
EPPHYDR	Run of River HPPs	0.799		11.434	0.157	ESCO	1%
* Thermal							
EPPGASN	Mtkvari Unit 9 [Gas]	0.300	11.64	4.365	0.221	ESCO, GGTC	5%
EPPGASE	Gpower [Gas]	0.110	0.44	0.161	0.008	ESCO, GGTC	5%
EPPGAST	Tbilsresi Unit 3+4 [Gas]	0.270	8.03	2.814	0.143	ESCO, GGTC	5%
	Total	3.431	20.11028706	37.3364	0.7835		
	Total from 2014 Energy Balance		20.11028706	37.3364	0.78350969	[illegible]	

	Costs	Fixed O&M costs	Variable O&M costs (excluding fuels)	Data Source
	Centralized Power Plants			
* Hydro		€/kW	m€/PJ	
EPPHYDE	Enguri HPP and Vardnili HPP (Reservoir)	2.880	1.296	GNERC
EPPHYDR	Other Regulating HPPS	15.913	2.745	GNERC
EPPHYDR	Run of River HPPs	25.408	3.051	GNERC
* Thermal				
EPPGASN	Mtkvari Unit 9 [Gas]	25.530	0.082	GNERC
EPPGASE	Gpower [Gas]	49.999	0.318	GNERC
EPPGAST	Tbilsresi Unit 3+4 [Gas]	20.632	0.030	GNERC

Figure 32. Inputting existing power plant data



	Calibration of power and heat generation	Existing Capacity	Fuel consumption	Electricity Produced	Base Year Capacity factor	Availability (for model)	Efficiency			Energy input INP(ENT)c
			From EB	Est/known elc prod	Calc. from Elc and Cap	Max capacity factor AF	Based on elc:fuel ratio	Standard/ Estimate	Model input	(1/Model input eff)
	Centralized Power Plants	GW	PJ	PJ	%	%	%	%	%	
* Hydro										
EPPHYDEAV	Enguri HPP and Vardnili HPP (Reservoir)	1.480		14.082	30.17%			100.0%	100.0%	1.000
EPPHYDRES	Other Reservoir HPPs	0.471		4.235	28.50%			100.0%	100.0%	1.000
EPPHYDROR	Run of River HPPs	0.799		11.277	44.73%			100.0%	100.0%	1.000
* Thermal										
EPPGASMTK	Mtkvari Unit 9 [GAS]	0.300	11.641	4.134	43.70%	85.00%	35.5%		35.5%	2.816
EPPGASENE	Energy Invest [GAS]	0.110	0.439	0.153	4.40%	85.00%	34.8%		34.8%	2.875
EPPGASTBI	Tbilsresi Unit 3+4 [GAS]	0.270	8.030	2.671	31.37%	85.00%	33.3%		33.3%	3.006
	Total	3.431	20.110287	36.55						
	Total from Energy Balance		20.1102871	36.55						

Figure 33. Calibrating Base Year Efficiencies and Capacity factors

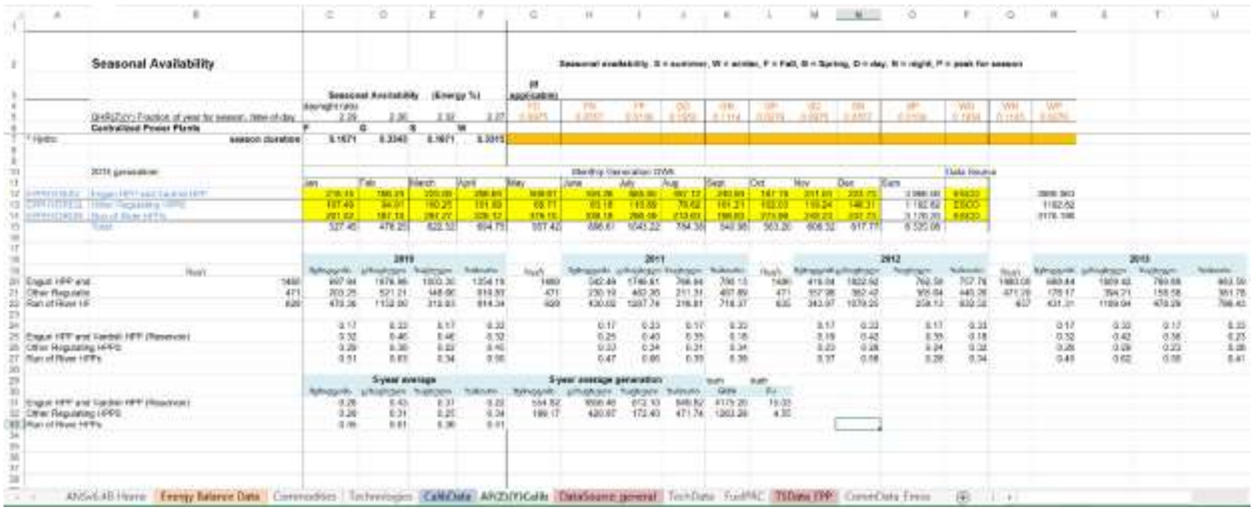


Figure 34. Calculation of Seasonal Availability factors of hydro plants

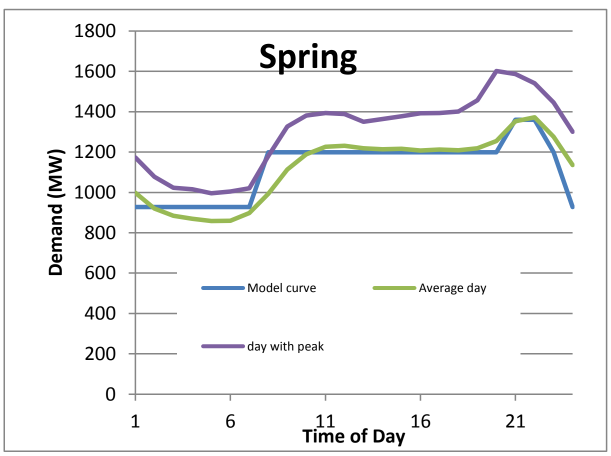
Table 20. Summary of Data Sources for Existing Power Plants

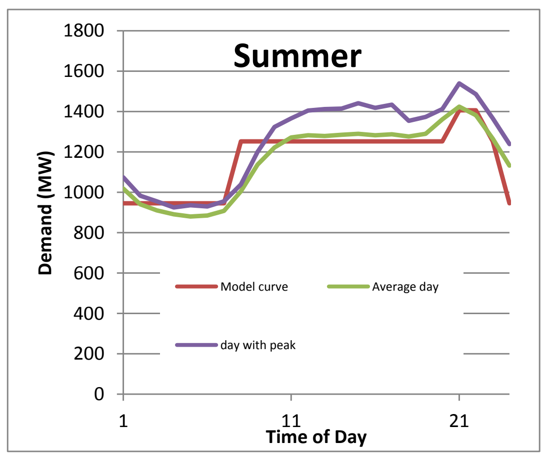
Data Type	Data Source/Assumptions
Capacity of existing plants	**Ministry of Energy**
Planned retirements	**For BAU scenario, it is assumed that none of existing plants retire during model horizon**
Fuel consumption by plant type	**Ministry of Energy**
Electricity production by plant type	**Ministry of Energy**
Own consumption by plants	**ESCO, GGTC**
Plant efficiency	**calculated**
Plant availability	**Ministry of Energy**
Minimum operation by plant type	**For BAU scenario it is assumed that thermal plants operate at least by same level as in Base year**
Fixed operating and maintenance costs	**GNERC**
Variable operating and maintenance costs	**GNERC**

4.2.8 Load Calibration

An important aspect of defining the electric sector is creating the annual time-slices for the model and shaping the timing of the electricity demands to match the base year load duration curve. MARKAL-Georgia is setup with twelve divisions of the year corresponding to four seasons (summer, fall, winter and spring) and three times of the day (day, night and peak) that apportion the load curve adequately for long-term planning purposes. Since Georgia's electricity system is dominated by hydro plants, the seasonal distribution in MARKAL-Georgia is set according to hydrological seasonality, thus each season covers the following months: Spring (April-July), summer (August-September), fall (October-November), winter (December-March).

The MARKAL-Georgia template used for load calibration is DataSource_Georgia_LoadCalibration. The complete annual hourly load data is entered on the Load data sheet. The number of months and hours of the day corresponding to each timeslice are indicated on the same sheet workbook by entering the start and end day for each season. Based on the load duration curve entered, which consists of 8760 hourly electricity load values the base year (or most recent year available), the user must iterate on the load fractions for each end use demand in each timeslice and sector to get a reasonable approximation of the associated aggregate load curve that will be used by the model. For each season Figure 35 shows the average daily load curves real and modeled, as well as the day in that season with peak demand. Based on the peak value compared to modeled peak, as well as required peak reserve margin, the modeled reserve margin is calculated to be used in MARKAL-Georgia.





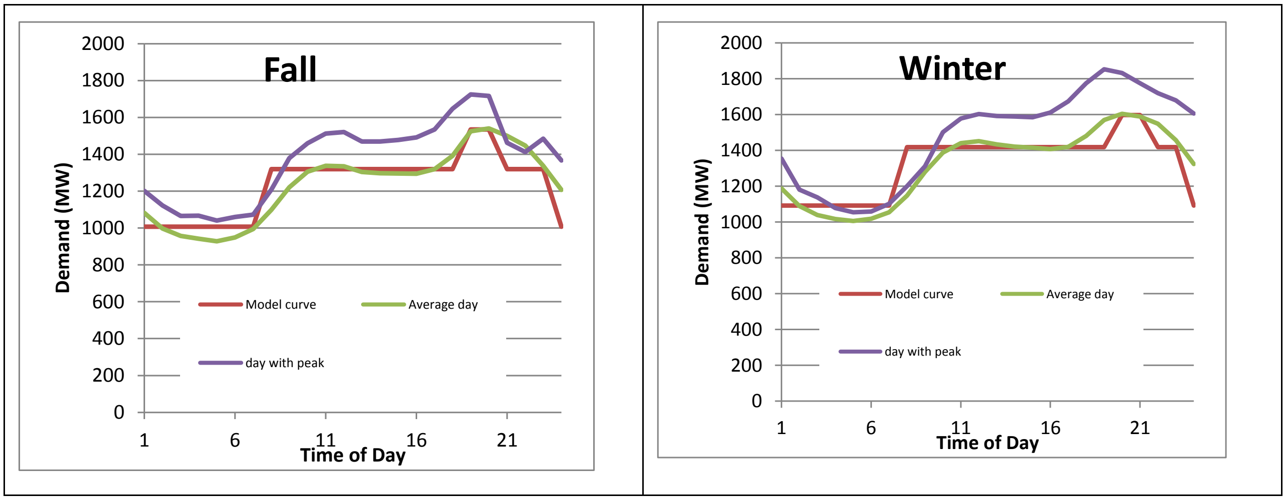
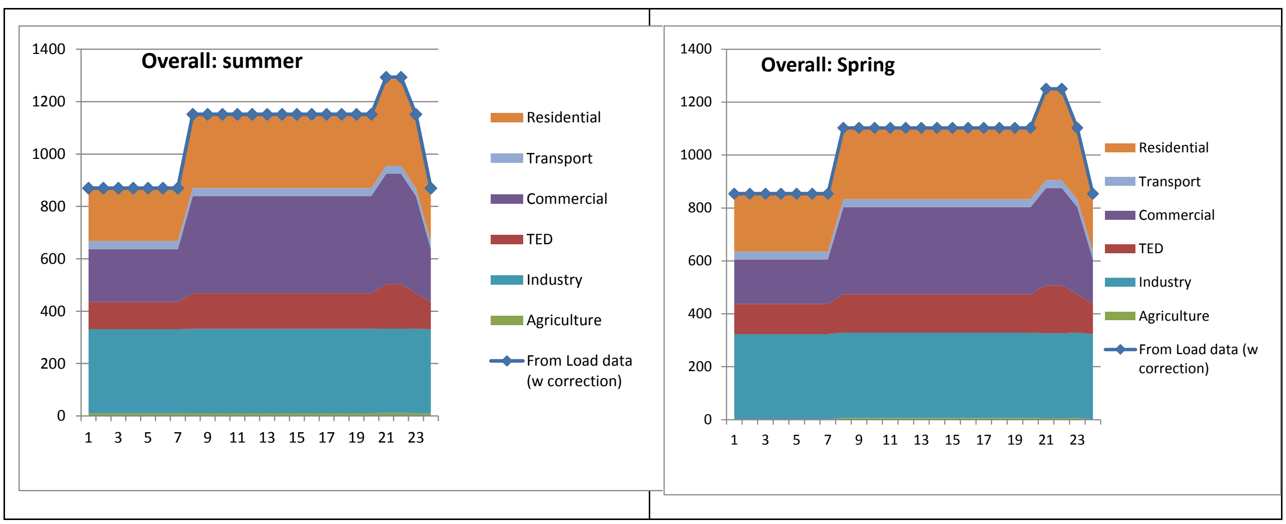


Figure 35. Modeled and actual seasonal load curves

The sheet Calib then takes electricity consumption data for each sector and service from sectoral templates and breaks it down by seasons and timeslices. As a result each the MARKAL load fractions (the FR (Z)(Y)s) are generated which indicate the split of each demand (service) by timeslice. These values are calculated here and then cascaded into each of the sector workbooks.

For each season Figure 36 shows the results of this calibration exercise, represented by sectoral load for average day in each season.



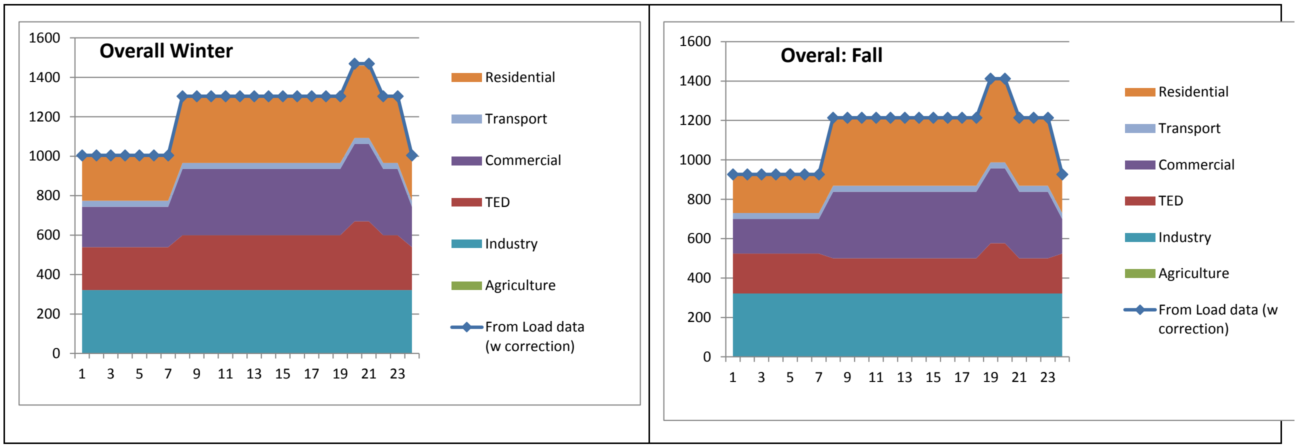


Figure 36. Seasonal load curves split by sectors

The sheet LoadVector is used for some calculations necessary for the workbook and sheet TED holds monthly energy consumption information for TED, and is used to calculate TED electricity consumption splits by seasons.

Table 24 Table 24: Summary of Data Sources for New Demand Devices documents any data or assumptions used for load calibration in MARKAL-Georgia.

Table 21. Summary of Data Sources for Existing Power Plants

Data Type	Data Source/Assumptions
Hourly load data	**Ministry of Energy**
Required reserve margin	**10%, the value used in model to cover also difference between actual and average peak is 27.5%**
Seasonal distribution of electricity consumption in TED	**Ministry of Energy**
Timeslice split by seasons and time of day by sectors and end-uses	**Judgement and iteration**

4.3 Defining Business as Usual (BAU) Scenario

4.3.1 What is the BAU scenario

The Business as Usual, or BAU Scenario is designed to reflect the evolution of the energy system assuming no changes in energy sector policy. This scenario doesn't represent a forecast of the energy system evolution, rather it serves as a baseline for comparison with policy scenarios. Because of this it is also often called the Reference scenario.

The Reference scenario can be defined with different meaning, depending upon the analysis that is needed to be carried out. The main idea is that the Reference scenario should not include the policies for which analysis is required. The policies that are analyzed need to be included in policy scenarios and the difference between them and the reference scenario will represent the impact of these policies.

For LEDS purposes we have chosen the definition of BAU(Reference) scenario, similar to the definition of "without measures" scenario in UNFCCC guidelines for the preparation of national communications by parties included in annex I of the convention (FCCC/CP/1999/7), para 29.
*"If provided, a **'without measures'** projection excludes all policies and measures implemented, adopted or planned after the year chosen as the starting point for this projection. In reporting, Parties may entitle their 'without measures' projection as a **'baseline'** or **'reference'** projection, for example, if preferred, but should explain the nature of this projection.*"

Developing the BAU scenario requires some analyst judgment and iteration. To develop it, the following activities need to be carried out:

- Project future useful energy service demands
- Identify and describe the future resource supply and technology options
- Smooth model behavior

Each activity is described below together with the corresponding MARKAL-Georgia templates.

4.3.2 Demand Projection

The evolution of the energy service demands over the modeling horizon is based on national projections regarding the evolution of population and economic activity over the study period ending in 2040. Demands are related to these drivers by means of *elasticity* factors – ratios that say how much each demand increases due to a percentage increase in the drivers. Specifying these elasticities is a matter of analyst judgment, based on an understanding of the level of existing demand penetration in the country, the typical growth of demand with demographics and economic changes, and review of model behavior. Demand growth is also affected by projected changes in the penetration levels for relatively new demands (e.g., residential space cooling and clothes drying) and by Autonomous Efficiency Improvement (AEI) factors that represent non-technological improvements in energy efficiency (such as building management practices and industrial process changes).

Any MARKAL/TIMES model solves to meet the projected future demand for energy services for each and every end-use service. Thus the demand projection is a very important aspect of establishing a MARKAL/TIMES model. There are two demand projections templates in MARKAL-Georgia. The LEDS_Georgia_Demand_Projections-REF establishes demand projections for all sectors other than transport, and template LEDS_Georgia_Demand_Projections-TRN is used to establish demand projections specifically for transport sector[11].

The LEDS_Georgia_Demand_Projections-REF demand template has four (4) types of worksheets, each of which are discussed in this section.

- Sheet Base year calibration data, which is linked to sectoral templates for getting base year service demand values;
- Sheet Demand drivers establishing national demand drivers such as GDP growth rates, population growth rates, etc.;
- Sheets <Sector> Demand Projection, calculating demand projections for each sector, other than transport;

[11] The Transport demand projection template is separate from the rest of the demand sectors only because of the historical development of the MARKAL-Georgia model.

- Sheets useful energy demand and useful energy intensities, which graph the breakdown of each sectoral demand projection and calculate the useful energy intensities according to specific sectoral inticators, and
- The ANSWER-MARKAL loadsheets with the commodities (end-use service demand definitions) and projection (end-use service levels).

While there are various sophistications in terms of approaches to forecasting the energy service demands, including linking to macro-economic models[12], a rather straightforward yet reasonable and transparent approach is employed for the MARKAL-Georgia. The demand projections are seeded by the base year energy service demand, as determined by the calibration process. **Error! Reference source ot found.** shows that these BY values are coming from the BY templates, and Figure 38 shows the current levels as collected on the base year calibration data tab.

[12] Workshop on linking TIMES with economic model can be found at http://www.iea-etsap.org/web/UCC_Workshop14.asp and http://www.iea-etsap.org/web/Copenhagen_Nov2014.asp and summarized in '*Economic Impacts of Future Changes in the Energy System—Global Perspectives* chapter in **Springer Book** 'Informing energy and climate policies using energy systems models' 2015.

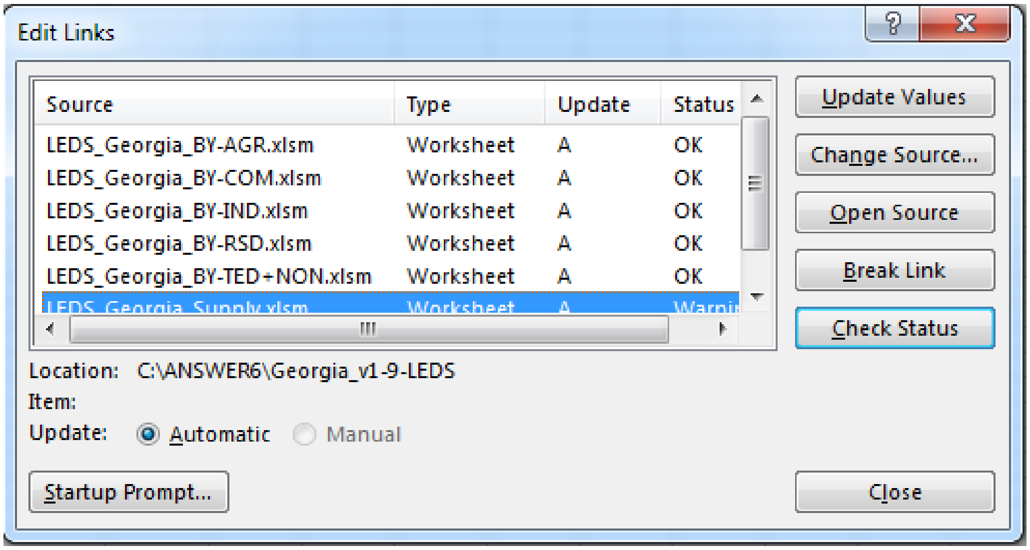


Figure 37. Demand Template Dependencies

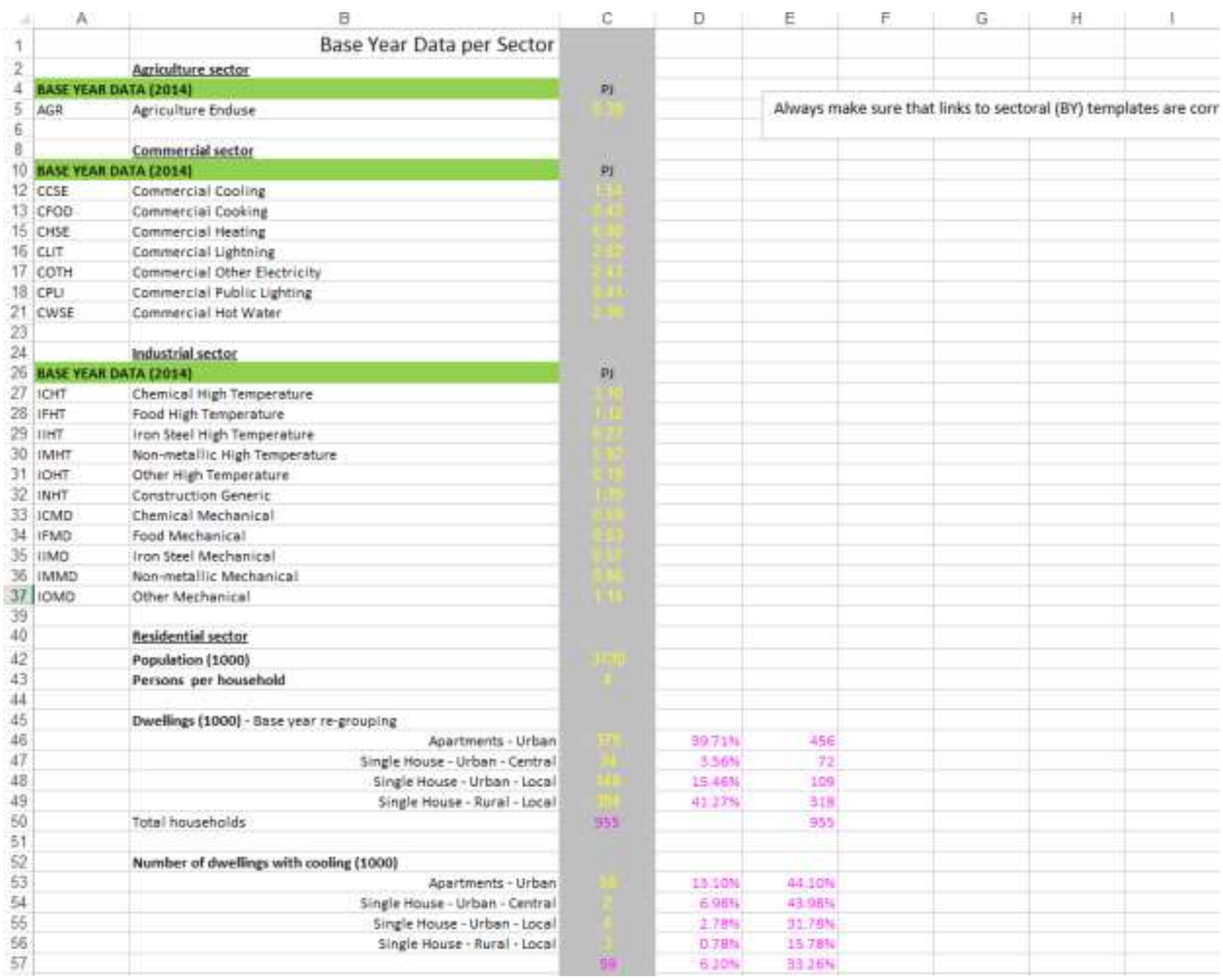


Figure 38. Screen shot of "Base Year Calibration data" sheet

The primary inputs to the demand projections are the demand drivers. The Demand drivers sheet is used to enter information on GDP projections, population projections and person per household projections. For the Industry subsectors, subsector-based value added (or production) growth indices are used, as shown in Figure 39. TED sector growth projections are entered separately. In addition this sheet is used to enter the base year and average degree days, which are used to correct the heating and cooling demands in base year to average values.

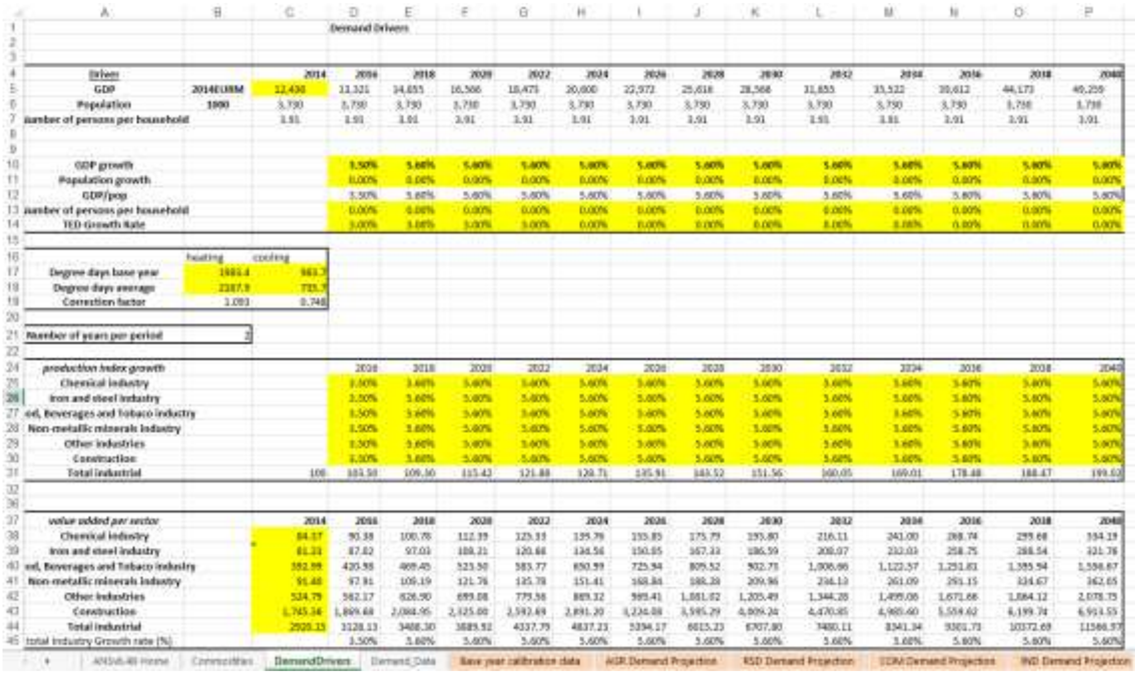


Figure 39. Demand Drivers

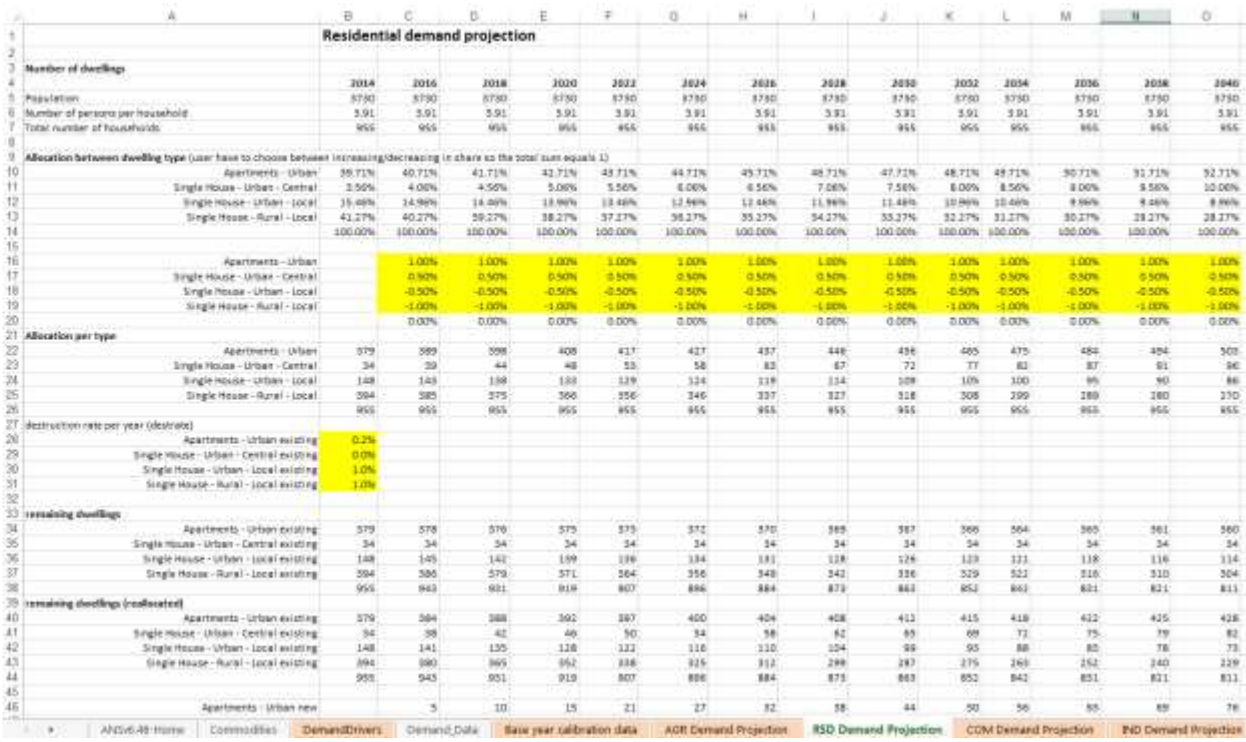
The lower part of Demand Drivers sheet (not shown in the Figure) enables the user to enter individual sectoral GDP growth rates if available, which can be used to make individual sectoral projections.

In addition to the demand drivers and elasticities, there are other factors that shape the demand projections, such as the migration rates, saturation rate for and end use service, and so on. Each sector has its own approach.

Agriculture sector demand projections use GDP growth rate as main demand driver with elasticities to GDP and AEI factors to calculate energy service demands. Figure 40 shows screen shot from “AGR Demand Projections sheet”

Figure 40. Screen shot from Agriculture demand projections

Residential sector demand projections are the most complicated. This sector uses assumptions on migration levels (i.e. from rural to urban) to calculate allocation of households in each of the four household dwelling types that are considered in MARKAL-Georgia. Furthermore, a destruction rate for each type of dwelling is used to calculate the remaining stock of buildings and the need for new buildings. The special factor (neffgain) is used to establish heating demand of new houses compared to old houses (this factor is set as 1 in MARKAL-Georgia, assuming that new houses have same efficiency level as old houses). Heating, cooling, and hot water demands are then calculated separately for each of four dwelling types using GDP per capita as the main demand driver, with elasticities to this driver and AEI factor. Heating and cooling demands are corrected based on degree days. These services also use a penetration rate forecast. For heating this represents the increase of heated area in each of four types of dwelling, and for hot water and cooling it represents the increase of the share of households where the service is installed. Other demands are also calculated based on the GDP per capita demand driver, elasticities and penetration rates (where relevant). **Error! Reference source not found.** shows screen shot from the RSD Demand Projections sheet with calculation of dwelling numbers in each category. This sheet cannot be displayed completely, because it is too large.



A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Residential demand projection														
Number of dwellings														
	2014	**2016**	**2018**	**2020**	**2022**	**2024**	**2026**	**2028**	**2030**	**2032**	**2034**	**2036**	**2038**	**2040**
Population	3730	3730	3730	3730	3730	3730	3730	3730	3730	3730	3730	3730	3730	3730
Number of persons per household	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91
Total number of households	955	955	955	955	955	955	955	955	955	955	955	955	955	955
Allocation between dwelling type (user have to choose between increasing/decreasing in share so the total sum equals 1)														
Apartments - Urban	39.71%	40.71%	41.71%	42.71%	43.71%	44.71%	45.71%	46.71%	47.71%	48.71%	49.71%	50.71%	51.71%	52.71%
Single House - Urban - Central	3.56%	4.06%	4.56%	5.06%	5.56%	6.06%	6.56%	7.06%	7.56%	8.06%	8.56%	9.06%	9.56%	10.06%
Single House - Urban - Local	15.46%	14.96%	14.46%	13.96%	13.46%	12.96%	12.46%	11.96%	11.46%	10.96%	10.46%	9.96%	9.46%	8.96%
Single House - Rural - Local	41.27%	40.27%	39.27%	38.27%	37.27%	36.27%	35.27%	34.27%	33.27%	32.27%	31.27%	30.27%	29.27%	28.27%
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Apartments - Urban		1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%
Single House - Urban - Central		0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
Single House - Urban - Local		-0.50%	-0.50%	-0.50%	-0.50%	-0.50%	-0.50%	-0.50%	-0.50%	-0.50%	-0.50%	-0.50%	-0.50%	-0.50%
Single House - Rural - Local		-1.00%	-1.00%	-1.00%	-1.00%	-1.00%	-1.00%	-1.00%	-1.00%	-1.00%	-1.00%	-1.00%	-1.00%	-1.00%
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Allocation per type														
Apartments - Urban	379	389	398	408	417	427	437	446	456	465	475	484	494	503
Single House - Urban - Central	34	39	44	48	53	58	63	67	72	77	82	87	91	96
Single House - Urban - Local	148	143	138	133	129	124	119	114	109	105	100	95	90	86
Single House - Rural - Local	394	385	375	366	356	346	337	327	318	308	299	289	280	270
	955	955	955	955	955	955	955	955	955	955	955	955	955	955
destruction rate per year (destrate)														
Apartments - Urban existing	0.2%													
Single House - Urban - Central existing	0.0%													
Single House - Urban - Local existing	1.0%													
Single House - Rural - Local existing	1.0%													
remaining dwellings														
Apartments - Urban existing	379	378	376	375	373	372	370	369	367	366	364	363	361	360
Single House - Urban - Central existing	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Single House - Urban - Local existing	148	145	142	139	136	134	131	128	126	123	121	118	116	114
Single House - Rural - Local existing	394	386	379	371	364	356	349	342	336	329	322	316	310	304
	955	943	931	919	907	896	884	873	863	852	841	831	821	811
remaining dwellings (reallocated)														
Apartments - Urban existing	379	384	388	392	397	400	404	408	411	415	418	422	425	428
Single House - Urban - Central existing	34	38	42	46	50	54	58	62	65	69	72	75	79	82
Single House - Urban - Local existing	148	141	135	128	122	116	110	104	99	93	88	83	78	73
Single House - Rural - Local existing	394	380	365	352	338	325	312	299	287	275	263	252	240	229
	955	943	931	919	907	896	884	873	863	852	842	831	821	811
Apartments - Urban new		5	10	15	21	27	32	38	44	50	56	63	69	76

ANSv6.48 Home | Commodities | DemandDrivers | Demand_Data | Base year calibration data | AGR Demand Projection | RSD Demand Projection | COM Demand Projection | IND Demand Projection

Figure 41. Screen shot from Residential demand projections

Commercial sector demand projections use GDP growth rate as the demand driver along with elasticities and AEI factors. A space cooling penetration rate projection is also used, but for others services, the possible increase in penetration is embedded in the elasticity factor. Heating and cooling demands are corrected based on the degree-days correction factor. Figure 42 shows screen shot from COM Demand projection sheet.

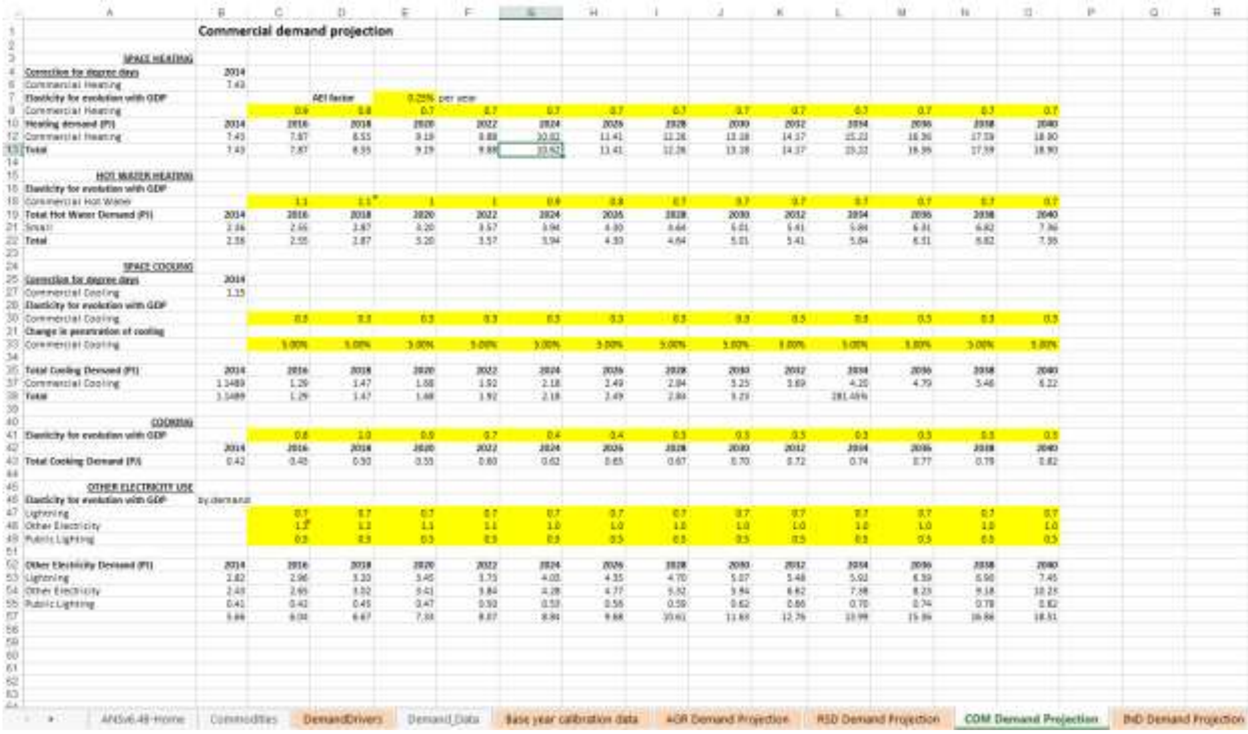


Figure 42. Screen shot from Commercial demand projections

Industry sector demand projections use the value added (or production) growth rate for each industrial subsector as the main demand driver in addition to elasticities and AEI factors. Figure 43 shows screen shot from "IND Demand projection" sheet. Figure 44Figure 43 shows screen shot from the IND Demand projection sheet.

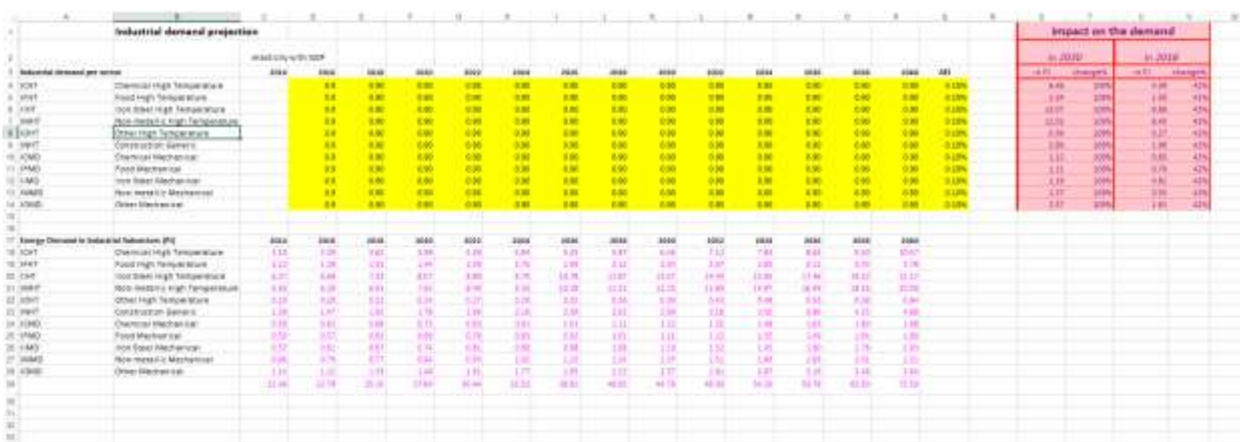


Figure 43. Screen shot from Industrial demand projections

Non-energy sector demand projections use GDP growth rate as the main demand driver and apply elasticities to calculate demands. TED projections are calculated separately based on TED growth rates. Figure 44Figure 43 shows a screen shot from the LEDS_Georgia_BY-TED+NON sheet.

Figure 44. Screen shot from non-energy and TED demand projections

LEDS_Georgia_Demand_Projections-TRN template is used to calculate demand projections for transport end uses. It links to LEDS_Georgia_Demand_Projections-REF template to take assumptions on GDP and population growth rates which are the main demand drivers for transport sector as well. The base year demand values are taken from base year transport template.

In addition to GDP and population growth, the transport service projections depend on other parameters, which include annual mileage and load factors, which in case of MARKAL-Georgia are kept constant over whole projection period. The sheet Inputs is used to display the base year service demands and make changes in future year projections for mileage and/or load factors, if desired. Figure 45 shows the screen shot from this sheet.

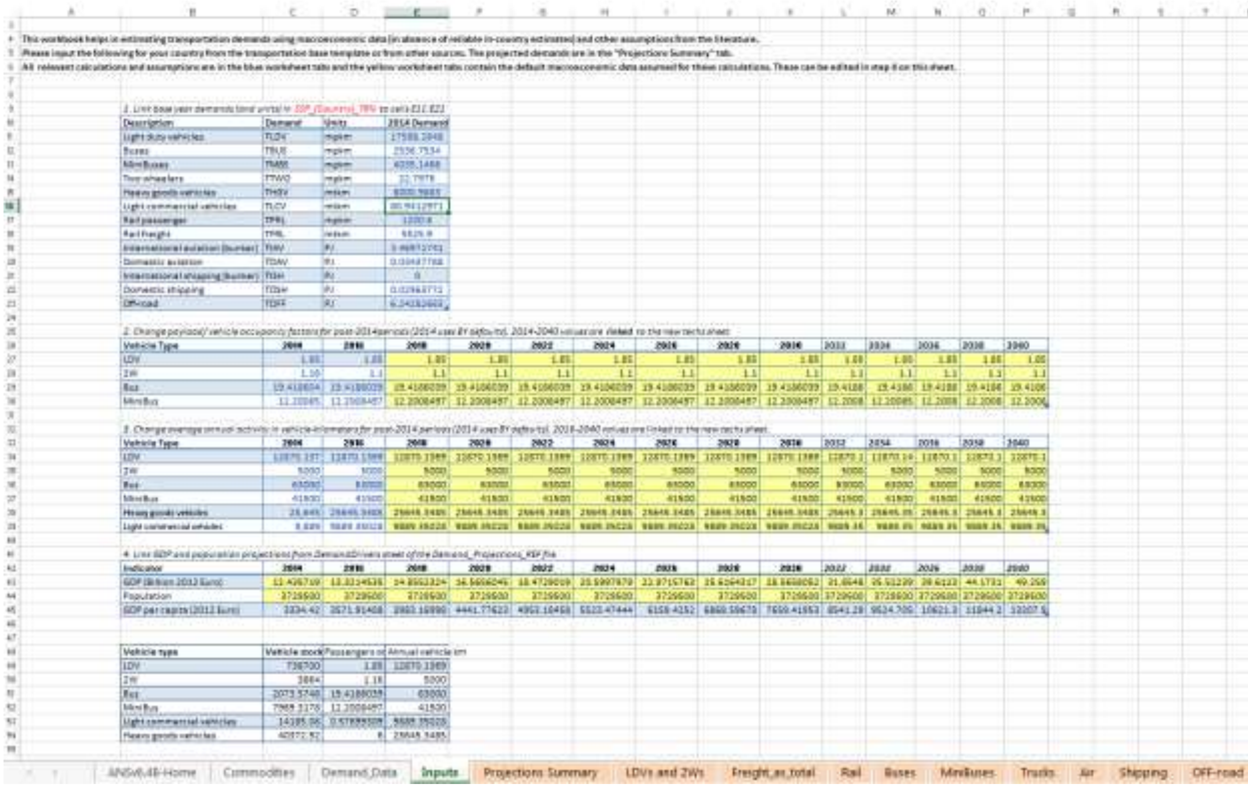


Figure 45. Transport sector demand projections "Inputs" sheet

The calculations of end use projections for individual transport services are given in individual sheets. The demand for LDV and 2-wheeler travel is using GDP per capita growth rate as demand driver with corresponding elasticities. Figure 46 shows screen shot from transport demand projections file for LDVs and two-wheelers.

Figure 46. Transport demand projections for LDV and two-wheelers

Bus and mini-bus demand projections are based on bus stock projection rates. All other demands use national GDP as demand driver and individual elasticity factors. The sheet Projections Summary shows total projections for transport services by tables and graphs.

Table 22 lists the data that is needed for projecting demand and documents the data sources and assumptions for MARKAL-Georgia

Table 22. Summary of Data Sources for the Demand Projections

Data Type	Data Source/Assumptions
Population:	
Base-year population;	GeoStat
Projected population growth (%) to 2030;	When current version of MARKAL-Georgia model was developed, the results of 2014 national census were just published, but the trends of population numbers haven't been yet corrected. Thus it was impossible to judge whether population numbers are increasing or decreasing. Because of this it was decided to assume the constant population number (no growth)
Projected annual change in household size (%) to 2030;	This also was assumed to be 0.
GDP:	
Base-year GDP;	GeoStat
Projected GDP growth (%) to 2030;	3.5% in first two periods 9based on actual data and forecast for 2016) and 5.6% afterwards which is average growth rate for past 15 years.
Other:	
Base year degree days;	National Meteorological office (Tbilisi station used as proxy)
Average degree days;	National Meteorological office (Tbilisi station used as proxy)
Agriculture:	
Projected agriculture production growth (%) to 2030;	There are no separate projections for agriculture so it was assumed to equal national GDP growth rate.
Elasticity of agriculture energy demand with GDP;	0.7, assumption
AEI factor for agriculture;	0.3%, assumptions (based on other SSP models)
Commercial:	

Elasticity of each of the end-use demands with GDP;	Individual yearly assumptions for each service: Heating: 0.9, going down to 0.7 by 2020 and staying constant afterwards Hot Water: 1.1 (to account for increased penetration), going down to 0.7 by 2028 and staying constant afterwards Cooling: 0.3 Cooking: 0.8, going down to 0.3 by 2028 and staying constant afterwards Lighting: 0.7 Public Lighting: 0.5 Other electricity: 1.3 (to account for increased penetration), going down to 1 by 2024 and staying constant afterwards. This is consistent with overall GDP electricity consumption elasticities for middle income countries.
Projected growth of penetration of Cooling (%) to 2030;	Annual 5%, assumption
AEI factor for space heating (%)	0.25%, assumption (based on other SSP models)
Industry:	
Base-year value added for each of the industry sectors;	Geostat
Projected annual growth for each of the industry sectors (%) to 2030;	There are no official separate projections for individual sectors, so it was assumed that all increase with same rate equal to national GDP growth rate
Elasticity of each of the end-use demands, for each industry sector, with sectoral growth;	0.9. Since industry is energy intensive, elasticity should be close to 1.
AEI factors (%)	0.1%, assumption (based on other SSP models)
Residential:	
Projected annual changes in allocation between household types (%);	Moderate assumptions on 1% migration from rural to urban areas.
Destruction rate for each household type (%);	Moderate assumptions on 0.2% for apartments and 1% for single houses
Elasticity of each of the end-use demands, for each household type (C, H, W) with GDP/Capita;	Individual yearly assumptions for each service and dwelling type (please see template for details)

Projected growth of penetration of Cooling in each household type (%) to 2030;	Residential survey for base year and assumptions (please see template for details)
AEI factor for space heating (%);	0.01%, assumption (based on other SSP models)
non-energy and TED:	
Projected annual changes in TED (%)	Ministry of Energy
Elasticity of demand in non-energy;	0.8, assumption
Transport:	
Elasticity of LDV and 2W demands with GDP/Capita;	IEA/SMP Model Documentation and Reference Case Projection, L. Fulton, IEA / G. Eads, CRA, 2004
Elasticity of all other demands with GDP;	Thompson, 2003
Changes in bus and mini bus stocks	Thompson, 2003

4.3.3 New Power Generation Technologies

The New Power Plant Technologies template (NEWTCH-PP) contains the matrix of new technologies that represent potential investments in power generation technologies in Georgia.

For each technology a detailed set of technical and economical characteristics is provided:

1. The **lifetime** of the technology
2. The **starting period**, when a technology is available for investment
3. **Efficiency** (%)
4. **Annual Availability factor (%)**
5. **Seasonal and Time-slice availability factors (%):** especially for renewable technologies (hydro, wind and solar)
6. **Investment Costs:** representing overnight capital cost (€/KW)
7. **Fixed Operation and Maintenance Costs** (€/KW)
8. **Variable Operation and Maintenance Costs** (m€/PJ)
9. **Contribution to the Peak (%):** representing the upper limit a plant can generate when peak demand is met. Introduced in order to prevent unrealistic contribution to the peak demand from renewable technologies.
10. **Investment limits (up/fx/low):** upper limits capture national technical potential of heat/power technologies. Lower and fixed limits capture already committed heat/power projects for the future.

The Data source file DataSource_NewPPs holds information about different types of individual plants in Georgia, which either have already been constructed since 2014, are under construction, have memorandums of understanding signed, or are potential projects. Larger plants are represented individually, while others are grouped and represented as a power plant type in NEWTCH-PP.

The following new power plant technologies are represented in MARKAL-Georgia:

- Hydro Plants
    - Khudoni Hydro power Plant
    - Nenskra Hydro power plant
    - HPPs under construction, including all HPPs that are either already constructed, are under construction and those that have Power Purchase Agreement (PPA) of 10 months or more.
    - New HPPs (seasonal), includes hydro power plants that have PPA less than 10 years and other known potential hydro projects with seasonal dispatching possibility
    - New HPPs (RoR), includes run of river hydro power plants that have PPA less than 10 years and other known potential run of river hydro projects
    - General HPP type, that doesn't represent any known project but can be identified and built later on (after 2026)
- Solar
    - solar PV (not included in BAU, but can be included in other scenarios)
- Wind
    - Kartli wind farm (Kartli)
    - Other potential wind farms
- Natural gas
    - Gardabani Thermal Power Plants
    - New Natural Gas Combined Cycle Power Plants
- Coal
    - Small Coal Power Plant
    - Large Coal Power Plant

Number of new power plants are forced to be built in the BAU scenario, because either they are already under construction or are strongly committed. These include plants that have PPAs of more than 10 years.

Such forced plants include: Khudoni (700 MW in 2024), Nenskra (280MW in 2022), PPs under Construction (114MW in 2016, 364MW in 2018, 117MW in 2020, 6MW in 2022, 177MW in 2024), Kartli Wind Plant (20.7MW in 2018), Gardabani TPP (232.1MW in 2016), small coal plant (13 MW in 2016) and large coal plant (150MW in 2020).

The NEWTCH-PP template links to the DataSource_NewPPs file to take all information that it requires. This information is assembled in data sheet "CON_TECHS_NEW", where the user can review and adjust the values. Figure 47 shows the screen shot from this sheet. Other sheets in this template take values from this sheet and prepare them for model input.

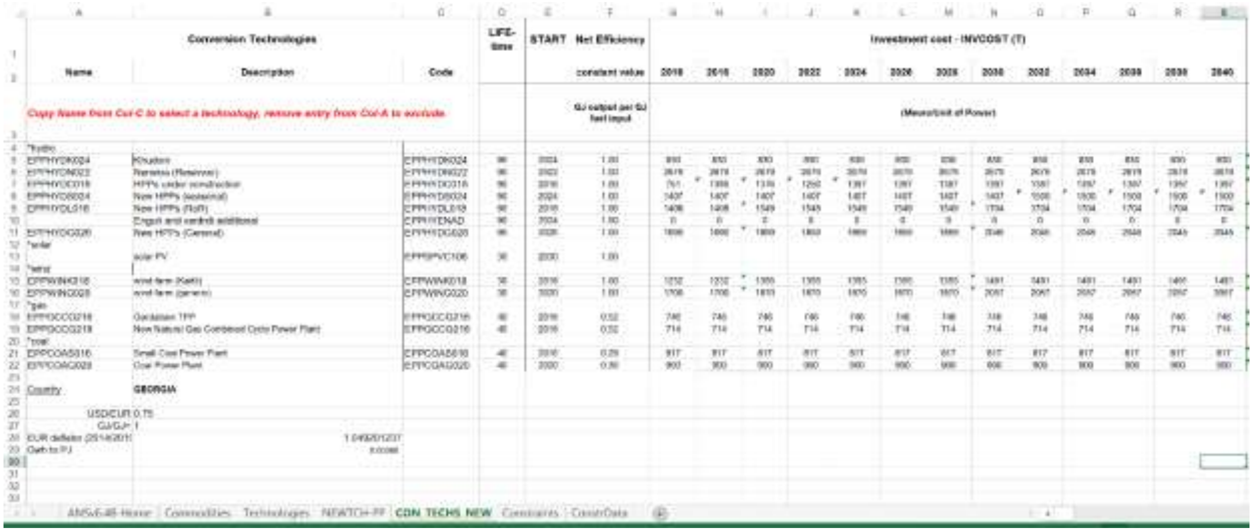


Figure 47. Screen shot from NEWTCH-DMD template

There is one more template which affects power sector behavior in the BAU scenario. This is LEDS_Georgia_UC-thermalPP. The template sets a User Constraint, ensuring that the split of generation shares of thermal and hydro plants (20% thermal – 80% hydro) in base year is maintained over future periods.

Table 23 documents data sources for defining characteristics of new power plants.

Table 23: Summary of Data Sources for New Power Plants

Data Type	Data Source/Assumptions
Investment Costs of power Plants	Ministry of Energy, based on investment costs of existing projects with assumptions that: Cost of new RoR HPPs increases by 10% compared with existing projects by 2020, and by 10% more by 2030. This is based on the assumption that easier/cheaper projects are implemented in the beginning and HPPs built later on will require more finances. Investment cost of generic hydro power plant is 10% higher than cost of new RoR HPPs. This is due to the necessity for the model to pick existing projects before picking generic HPP. Costs of generic wind farm are based on IEA Wind, 2011.
Fixed and variable Costs of power Plants	Fixed and Variable Costs of hydro and gas plants - Fixed and Variable Costs of existing (BY) Plants Fixed and Variable Costs of wind plants are based on IEA Wind, 2011. Fixed and Variable Costs of coal plants – Ministry of Energy.
Efficiencies	Ministry of Energy
Available factors/Capacity factors	For thermal plants – Ministry of Energy For hydro plants – 5-year average seasonal AFs of existing plants

	For wind plants – Ministry of Energy, EC-LEDS wind power report
Starting period and Investment limits	Ministry of Energy as described above.

4.3.4 New Demand Technologies

The new demand devices are made available through the NEWTCH-DMD template library of the possible future demand technologies, from which the country analyst selects those to be made available to the energy system.

For each technology a detailed set of technical and economic characteristics is provided:

1. The **lifetime** of the technology
2. The **starting period**, after which a technology is available for investment
3. **Annual Capacity factor (%),** representing the annual utilization percentage of each technology. Note that this stays fixed through the years, is unique for each end use (e.g. all the cooling devices have the same capacity factor) and, also remains the same for each season and time slice.
4. **Efficiency Rate**
5. **Investment Costs(€/KW)**
6. **Fixed Operation and Maintenance Costs(FIXOM) (€/KW)**
7. **Variable Operation and Maintenance Costs(VAROM) (m€/PJ)**

The whole list of technologies has been reviewed to determine which are to be available for investment in MARKAL-Georgia. This has been mostly determined by either the presence of a technology/fuel in the base year or the potential of its introduction in future years.

The template LEDS_Georgia_NEWTCH-DMD has several sheets. The main data sheet is NewDMD_Char, where the repository of demand technologies is given. The technology will be included in the model as possible investment option if its name is included in Column A. Some information from other data sources that have been used are kept in separate sheets, such as “Current_Data” and “Seven data”. The Demand sheet links to the Demand projection template to get information on heating and cooling demands and to correctly set insulation technology limits. Other sheets set necessary inputs for MARKAL model and define UCs for heat pumps, which make sure that heat pumps satisfy both heating and cooling demands.

Another template specifically for the transport sector is LEDS_Georgia_NEWTCH-TRN, where new demand technologies for transport are specified. The sheet “User Input” links to the BY and Demand projections templates to take information on demands and other transport characteristics, such as mileages, load factors and efficiencies, which are needed to calculate model input parameters for new transport technologies based on international datasets. There are several data sheets in the template that hold information from international datasets that then are converted for model inputs. The sheets are: Freight&rail, DOE LDV Data, DOE Bus Data, Mini-Bus Data, UK+DOE Other Transport Data, and EU GHG 2050 Sultan Tool, which list information and include all necessary calculations. Sheet Conversion Factors holds deflator values for different currencies and other conversion factors needed to convert information in international databases to the units used in MARKAL-Georgia. All other sheets represent MARKAL-Georgia inputs.

Table 24 provides information on the data sets used for setting up parameters for new demand technologies.

Table 24: Summary of Data Sources for New Demand Devices

Data Type	Data Source/Assumptions
New demand technology characteristics in all sectors other than Transport	Initial data source was the NEEDS database, which has been updated and revised using recent data from the ETSAP demand technology data sets[13] and from the National Renewable Energy Lab[14]. Efficiencies and CFs have been reviewed and revised in some cases to match the BY data
Transport new demand Technologies	US Department of Energy transport technology database from the National Energy Modeling System EU Transport GHG: Routes to 2050 project (http://www.eutransportghg2050.eu/cms/?flush=1)

4.3.5 Scenario Specific User Constraints

The UC workbook contains data that specifies the constraints on the share of competing technologies to meet end-use demands for all the demand sectors. They are used, for example, to prevent excessively rapid fuel switching for residential space heating based on short term price fluctuations.

Most of the parameters imported from this template are calibrated to the data in the sector energy balances. By default, all the constraints are set such that the base-year picture is maintained throughout the study period. The process of setting up the model includes working through each of these default values one-by-one, with a careful review of model behavior, in order to establish the Reference Case.

The data needed for this workbook:

1. **Final year upper limits (%):** some of the demand technologies have been assigned upper limits of penetration. The data needed is for a business as usual scenario, and specifies what the maximum penetration/share may be by 2030 (kept constant after 2030). The limits for the intermediate years are interpolated from the initial share based on the energy balance.
2. **Final year lower limits (%):** In the same way that some of the demand technologies have been assigned upper limits of penetration/share, others have been assigned lower limits, and some both. The data needed is for a business as usual scenario, and specifies what the lowest penetration/share will be by 2030 (kept constant after 2030). The limits for the intermediate years are interpolated from the initial share – based on the energy balance.

LEDS_Georgia_UC10 is the template setting UCs for BAU scenario. UCs in each of the sectors are presented in separate sheets. The Shares sheet is used to calculate initial share of each fuel in each service demand. The Demands sheet links to the demand projections templates to get projections of demands necessary for setting up some of the UCs.

[13] http://iea-etsap.org/index.php/energy-technology-data/energy-demand-technologies-data

[14] National Residential Efficiency Measures Database, Final Draft, June 2012

Figure 48 shows a screen shot of the user-constraint input template, constraints highlighted in red are upper limits and the ones in green are lower limits.

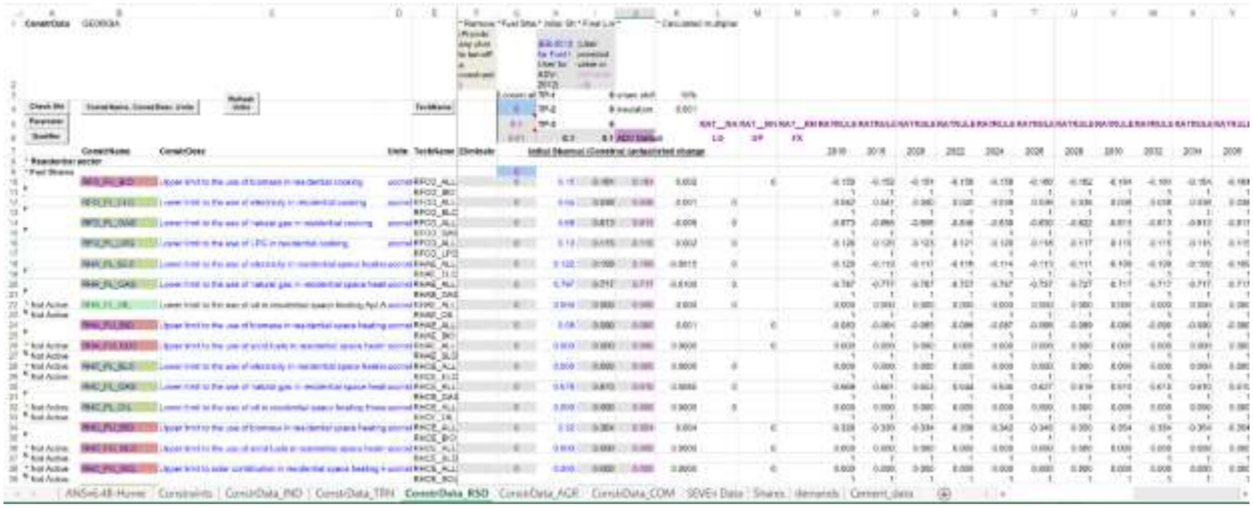


Figure 48. Scenario-user constraints on demand technologies

Table 25 documents the assumptions used to set final shares of fuels and technologies.

Table 25. Summary of Data Sources for User Constraints

Data Type	Data Source/Assumptions
Advanced Technology penetration	10% by 2030
Fuel share change in each end use	10% change compared to BY levels by 2030
Insulation penetration	Assumed to be 1% in BAU scenario

Another template that helps to smooth model behavior is LEDS_Georgia_BAU-BOUNDLO, which sets gradually decreasing lower bounds on existing BY demand technologies, making sure that none of the existing technologies are retired or discarded too quickly. There is no need to make any changes to this template, but if any of BY templates have been modified, this template needs to be opened, links updated and reimported into ANSWER.

4.3.6 Country Specific Limits

The POT-LIM workbook allows for the specification of any additional limits desired to reflect country-specific conditions. LEDS_Georgia_BAU-POT_LIM template sets limits for solar and geothermal energy in Georgia. For example, limits on the potential of renewable electricity generation technologies must be specified here, if not in the NEWTCH-PP workbook. Table 26 documents the limits imposed in MARKAL-Georgia.

Table 26. Summary of Data Sources for Country Specific Limits

Data Type	Data Source/Assumptions

Solar energy limits	2PJ
Geothermal energy limits	7.6PJ

4.4 Alternative Scenario Basics

Alternate scenarios are usually designed to test the impact of possible changes from the BAU (Reference) scenario arising from policy, supply, price or technology interventions that may alter the evolution of the energy system. Therefore, these scenarios are usually based upon imposing explicit changes from the Reference scenario values. These can take the form of:

- A forced change in the absolute value of a Reference scenario result, e.g. decrease in final energy consumption of 25% by a target year;
- A forced change in the share of a Reference scenario result, e.g., a target share of 50% renewable electricity generation by a target year, and
- The introduction of a cost or tax on the system, e.g., imposing a price on carbon emissions.
- Addition of a new technology or resource supply option, and any other change in Reference scenario assumptions.

In the case of those scenarios that are based upon setting a target derived from a Reference scenario level, these scenarios must be seeded with the appropriate Reference scenario values, which may be done via Copy/Paste from the appropriate VBE table, and then the desired policy described and imported into ANSWER as a separate scenario that can be then be included in the model runs independently of or in combination with other such scenario variants. This ability to directly impose a policy goal or other alternative view of the future and have ANSWER/TIMES reconfigure the resulting energy system to find the new least-cost evolution of the energy system adhering to this new development is one of the key differences between an optimization framework such as TIMES and a simulation or accounting framework (such as LEAP[15]).

As mentioned in the previous section, under most policy situations the user will want to replace the Reference scenario UCs and other Reference guidance mechanisms that restrict the rate at which fuel switching and new technology uptake can take place with looser versions that permit more fuel switching and more rapid uptake of new technologies.

Here we consider just one example of such scenario, which is the forced reductions in Greenhouse Gas emissions (in CO_2 equivalent) by 2030 below the Reference scenario levels. This can be done using template LEDS_Georgia_Scen_GHG-LIM20.

The template creates a upper bound on GHGNRG (GHG emissions from energy sector) to a certain number, which is 20% less than the BAU reference value. The target levels are specified to the model via the CommData tab, but they are generated on the GHG_REF tab, where the Reference scenario results are captured by copy-pasting the specified VBE table as shown in the screen shot in Figure 49. The VBE table shows total CO2 equivalent emissions from all GHGs, and the calculations below the table provide the calculation of GHG levels for new scenario. The reduction percentage rates are user-specified in the yellow cells and may vary over time.

[15] http://www.energycommunity.org/default.asp?action=47

The proper operation of the scenario may be checked on the GHG_Scen tab – by using the same VBE table, but copy-pasting the new scenario results into this checking sheet, where any variation can be seen.

Global Filter Applied For: Scenario - R05

Table Name: Use-Aggregated CO2 eq Energy only

Active Unit: kt

Scenario	CommodityDesc\TimePeriod	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
R06	CO2 eq Methane Emissions -Energy u	1460.026	1595.1	1751.426	2092.835	2256.407	2411.269	2547.726	2735.251	2926.678	3108.211	3297.404	3489.981	3701.28	3931.022
R06	CO2 eq N2O Emissions - Energy use	52.8413	56.6001	60.5205	65.3423	69.9437	73.9759	77.7786	82.0201	86.3796	91.0123	95.8514	101.0212	106.5843	112.5713
R06	Total Energy Sector CO2 Emissions (	7674.286	8263.058	9112.303	10970.26	11922.9	12692.6	13435.69	14359.02	15224.01	16197.91	17191.59	18253.18	19416.93	20685.05
R06	Total	9187.153	9914.758	10924.25	13128.23	14249.25	15178.04	16061.2	17176.29	18237.07	19397.13	20584.85	21844.15	23224.8	24728.64
	Target %		0%	3%	5%	8%	11%	14%	17%	20%	20%	20%	20%	20%	20%
	Target Emissions, kt		9914.758	10851.14	12471.82	13109.31	13508.46	13812.63	14256.32	14589.65	15517.71	16467.88	17475.32	18579.84	19782.91

Figure 49. GHG Emission Reduction Adjustment Table

During the recent EC-LEDS GHG emission mitigation analysis 55 different scenarios have been created and analyzed. Each scenario has its own assumptions and logic, which is not discussed here. For information on scenarios and their results please see EC-LEDS project report on mitigation measures.