Rumi

An open-source energy systems modelling platform developed by Prayas (Energy Group)

Demand documentation

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1 Introduction

This document describes the various inputs that need to be provided to set up a model instance that can help estimate energy demand. Energy demand arises from a set of 'demand sectors'. Each demand sector has a set of 'consumer types' or 'consumer categories' – the types/categories of entities in that sector who demand 'energy services'. Energy demand is specified for each consumer type who demands an energy service in a demand sector. This energy demand can be specified in multiple ways as described in this document. The most detailed way of specifying energy demand is by describing it bottom-up, as briefly explained below. Energy services are requirements / needs of consumers in a demand sector, which are typically met through 'energy service technologies'. Note that the same energy service may be demanded in multiple demand sectors (e.g. lighting or cooling in both residential and commercial sectors). Energy service technologies provide an energy service through the use of some energy carrier. Different energy service technologies can provide the same energy service, perhaps using different energy carriers. Each energy service technology can have multiple 'efficiency levels' – i.e. different amounts of input energy required to provide the same unit of energy service. Rumi allows such specification from which demand is computed.

The demand inputs are intended to capture the above set of information from the modeller at the level of detail of interest to the modeller. All inputs to Rumi are in the form of comma-separated value (csv) files with a certain structure. Many input files have header rows with defined column names, but some do not. For any input file that has a header row with named column headers, the order of the columns is immaterial. But if there is no header row, then the order of columns is important and should be exactly as documented. The Rumi platform will then compute the total energy demand (by energy carrier, by energy service, by demand sector, by consumer category etc.) for each time and geographic granularity of interest, so that the demand can be satisfied through suitable supply options.

All demand side inputs are provided through files under the `Demand/Parameters` top-level directory (referred to as the `Root` directory henceforth) under the scenario root directory (or, alternatively, `Global Data/Demand/Parameters` if the information is common across many scenarios). Depending on the inputs provided, there is a further directory structure under `Demand/Parameters`, which is explained further in this document. Broadly, the `Root` directory consists of input files which are cross-cutting in nature, such as the definition of demand sectors, energy services and service technologies, and other inputs that apply across various demand sectors, energy services, etc. At the root level, there will also be one directory per demand sector. Inputs specific to a demand sector are provided in the corresponding directory. Each demand sector directory may have further sub-directories – one corresponding to each energy service. These have files with information specific to that combination of demand sector and energy service.

2 High level inputs

These inputs define the various demand sectors, energy consumers, energy services, and technologies providing energy services along with their characteristics. In addition, these inputs also define the relationships across these entities and the geographic and temporal granularity at which demand inputs are provided for them.

2.1 DS_ES_Map.csv

Directory: `Root`

Columns: `DemandSector, EnergyService, InputType`

Each row in this file provides a combination of a demand sector (DS) and an energy service (ES) required in that demand sector. In addition, in the last column, it also provides information about how the demand for this energy service as used in this demand sector is specified. This value can be one of `EXTRANEOUS, GDPELASTICITY, BOTTOMUP` or `RESIDUAL`. Briefly, these mean the following:

- `EXTRANEOUS` means the energy demand for this DS-ES combination is provided exogenously
- `GDPELASTICITY` means the energy demand for this DS-ES is to be estimated based on a supplied GDP elasticity of demand
- `BOTTOMUP` means that energy demand is to be estimated based on energy service demands, and details of energy service technologies that are provided
- `RESIDUAL` means that the energy demand for this DS-ES is a residual demand over and above all other demand that has been estimated. For a DS, at most one ES can be residual.

Further details of these are given later in this document. Note that this file implicitly defines all the demand sectors and energy services that are being modelled. Any sector or service that is not listed in this file cannot appear later in subsequent inputs.

Example[1]:

- `D_RES, LIGHTING, BOTTOMUP`: The residential demand sector (`D_RES`) needs the lighting energy service which is defined in a bottom-up manner
- `D_AGRI, IRRIGATION, GDPELSATICITY`: The agricultural demand sector (D_AGRI) needs the irrigation energy service, the energy demand for which is defined using GDP elasticity.

2.2 DS_ES_EC_Map.csv

Directory: `Root`

This file maps a DS-ES combination to the various energy carriers (EC) that may provide that ES, and is relevant only for those DS-ES combinations that are not specified bottom-up. The first column should be the name of a demand sector as specified in the `DS_ES_Map.csv` file or the keyword `ALL` to signify all demand sectors for which demand inputs for this ES (listed in the second column) is specified in a non-bottom-up way. The second column is the name of an ES relevant to this DS and whose input-type

[1] All examples provided in these documentation files are intended to be purely for illustrative purposes and do not necessarily present ‘realistic’ values.

is not BOTTOMUP. Each of the third and subsequent columns contains the name of an energy carrier that provides this energy service for this demand sector. The EC must be one of the carriers specified in the common inputs, but it cannot be a non-physical primary energy carrier.

This file does not contain a header row, as it has a variable number of columns. Hence, the order of the columns as described above should be adhered to. If the DS_ES_Map.csv file defines the input-type for a DS-ES combination as RESIDUAL, then for each EC given in this file for such a DS-ES combination, there must be at least one other ES for that DS in DS_ES_Map.csv whose input type is not RESIDUAL. This ensures the presence of a base value whose residual can be computed.

Example:

- D_AGRI, IRRIGATION, ELECTRICITY, HSD: The irrigation service for the agricultural sector is provided by two energy carriers, namely electricity and high-speed diesel.

2.3 DS_ES_ST_Map.csv

Directory: Root

This file maps a DS-ES combination whose demand inputs are provided bottom-up (as given in DS_ES_Map.csv) to the service technologies (ST) providing this ES for this DS. The first two columns of each row are the demand sector and the energy service. The subsequent columns indicate the names of the service technologies providing this ES in this DS[2]. The DS column can be ALL indicating that all the listed STs are used to provide this ES in all the demand sectors for which this ES is specified in a bottom-up way. One ST can only provide one ES across all the demand sectors.

This file does not have a header row, and can have a variable number of columns. Hence, the order of the columns as described above should be adhered to.

Examples:

- D_RES, COOL, CL_FAN, CL_COOLER, CL_AC: The cooling service in the residential sector is provided by three technologies, namely fans, coolers and ACs.
- D_RES, COOK, CK_LPG, CK_BIOGAS, CK_ELEC: The cooking service in the residential sector is provided by three technologies, namely LPG stoves, biogas stoves and electric stoves.

2.4 ST_Info.csv

Directory: Root

Columns: ServiceTech, EnergyCarrier, EnergyServiceUnit, NumEfficiencyLevels

[2] Note that the name of the ST cannot contain a plus (+).

This file provides further information about the various service technologies (STs) that provide energy services. The first column mentions the service technology for which information is being provided. The second names the energy carrier used to provide the service. The third gives the name of the unit in which the energy service provided by this technology is measured – this is just for documentation and clarity for the modeller. The last column lists the number of different efficiency levels modelled for this ST, which is a positive integer.

Example:

- `CL_FAN, ELECTRICITY, CH, 1`: Indicates that fans use electricity as the energy carrier, use ch (cooling hours) as the energy service unit and only have one efficiency level.
- `CL_AC, ELECTRICITY, CDH, 3`: Indicates that ACs use electricity as the energy carrier, use cdh (cooling degree hours) as the energy service unit and have three efficiency levels (perhaps corresponding to different star ratings).
- `CK_LPG, LPG, USEFULMJ, 2`: Indicates that LPG cookstoves use LPG as the energy carrier, their energy service unit is the amount of useful energy required (in MJ) and two efficiency levels are modelled (perhaps BIS standard and unlabelled).

2.5 DS_Cons1_Map.csv

Directory: `Root`

Consumer types (CT) in Rumi can be specified as a two-level hierarchy to allow structured definition of different types of consumers. Every DS must map to at least one (first level) CT. This file maps a DS to a set of first level consumer types for that DS, and the time and geographic granularities at which the input regarding number of consumers is given.

This file has no header row since it has a variable number of columns, thus the following column order should be adhered to. The first column specifies the name of the DS for which consumer details are being given. The second column mentions the geographic granularity at which consumer details are given for this sector (for example, see Section 2.9) and it can be one of the keywords `MODELGEOGRAPHY, SUBGEOGRAPHY1, SUBGEOGRAPHY2`, or `SUBGEOGRAPHY3` corresponding to the level at which this information is provided. Similarly, the third column indicates the temporal granularity at which consumer details are specified and it can be one of the keywords `YEAR, SEASON, DAYTYPE, DAYSLICE`. Each column from the fourth column onwards gives the name of a first level CT for this DS.

The geographic granularity must be finer than or equal to the granularity at which any demand input is given for this DS (see `DS_ES_EC_DemandGranularity_Map` below). The time granularity must be coarser than or equal to the time granularity at which any demand input is given for this DS. These restrictions allow the number of consumers for the right time-geographic granularity to be estimated consistent with the requirement of all the ECs, as they can be aggregated over the finer geographies and the value for the coarser time granularity can be used for each finer granularity[3]. The geographic and temporal granularity provided in this file are relevant only for DS-ES combinations for which demand is specified bottom up, and is not used for the non-bottom-up combinations.

Each element of this first level CT can optionally further map to a set of second level consumer types. However, for a given DS, either there is no second level CT at all, or every element of the first level CT maps to at least one second level CT.

Example:

- `D_RES, SUBGEOGRAPHY2, YEAR, RES_URBAN, RES_RURAL`: to indicate that the residential sector has two first level CTs corresponding to urban and rural residences, whose details are given at the mentioned geographic and temporal granularity
- `D_TRANS, SUBGEOGRAPHY1, YEAR, TRANS_LOCAL, TRANS_NONLOCAL`: to indicate that the transport sector has two first level CTs corresponding to local and non-local transport.
- `D_IND, MODELGEOGRAPHY, YEAR, IND_STEEL, IND_CEMENT, IND_PAPERPULP, IND_OTHERS`: to indicate that the industry sector has four first level CTs corresponding to the steel, cement, paper & pulp and other industries.

2.6 Cons1_Cons2_Map.csv

Directory: `Root`

This file lists the second level consumer types for first level consumer type. It is also without a header row, hence the order of the columns matters. The first column indicates the first level consumer type while the subsequent columns indicate the further split of the first level consumer type into finer consumer types. As stated above, either there is no second level CT at all for a DS, or every element of the first level CT of a DS maps to at least one second level CT. For those first-level CTs that don't have second-level CTs, no rows need to exist in this file.

Example:

- `RES_URBAN, UQ1, UQ2, UQ3, UQ4, UQ5`: Indicates that urban residential consumers are split into five sub-categories corresponding to five expenditure quintiles.
- `RES_RURAL, RQ1, RQ2, RQ3, RQ4, RQ5`: Indicates that rural residential consumers are split into five sub-categories corresponding to five expenditure quintiles.
- `TRANS_LOCAL, L_PASS, L_FREIGHT`: Indicates that local transport consumers are split into local passenger and local freight consumers.
- `TRANS_NONLOCAL, N_PASS, N_FREIGHT`: Indicates that non-local transport consumers are split into non-local passenger and non-local freight consumers.

[3] Typically, throughout Rumi, inputs that can be aggregated up along a dimension can be provided at finer granularities than required for that dimension, and inputs that can be identically applied to finer granularities can be provided at coarser granularities.

- IND_STEEL, LARGE_STEEL, SMALL_STEEL: Indicates that steel industry is split into large and small steel manufacturers.
- IND_CEMENT, ALL_CEMENT: Does not split the cement industry into finer categories, but this input is required because the steel industry (a first level consumer type of the industry demand sector) has been mapped to second level consumer types.

2.7 DS_ES_EC_DemandGranularity_Map.csv

Directory: Root

Columns: DemandSector, EnergyService, EnergyCarrier, ConsumerGranularity, GeographicGranularity, TimeGranularity

For each DS-ES-EC combination, this file specifies the finest consumer, geographic and time granularity at which the demand inputs (either energy carrier demand directly or energy service demand in the case of bottom-up specification) will be given. The consumer granularity must be one of the following keywords: CONSUMERALL, CONSUMERTYPE1, CONSUMERTYPE2. The CONSUMERTYPE1 keyword signifies that the demand input would be given at the first consumer level granularity, while the CONSUMERTYPE2 keyword signifies that the demand input would be given at second consumer level granularity. On the other hand, the CONSUMERALL keyword signifies that the demand input would be given at the demand sector level i.e. for the entire demand sector, without any consumer granularity. The consumer granularity specified must be coarser or equal to the actual number of consumer levels for this demand sector.

The geographic and time granularities[4] must be one of the values mentioned in Section 2.5. The time and geographic granularities must be respectively finer than or equal to the balancing time and balancing area of the EC, to allow the energy demand to be aggregated at the balancing time and area of the EC. The energy service column can be ALL to indicate that all ES for a particular DS provided by a particular EC will be specified at the indicated granularities.

The consumer, time and geographic granularities of a RESIDUAL energy service must be respectively coarser than or equal to the corresponding granularities of all the other ES for that DS using this EC. This allows the demand from the other ES for this DS-EC combination to be aggregated up to the level required for the RESIDUAL energy service, allowing the calculation of the residual value.

Example:

- D_AGRI, IRRIGN, ELEC, CONSUMERTYPE1, SUBGEOGRAPHY2, DAYSLICE: states that inputs for the irrigation energy service provided by electricity would be given at the first consumer type, sub-geography2 and day-slice granularities.

[4] The time granularity is irrelevant for DS-ES combinations whose input-type is GDPELASTICITY since GDP values are accepted at an annual granularity. In such cases, it is simply ignored.

- D_AGRI, IRRIGN, HSD, CONSUMERTYPE1, SUBGEOGRAPHY1, YEAR: states that inputs for the irrigation energy service provided by diesel would be given at the first consumer type, sub-geography1 and annual granularities.

2.8 DS_ST_Granularity_Map.csv

Directory: Root

Columns: DemandSector, ServiceTech, ConsumerGranularity, GeographicGranularity, TimeGranularity

This map is relevant for the inputs that provide the characteristics of an ST such as efficiency and penetration (refer to Sections 3 and 4). Since STs are applicable only to DS-ES combinations whose demand is specified bottom up, this map is applicable only to those combinations. For each DS-ST combination, it specifies the consumer, geographic and time granularities at which these inputs will be given where the granularities are specified similar to the sections above. Each of these consumer, geographic and time granularities must be coarser than or equal to the corresponding consumer, geographic and time granularities at which the energy service demand input for this DS-ST combination will be given (as specified in the corresponding entry of DS_ES_EC_DemandGranularity_Map).

Example:

- D_RES, CL_FAN, CONSUMERTYPE2, SUBGEOGRAPHY2, DAYSLICE
- D_RES, CK_LPG, CONSUMERTYPE1, SUBGEOGRAPHY1, YEAR

2.9 NumConsumers.csv

Directory: Root/<DemandSector>

Columns: C*, G*, T*, NumConsumers

This input is only relevant for DS-ES combinations whose demand is specified in a bottom-up fashion. This file describes the number of energy consumers in the demand sector by consumer type, geography and time. The granularity at which this input is given is as defined by DS_Cons1_Map and the number of consumer levels defined for this DS. Thus, C* in the column description above represents either one or two consumer type columns. The file would have one column with header ConsumerType1 if this DS has only defined one level of consumer types (i.e. Cons1_Cons2_Map is empty for this DS) and it would have both consumer type columns with headers ConsumerType1, ConsumerType2 if this DS has two levels of consumer types. Similarly, G* represents up to 4 columns (with headers ModelGeography, SubGeography1, SubGeography2, SubGeography3) and T* represents up to 4 columns (with headers Year, Season, DayType, DaySlice) depending on the geographic and temporal granularity given in DS_Cons1_Map. Thus, the file would have at least three columns (one each for C*, G*, T*) and at most 10 columns (2 for C*, 4 for G* and 4 for T*) corresponding to C*, T*, G*. In addition, it has the column NumConsumers which gives the number of consumers of this consumer type (defined by the C* columns) for this DS at this geographic (G*) and temporal (T*) granularity. The number of consumers is a positive integer.

Example:

- `D_RES/NumConsumers.csv`: These rows indicate that, in 2021, in Maharashtra, there are 23000 rural quintile 1 households and, in 2024, in Tamil Nadu, there are 10000 urban quintile 5 households.
    - `RES_RURAL, RQ1, INDIA, WEST, MH, 2021, 23000`
    - `RES_URBAN, UQ5, INDIA, SOUTH, TN, 2024, 10000`
- `D_TRANS/NumConsumers.csv`: These rows indicate that, in 2025, in the Northern region, there are 10000 local passenger transport consumers and, in 2027, in the North-Eastern region, there are 2000 non-local freight transport consumers.
    - `TRANS_LOCAL, L_PASS, INDIA, NORTH, 2025, 10000`
    - `TRANS_NONLOCAL, N_FREIGHT, INDIA, NORTHEAST, 2027, 2000`
- `D_IND/NumConsumers.csv`: These rows indicate that, in 2023, there are 1000 large steel industrial consumers in India, and, in 2026, there are 1200 cement industries in India.
    - `IND_STEEL, LARGE_STEEL, INDIA, 2023, 1000`
    - `IND_CEMENT, ALL_CEMENT, INDIA, 2026, 1200`

3 Service technology details

For each service technology (that provides some energy service using some energy carrier) being modelled, some information is expected as described in this section. Service technology details are relevant only for DS-ES combinations whose demand is specified in a bottom-up fashion.

3.1 ST_Efficiency.csv

Directory: `Root/<DemandSector>`

Columns: `ServiceTech, EfficiencyLevelName, Year, Efficiency`

This input describes the 'efficiency' of each energy service technology – i.e. the amount of energy required to provide one unit of energy service. Since an ST can have multiple efficiency levels, the efficiency input has to be provided for each such level. The `ServiceTech` column is the name of the ST, the `EfficiencyLevelName` column gives a name for the efficiency level, the `Year` column is the year for which the efficiency applies and the `Efficiency` column is a positive number that describes the amount of energy required (in the energy units of the EC of this ST) to provide one unit of energy service (as described in the `ST_Info` file). Thus, implicitly, the efficiency level does not change within a year. Moreover, note that the Efficiency given here corresponds to the efficiency of the *stock* of instances of the specified service technology and efficiency level in the specified year – and not the *new* instances of that technology and efficiency level that are purchased in that year.

Example:

- `D_RES/ST_Efficiency.csv`: The following rows indicate that for residential energy services, there are three types of electric light technologies corresponding to incandescent bulbs, CFLs and LEDs with efficiencies of 60W, 15W and 9W respectively in 2021 (i.e. 0.06 kWh / hour, 0.015 kWh / hour and 0.009 kWh / hour respectively). They also indicate that there are two types of ACs (3-star and 5-star) which have efficiencies of 0.055 and 0.046 kWh/CDH respectively in 2025. Further, it states that in 2024, LPG stoves (just one efficiency level) require 1.54 MJ to produce one 'useful MJ' of heat – i.e. have a 65% efficiency. Similarly, induction stoves in 2024 require 0.33 kWh to produce one useful MJ – i.e. an 85% efficiency.
    - `ELEC_LIGHT, INCAND, 2021, 0.06`
    - `ELEC_LIGHT, CFL, 2021, 0.015`
    - `ELEC_LIGHT, LED, 2021, 0.009`
    - `AC, 3STAR, 2025, 0.055`
    - `AC, 5STAR, 2025, 0.046`
    - `COOK_LPG, LPGSTOVE, 2024, 1.54`
    - `COOK_ELEC, INDUCTION, 2024, 0.33`
- `D_IND/ST_Efficiency.csv`: This states that industrial 3-star and 5-star ACs have efficiencies of 0.79 and 0.63 kWh/CDH respectively in 2025.
    - `AC, 3STAR, 2025, 0.79`
    - `AC, 5STAR, 2025, 0.63`
- `D_TRANS/ST_Efficiency.csv`: This states that, in 2026, compact petrol cars and petrol limousines respectively require 1.2 and 3 MJ per passenger-km.
    - `PCAR, COMPACT, 2026, 1.2`
    - `PCAR, LIMO, 2026, 3.0`

3.2 ST_EmissionDetails.csv

[This input is currently accepted but not processed by Rumi]

Directory: `Root/<DemandSector>`

Columns:

`ServiceTech, Year, EmissionType, DomEmissionFactor, ImpEmissionFactor`

This is an optional parameter. It is required only when using an ST results in emissions that are different from the default emissions for the energy carrier as specified in the common input specifications. Moreover, it is only relevant when the input carrier for the ST is a physical carrier as only their usage can result in emissions. If this input is not given, then the carrier's default emission details are used.

This information is given for each model year for the ST. It is assumed that emissions do not vary by geographic area. If the ST uses a primary physical EC, then for each applicable emission type, two emission values can be specified corresponding to usage of a domestic variant of the carrier or an imported variant. For derived ECs, since imports are not supported; only the domestic emission factor column is used, though imported emission factor also must be specified for syntactic reasons.

For a given service technology, the emissions arising out of it could in general vary by the demand sector in which it is used. Hence this parameter is to be given for each demand sector.

Example:

- `D_RES/ST_EmmisionDetails.csv`: This indicates that there are 1800 units of CO2 emission per unit of input biomass used for cooking in the residential sector.
    - `COOK_BIOMASS, 2021, CO2, 1800, 1800`

4 Energy services that are modelled bottom-up

For energy services that are modelled bottom-up in a demand sector, energy demand is calculated based on the quantity of energy service required, the service technologies providing that service, their efficiency, and the number of consumers owning and using those technologies at various geographic and temporal units. Multiple STs can provide the same energy service, and a single consumer may use a combination of such STs to satisfy the energy service need. Rumi supports input specifications with such 'stacking' of technologies to avail a single energy service. In the case where multiple STs simultaneously provide an energy service, the ownership of different combination of STs can be specified (refer to Section 4.2) and the corresponding energy service demand for each combination can be input (refer to Section 4.1). Thus, the following inputs are required from the modeller at the appropriate granularities.

1. The energy service demand per instance of an ST providing that service for a consumer type
2. The number of instances of an ST per consumer of a given type
3. For each combination of STs that can provide the service, the share of consumers of each type who own and use that combination of STs
4. For each consumer type, the split of its ownership of an ST across the various efficiency levels of the ST.

These inputs are provided in files as described below. All these files are expected in a sub-directory named for the energy service within the demand sector's directory, i.e. `<DemandSector>/<EnergyService>`.

4.1 <ST >_ES_Demand.csv

Directory: `Root/<DemandSector>/<EnergyService>`

The name of this is the name of a service technology (ST), appended with `_ES_Demand.csv`. It gives the energy service demand required from the chosen ST. Thus, for example, `AC_ES_Demand.csv` gives the space cooling demand from air conditioners. Since multiple STs can provide the same energy service, and a single consumer may use a combination of such STs to achieve the energy service, this file is structured to provide the energy service demanded from an ST when it is used singly and in combination with other STs providing the same service. Effectively, this allows the modelling of the feature that is known as 'stacking' in the household cooking energy literature – where multiple cooking appliances may be present and used in the same household. The same may, of course, be true for any other energy service (e.g. space cooling, passenger transport, industrial heating etc.). The geographic and temporal granularity at which these inputs are provided are as defined in the file DS_ES_EC_DemandGranularity (Section 2.7).

The file has a header row with values C*, G*, T*, ST, ST+ST1, ST+ST2, ST+ST1+ST2 … where

- C*, G*, T* stand for columns corresponding to consumer type, geographic units and temporal units respectively, as described in Section 2.9 and to the granularity as specified in DS_ES_EC_DemandGranularity corresponding to this ST – i.e. the input EC and output ES of this ST. Thus, if it specifies the granularity as <CONSUMERTYPE1, SUBGEOGRAPHY1, DAYSLICE>, then the C*, G*, T* columns would have headers ConsumerType1, ModelGeography, SubGeography1, Year, Season, DayType, DaySlice.
- ST stands for the ST for which input is being provided. The column with header as just ST gives the energy service demand (in the energy service units as given in the ST_Info file) when only this ST (i.e. without other STs providing the same service) is used by consumer types in the C* columns in the geography given in the G* columns and in the time unit corresponding to the T* columns.
- The columns ST+ST1, ST+ST2, ST+ST1+ST2 etc. correspond to using ST in conjunction with one or more other STs (ST1, ST2 etc.) to provide the same energy service to consumers defined in the C* column in the geography and time defined by the G* and T* columns. Note that the column entry corresponds to the energy service demanded only from ST but when it is used in conjunction with these other STs, where the column header defines which are the other STs. The energy service demanded from those STs when used in conjunction with this ST is provided in the file for that ST.

Example:

- D_RES/LIGHTING/ELEC_LIGHT_ES_Demand: This gives the demand for ELEC_LIGHT, and since the LIGHTING energy service is only provided by this technology, there's just one column giving energy service demand (since it can't occur in conjunction with other technologies).
  - RURAL, RQ1, INDIA, WEST, MH, 2021, WINTER, SEASONDAY, MORN, 1: says that 1 hour of lighting is required in rural Maharashtra quintile 1 households on 2021 winter mornings
- D_RES/COOLING/FAN_ES_Demand: This gives the demand for FAN which provides the (space) COOLING energy service which is also provided by COOLER and AC technologies.

Hence there are columns for when a fan is used conjunction with these in addition to just using a fan by itself. Thus, the last three column headers are FAN, FAN+COOLER, FAN+AC.

   - URBAN, UQ3, INDIA, SOUTH, TN, 2023, SUMMER, SEASONDAY, MID, 3, 1.33, 1.33: indicates that, in TN urban Q3 households on 2023 summer mid-days, the energy service required per fan is 3, 1.33 and 1.33 cooling hours respectively when used by itself, in combination with a cooler and in combination with an AC.

- D_TRANS/PASS_MOBILITY/TWH_ES_Demand: Gives the demand from TWH (two-wheelers) for passenger mobility. This demand may also be provided by PCAR (passenger car). Thus, the last two columns have headers TWH, TWH+PCAR.
   - URBAN, UQ3, INDIA, SOUTH, AP, 2025, 1200, 500: This states that, in AP urban Q3 HHs in 2025, the energy service required per two-wheeler is 1200 and 500 pkm respectively when used by itself and in combination with a car.

4.2 ST1+ST2+...+STk+Penetration.csv

Directory: Root/<DemandSector>/<EnergyService>

Columns: C*, G*, T*, Penetration

The name of this file is similar to the column headers of the file <ST>_ES_Demand.csv, in that it allows the modeller to combine multiple STs. The intent of this file is to supply the 'penetration' of each combination of STs for each consumer type in a particular geographic and time unit – i.e. the percentage of consumers of that consumer type who own or use the particular combination of STs to avail that energy service in that geographic and time unit.

The C*, G*, T* columns have the usual interpretation as given above, where the granularity is equal to the coarsest granularity given in DS_ST_Granularity_Map for any ST in the combination for this file. The Penetration column is a fraction between 0 and 1 (both inclusive) representing the share of C* using this ST-combination in this <G*, T*> and is a number in [0, 1]. A few points to note:

- If the file for a particular combination of STs doesn't exist, then it is assumed that there is no usage of that combination for any consumer-type in any geographic and time unit.
- For any <C*, G*, T*>, the penetrations of the various combinations of STs offering the same ES in a DS have to add up to a value between 0 and 1, since it represents the total share of consumers of that type availing that service through any combination of STs.
- However, this sum can be less than 1, because some consumers of a given type may not avail the energy service at all.

Example:

- D_RES/LIGHTING/ELEC_LIGHT+Penetration.csv gives the penetration of electric lighting among household consumers

    - `RURAL, Q1, INDIA, WEST, MH, 2021, 1`: indicates that all households (100%) in rural Q1 Maharashtra in 2021 use electric lighting
- `D_RES/COOLING/FAN+Penetration.csv`, `D_RES/COOLING/COOLER+FAN+Penetration.csv`, `D_RES/COOLING/AC+FAN+Penetration.csv` give inputs about the share of households that use only fans, or fans with coolers or fans with ACs respectively. If these three files respectively have rows as given below, it indicates that, in 2023, in TN, 68% urban Q3 households own only fans, 25% own coolers and fans, and 5% own ACs and fans. This implicitly implies that 2% own no cooling appliance at all, i.e. are outside of the 68% + 25% + 5%.
    - `URBAN, Q3, INDIA, SOUTH, TN, 2023, 0.68`
    - `URBAN, Q3, INDIA, SOUTH, TN, 2023, 0.25`
    - `URBAN, Q3, INDIA, SOUTH, TN, 2023, 0.05`

4.3 EfficiencyLevelSplit.csv

Directory: `Root/<DemandSector>/<EnergyService>`

Columns: `ServiceTech, C*, G*, T*, EfficiencyLevelName, SplitShare`

In addition to identifying the share of consumers who use a particular ST to avail an energy service, it is also necessary to specify the split of different efficiency levels of an ST among the consumers using that ST. For each ST offering the energy service for the demand sector corresponding to the directory in which the file is present and for each CT of that DS at each geographic and time unit, this file specifies the split of the different efficiency levels among those of this CT who use this ST. Since this information is given for each ST, the same split of consumers across efficiency levels will carry through to all combinations of STs with this ST. The information to be given in each column is as follows:

- `ServiceTech` is the name of the ST
- `C*, G*, T*` have the usual interpretation and must be equal to the coarsest granularity given in `DS_ST_Granularity_Map` for this ST and all the other STs that can occur in combination with this ST. This is because the penetration of an efficiency level of an ST will have to be calculated in combination with all such STs.
- `EfficiencyLevelName` is the name of the efficiency level for which the split share is being given and should match the name given in `ST_Efficiency`. This input must be given for all efficiency level names mentioned in the `ST_Efficiency`.
- `SplitShare` is the share of consumers in this `<C*, G*, T*>` owning or using this ST who are using this efficiency level of the ST, and is a fraction between 0 and 1 (both inclusive). Since this input is just a split of the consumers using an ST into its various efficiency levels, the sum of the split-shares of the different efficiency levels of an ST for a `<C*, G*, T*>` should add up to 1. Else, an error would be issued.

Example:

- `D_RES/LIGHTING/EfficiencyLevelSplit.csv`: the following indicates that among quintile 1 households in rural West Bengal in 2024, electric lighting appliances are split as 50% incandescent bulbs, 10% CFLs and 40% LED lamps.
    - `ELEC_LIGHT, RURAL, RQ1, INDIA, EAST, WB, 2024, SUMMER, ALLDAYS, EVENING, INCAND, 50%`
    - `ELEC_LIGHT, RURAL, RQ1, INDIA, EAST, WB, 2024, SUMMER, ALLDAYS, EVENING, CFL, 10%`
    - `ELEC_LIGHT, RURAL, RQ1, INDIA, EAST, WB, 2024, SUMMER, ALLDAYS, EVENING, LED, 40%`
- `D_RES/COOLING/EfficiencyLevelSplit.csv`: the following indicates that among urban quintile 3 households of Gujarat in 2027, AC ownership is split as 40% owning 3-star ACs, 30% owning 4-star ACs and 30% owning 5-star ACs.
    - `AC, URBAN, UQ3, INDIA, WEST, GJ, 2027, WINTER, ALLDAYS, MORN, 3STAR, 40%`
    - `AC, URBAN, UQ3, INDIA, WEST, GJ, 2027, WINTER, ALLDAYS, MORN, 4STAR, 30%`
    - `AC, URBAN, UQ3, INDIA, WEST, GJ, 2027, WINTER, ALLDAYS, MORN, 5STAR, 30%`

This information will be used to derive the demand for an ST by efficiency level in any time/geographic unit, even when it occurs in combination with other STs. For example, for some `<C*, G*, T*>` if

- The AC service demand is 4 CDH (when used with a fan) and 8 CDH (when used by itself),
- The share of households with ACs with a fan is 5% and with only ACs is 0.1%,
- The split share of 3-, 4- and 5-star ACs is 50%, 30%, 20% respectively and
- There are 100,000 households (consumers) each owning 1 AC then
- The detailed break-up of AC service demand for that `<C*, G*, T*>` would be
    - 3-star ACs: 4 cdh from 2500 ACs + 8 cdh from 50 ACs
    - 4-star ACs: 4 cdh from 1500 ACs + 8 cdh from 30 ACs
    - 5-star ACs: 4 cdh from 1000 ACs + 8 cdh from 20 ACs

4.4 NumInstances.csv

Directory: `Root/<DemandSector>/<EnergyService>`

Columns: `ServiceTech, C*, G*, T*, NumInstances`

The final input required for bottom-up demand estimation is the number of instances of any ST that a consumer type uses in a geographic and time unit. This file captures that information. The `ServiceTech, C*, G*, T*` columns have the usual interpretation and the `NumInstances` column is a positive number (not necessarily an integer) representing the average number of instances of the ST used by this consumer type in this geographic and time unit. This allows modelling of cases where multiple instances of an ST may be used by a consumer. The same number is used for this ST even when it occurs in combination with other STs. As with other inputs related to STs, `<C*, G*, T*>` must be given at a granularity equal to the coarsest granularity given in `DS_ST_Granularity_Map` for this ST and all the STs that can occur in combination with this ST.

Example:

- `D_RES/COOLING/NumInstances.csv`: This states that an urban quintile 3 household in TN in 2023 that has fans has 1.9 of them, and a similar household that has coolers has 1.2 of them.
    - `FAN, URBAN, UQ3, INDIA, SOUTH, TN, 2023, MONSOON, ALLDAYS, NIGHT, 1.9`
    - `COOLER, URBAN, UQ3, INDIA, SOUTH, TN, 2023, MONSOON, ALLDAYS, NIGHT, 1.2`

5 Energy services that are not modelled bottom-up

Energy services whose demand is not modelled in a bottom-up fashion can be described in three ways: by providing the energy demand extraneously, or through GDP elasticity or as a residual of some other services. All the files relevant to such inputs are provided in the demand sector's directory.

5.1 ExtraneousDemand.csv

Directory: `Root/<DemandSector>`

Columns: `EnergyService, EnergyCarrier, CONSUMERTYPE1, CONSUMERTYPE2, MODELGEOGRAPHY, SUBGEOGRAPHY1, SUBGEOGRAPHY2`, or `SUBGEOGRAPHY3, YEAR, SEASON, DAYTYPE, DAYSLICE, EnergyDemand`

If the energy demand for an ES in a DS is specified extraneously, then it is given through this file. `EnergyService` indicates the ES for which this row contains extraneous demand. `EnergyCarrier` indicates the EC for which this row contains extraneous demand. All ten possible columns for the consumer and geographic granularity are provided as headers in this file. But, for a particular energy carrier, depending on the granularity specified in `DS_ES_EC_DemandGranularity_Map` only the relevant columns need to have values and the other columns can be left empty. All columns are included in the file because demand for different energy carriers may be specified at different granularities. `EnergyDemand` represents the energy demanded at this granularity and is expressed in the energy units of the energy carrier.

Example:

- `D_IND/ExtraneousDemand.csv`: The following indicates an energy demand of 1 million MJ industrial heating from coal for large steel industries in OD in 2023, 2 million MJ industrial heating from coal for cement plants in JH in 2025 and half a million MJ industrial heating from other petroleum products for cement plants in JH in 2025.

- IND_HEATING, COAL, IND_STEEL, LARGE_STEEL, INDIA, EAST, OD, , 2023, , , , 1000000
- IND_HEATING, COAL, IND_CEMENT, ALL_CEMENT, INDIA, EAST, JH, , 2025, , , , 2000000
- IND_HEATING, OTHER_PP, IND_CEMENT, ALL_CEMENT, INDIA, EAST, JH, , 2025, , , , 500000

5.2 BaseYearDemand.csv

Directory: Root/<DemandSector>

Columns: EnergyService, EnergyCarrier, C*, G*, T*, BaseYearDemand

This input is required to compute demand which is modelled based on GDP elasticity. Two inputs are required to estimate such demand: one is the demand for the carrier (at the right granularity) in the 'start year' and the second is the elasticity of demand with respect to GDP for the subsequent years. This file captures the first of these inputs. Since GDP is typically computed at annual time granularity, GDP-elasticity related demand inputs are also specified only at an annual level and the same elasticity is used for all finer levels, if the balancing time of the energy carrier is finer.

Since the intent is to compute the energy demand for the entire model period, the 'starting year' for which demand has to be provided exogenously is the year just before the model's first year. This year is called the 'base year' and hence this demand is called the base year demand. The column headers of the file are fairly self-explanatory and have the following additional conditions:

- The EnergyService must have been declared as being of the GDP elasticity type in DS_ES_Map.
- C*, G*, T* have the usual interpretation. The number of columns of C*, G*, T* required is determined by the energy carrier that requires the most granular (i.e. finest) information as specified in DS_ES_EC_DemandGranularityMap. Thus, if there are two energy carriers providing this energy service and one of them requires three geography columns and the other requires two, then the file would have three columns. The rows for the carrier that requires only two geography columns will have the third column as blank.
- The BaseYearDemand is specified in the energy units of the EnergyCarrier and is the energy demand for C* in <G*, T*>

This input needs to be provided for all energy carriers providing any energy service for this demand sector which has been declared to be of the GDP elasticity type.

Example:

- D_TRANS/BaseYearDemand.csv: This indicates that 234234 MJ of MS and 50000 MJ of HSD is demanded in the base year 2019 for local passenger mobility in India.
    - PASS_MOBILITY, MS, TRANS_LOCAL, L_PASS, INDIA, 2019, 234234

- o PASS_MOBILITY, HSD, TRANS_LOCAL, L_PASS, INDIA, 2019, 50000

5.3 DemandElasticity.csv

Directory: Root/<DemandSector>

Columns: EnergyService, EnergyCarrier, C*, G*, Year, Elasticity

This is the second input required for GDP elasticity based demand computation. This input is only accepted at an annual granularity since GDP values are only available at that granularity. The same elasticity is applied to all finer time units. GDP elasticity values have to be given for each model year for each DS-ES-EC combination where the ES is of GDPELASTICITY type. Here too, C* and G* have as many columns as required for the energy carrier with the maximum granularity as given in DS_ES_EC_DemandGranularityMap. Elasticity is a real number which would be multiplied by the GDP growth rate to arrive at the energy demand growth rate for that year for that C* in that G*.

If GDP values are provided at a finer (or equal) geographic granularity than elasticity, then GDP values will be aggregated up to the granularity of elasticity to calculate the relevant GDP growth rates. If GDP values are provided at a coarser granularity than elasticity, then GDP growth rates calculated at the coarser level are assumed for all the corresponding finer geographic granularities at which elasticities are given. Note that, since elasticity is a real number, it can also be negative – indicating a negative correlation between GDP and energy demand[5].

Example:

- D_TRANS/DemandElasticity.csv: This file states that the GDP elasticity of demand for MS in 2024 is 0.92 and GDP elasticity of demand for HSD in 2023 is 0.67 for local passenger mobility.
  - o PASS_MOBILITY, MS, TRANS_LOCAL, L_PASS, INDIA, 2024, 0.92
  - o PASS_MOBILITY, HSD, TRANS_LOCAL, L_PASS, INDIA, 2023,0.67

5.4 ResidualDemand.csv

Directory: Root/<DemandSector>

Columns: EnergyService, EnergyCarrier, C*, G*, T*, ResidualShare

This input captures the information required to calculate demand by the residual method. The columns are very similar to the columns in DemandElasticity.csv, except that the last column (ResidualShare) is a positive real number which will be multiplied by the total demand from the other energy services of this DS-EC for this <C*, G*, T*> to get the residual demand. The granularities for C*, G*, T* are as specified in DS_ES_EC_DemandGranularity_Map. In

[5] This will typically happen only for 'inferior' energy carriers whose usage reduces with increasing prosperity – e.g. solid biomass for cooking, kerosene for lighting etc.

addition, they need to respect the coarseness constraint for `RESIDUAL` services mentioned in the description of `DS_ES_EC_DemandGranularity_Map` (Section 2.7). Note that though only one energy service can be a residual service in a demand sector, each carrier providing that service can have a different residual share for each `<C*, G*, T*>`.

Example:

- `D_RES/ResidualDemand.csv`: The following indicates that residual residential electricity demand is 36% of the other residential electricity demand in Gujarat on a 2028 autumn evening.
    - `RES_OTHERS, ELECTRICITY, RURAL, RQ3, INDIA, WEST, GJ, 2028, AUTUMN, SEASONDAY, EVENING, 0.36`

Based on the input files, as given in the total energy demand for each combination of demand sector, energy service and energy carrier is calculated for each combination of consumer type, geographic and time unit granularity given in `DS_ES_EC_DemandGranularity_Map`. This demand is then aggregated to the demand for each energy carrier across all demand sectors and energy services, and aggregated up to the balancing geography and time of the energy carrier – to be provided as an input to Rumi's supply module.

6 Demand estimation

Based on the input files described above, the demand component of Rumi estimates the energy demand projections for the model period at the required granularity. All the outputs are produced by default in a directory called `Demand/Output` under the root directory of the scenario that is run, though this can be over-ridden by the user through a command line parameter (see the overview document). The following table provides a list of the files that are produced by the demand component and a brief description of the information they contain. Note that each indicated filename may represent many actual files, depending on the model set-up.

Filename	Description
EndUseDemandEnergy.csv	For each energy carrier, its end-use demand (in energy terms, in the energy units of the EC) in each balancing geography/time unit. This is the file used by the supply component
<EC>_Demand.csv	The demand (in energy terms) of energy carrier <EC> for each model year
<DS>_<EC>_Demand.csv	The demand (in energy terms) of <EC> for a particular demand sector <DS>, for each consumer type and balancing geography/time of <EC>

<ES>_<EC>_Demand.csv	The demand (in energy terms) of <EC> for a particular energy service <ES>, for each consumer type and balancing geography/time of <EC>
<DS>_<ES>_<EC>_Demand.csv	The energy demand of <EC> for <ES> in a demand sector <DS>, for each consumer type and balancing geography/time of <EC>
<DS>_<ES>_<ST>_<EC>_Demand.csv	The energy demand of <EC> used in service technology <ST> to provide <ES> in <DS>, for each consumer type and balancing geography/time of <EC>
<DS>_<EC>_EnergyService_ServiceTech_Demand.csv	The energy demand of <EC> used in <DS> for each service technology that uses <EC> to provide some energy service, for each consumer type, and balancing geography/time of the EC
TotalNumInstances_<ST>.csv	The number of instances of service technology <ST> in each year and balancing geography of the EC used by <ST>, for each consumer type