Rumi

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

Supply documentation

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1 Introduction

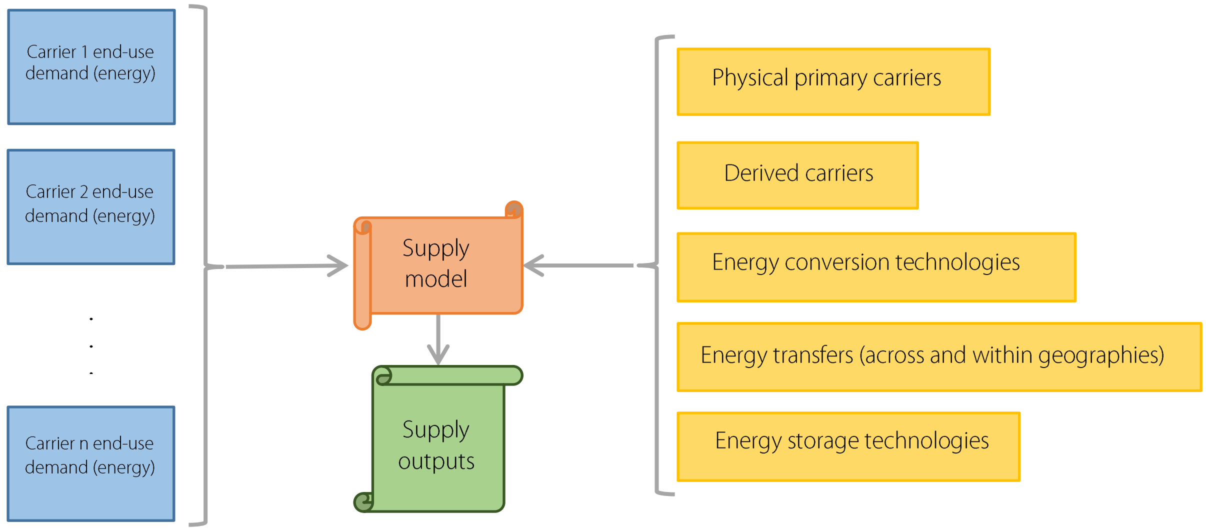
Given time and geographic-unit wise energy demand for each energy carrier, Rumi will try to satisfy the demand through an optimal energy supply mix, using storage facilities if required. This will be done at the balancing area and at the balancing time granularities of the energy carrier. Typically, the energy demand is expected to be produced as the output of the Rumi demand component, but it can also be exogenously provided by the modeller. In such a case, this input should be provided in the expected file, location, and format – see below for details. The supply specifications or inputs provide the details, constraints, costs etc. of the various elements relevant to energy supply such as energy carriers[1], energy conversion technologies, energy storage, and energy transfers. These inputs are used to identify the cost-optimal supply mix to meet the demand. All inputs to Rumi are in the form of comma-separated value (csv) files with a certain structure. Figure 1 depicts this architecture of the supply module of Rumi.

All supply inputs will be under a directory named `Supply`. These inputs are provided in the `Supply/Parameters` directory under the scenario root directory (or, alternatively, `Default Data/Supply/Parameters` if the information is common across many scenarios). This `Supply` directory is henceforth called `Root`. Under this `Root`, there would be separate folders for energy carriers, energy conversion technologies, energy storage technologies, and energy transfers. Like the demand inputs provided to Rumi, it is necessary to supply meta inputs that define the granularity for other inputs. All such inputs are described in this document. As with common and demand inputs, for any input file that has a header row with named column headers, the order of the columns is

[1] Note that all the physical characteristics of energy carriers such as their energy density and emission intensity are given in the common specification inputs.

immaterial. But if there is no header row, then the order of columns is important and should be exactly as documented.

Figure 1: Rumi supply processing



2 Granularity specifications

This set of 'meta' inputs are primarily intended to specify the granularity at which various other inputs related to energy carriers, conversion technologies and storage systems would be provided. Note that wherever inputs regarding energy carriers are expected, inputs should only be given for carriers that are not non-physical primary carriers, i.e. they are either physical primary carriers or they are derived carriers (physical or non-physical)[2].

2.1 EC_InfoGranularity.csv

Directory: `Root`

Columns: `EnergyCarrier, GeographicGranularity, TimeGranularity`

This file defines, for each primary or derived energy carrier (EC)[3], the geographic and temporal granularity at which inputs about that carrier, that can be identically applied for all finer granularities, are given. As with other inputs, `GeographicGranularity` must be one of `MODELGEOGRAPHY, SUBGEOGRAPHY1, SUBGEOGRAPHY2, SUBGEOGRAPHY3` and `TimeGranularity` must be one of `YEAR, SEASON, DAYTYPE, DAYSLICE`. For each energy carrier, the

[2] The only place non-physical primary carriers appear in the supply inputs are when they are an input to an energy conversion technology.

[3] Non-physical primary carriers should not be listed since there are no inputs pertaining to them.

GeographicGranularity must be coarser than or equal to the balancing geographic unit of the carrier and TimeGranularity must be coarser than or equal to the balancing time unit[4].

Example[5]:

COAL, SUBGEOGRAPHY1, SEASON

NATGAS, MODELGEOGRAPHY, YEAR

ELECTRICITY, SUBGEOGRAPHY2, SEASON

2.2 EC_ConstraintsGranularity.csv

Directory: Root

Columns: EnergyCarrier, GeographicGranularity, TimeGranularity

This file specifies, for each energy carrier that is not a non-physical primary carrier, the geographic and temporal granularity at which some inputs are provided, that can be aggregated up to coarser granularities. Currently, the only relevant inputs required at this granularity are for physical carriers. The expected values for the various columns are identical to those expected in EC_InfoGranularity with the difference being that, in this case, the specified granularities can be at any arbitrary granularity. If any of these specified granularity values is finer than the corresponding balancing unit for an energy carrier, then an input for that energy carrier which is provided at such a finer granularity, will be aggregated up to the level of the balancing unit. If the granularity is coarser than the balancing granularity then Rumi will distribute the input given at that granularity to the balancing granularity in a least cost manner.

Example:

COAL, SUBGEOGRAPHY2, SEASON

NATGAS, SUBGEOGRAPHY1, SEASON

2.3 ECT_InfoGranularity.csv

Directory: Root

Columns: EnergyConvTech, GeographicGranularity, TimeGranularity

This file is similar to EC_InfoGranularity except that it provides granularity information for inputs related to energy conversion technologies (rather than energy carriers). The expected values for the

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

[5] All examples provided in these documentation files are intended to be purely for illustrative purposes and do not necessarily present 'realistic' values, and they may not be mutually consistent.

granularity columns are identical to those expected in `EC_InfoGranularity` and these too should be coarser than or equal to the balancing granularities of the *output* carrier of the energy conversion technology (ECT).

Example:

`ELEC_SUPERCRIT, SUBGEOGRAPHY1, SEASON`

`MS_REFINERY, MODELGEOGRAPHY, YEAR`

2.4 ECT_InputsGranularity.csv

Directory: `Root`

Columns: `EnergyConvTech, GeographicGranularity, TimeGranularity`

This file is similar to `EC_ConstraintsGranularity` except that it provides granularity information for inputs related to ECTs rather than ECs. The expected values for the granularity columns are identical to those expected in `EC_ConstraintsGranularity` and these too should be finer than or equal to the balancing granularities of the *output* carrier of the energy conversion technology (ECT).

Example:

`ELEC_SOLARPV, SUBGEOGRAPHY2, DAYSLICE`

`HSD_REFINERY, SUBGEOGRAPHY1, YEAR`

2.5 EST_InfoGranularity.csv

Directory: `Root`

Columns: `EnergyStorTech, GeographicGranularity, TimeGranularity`

This file is similar to `EC_InfoGranularity` except that it provides granularity information for inputs related to energy storage technologies (ESTs) rather than ECs. The expected values for the granularity columns are identical to those expected in `EC_InfoGranularity` and these too should be coarser than or equal to the balancing granularities of the carrier stored in the EST.

Example:

`FOURHRBATTERY, SUBGEOGRAPHY1, SEASON`

`PUMPEDSTORAGE, MODELGEOGRAPHY, YEAR`

2.6 EST_InputsGranularity.csv

Directory: `Root`

Columns: `EnergyStorTech, GeographicGranularity, TimeGranularity`

This file is similar to `EC_ConstraintsGranularity` except that it provides granularity information for inputs related to ESTs rather than ECs. The expected values for the granularity columns are identical to those expected in `EC_ConstraintsGranularity` and these too should be finer than or equal to the balancing granularities of the carrier stored in the EST.

Example:

`FOURHRBATTERY, SUBGEOGRAPHY2, DAYSLICE`

`PUMPEDSTORAGE, SUBGEOGRAPHY1, SEASON`

3 Energy carrier details

The supply side inputs regarding energy carriers that are relevant include details regarding the prices, taxation and limits on production and import of the carrier. While Rumi supports specification of both ad-valorem and fixed amount taxes, for technical reasons, currently ad valorem taxes are allowed only for physical primary energy carriers. All these inputs are given in the `Root/Carriers` directory.

3.1 PEC_Info.csv

Directory: `Root/Carriers`

Columns: `EnergyCarrier, G*, T*, NonEnergyShare, DomesticPrice, AVTaxOHDom, FixedTaxOHDom, ImportPrice, AVTaxOHImp, FixedTaxOHImp`

For each physical primary energy carrier (PEC), this file provides some assumptions regarding the PEC. These inputs are provided at the granularity given in `EC_InfoGranularity` for this EC. The number of columns that `G*` (`T*`) stands for is the maximum of the corresponding columns required for all primary carriers as determined by the specified granularities in `EC_InfoGranularity`. The corresponding column headings would be from `ModelGeography, SubGeography1, SubGeography2, SubGeography3` (similarly, `Year, Season, DayType, DaySlice`). The information expected in the columns is as follows:

- `EnergyCarrier`: the name of the EC
- `G*, T*`: the number of time/geography columns in the file would be the maximum of the corresponding columns required for all primary carriers as determined by the specified granularities in `EC_InfoGranularity`. The columns contain the geographic and temporal units for which the various parameters in this input are being specified. If the columns are not relevant to some carrier, they should be left blank.
- `NonEnergyShare`: some energy carriers also get used for other (non-energy) purposes. This column mentions the share of the ‘domestic’ production of the energy carrier that will be used for non-energy purposes. This is a fraction between 0 and 1 (both inclusive). Note that domestic production refers to production of the EC within the entire modelled geography.

- `DomesticPrice`: the unit price of this EC produced domestically (i.e. within the model geography), at this geographic and time unit mentioned. The unit for this is (currency unit / physical unit) of the EC.
- `AVTaxOHDom`: the ad valorem taxes and overheads to be applied to this EC when produced domestically. This is a non-negative real number, which is multiplied with the domestic price.
- `FixedTaxOHDom`: the fixed taxes and overheads to be applied to this EC when produced domestically. The unit is the same as the domestic price.
- `ImportPrice`: the unit price of this EC if it is imported, i.e. obtained from outside the modelled geography. The unit is (currency unit / physical unit). Typically, this should represent the 'landed price' of the EC.
- `AVTaxOHImp`: the ad valorem taxes and overheads to be applied to this EC when it is imported. It is a non-negative real number, which is multiplied with the imported price.
- `FixedTaxOHImp`: the fixed taxes and overheads to be applied to this EC when it is imported. The unit is (currency unit / physical unit)

Example:

```
COAL, INDIA, EAST, , , 2021, SUMMER, , , 0, 1600, 0.05, 400, 4000,
0.08, 500
```

```
NATGAS, INDIA, , , , 2025, , , , 0.40, 10000, 0.20, 0, 50000, 0.12, 0
```

3.2 PEC_ProdImpConstraints.csv

Directory: `Root/Carriers`

Columns: `EnergyCarrier, G*, T*, MaxDomesticProd, MaxImport`

This file specifies the limits on how much quantity of a physical primary energy carrier can be either produced within a geographic area or imported into the geographic area from outside the model geography in a given time unit. The `MaxDomesticProd` and `MaxImport` columns represent these quantities and are in the physical units of the EC. The number of columns for `G*, T*` in the file would be the maximum of the columns required for all physical carriers as determined by the specified granularities in `EC_ConstraintsGranularity`. As usual, if the columns are not relevant to some carrier, they should be left blank.

Example:

```
COAL, INDIA, EAST, , , 2021, SUMMER, , , 200000000, 70000000
```

```
NATGAS, INDIA, , , , 2025, , , , 40000, 40000
```

These rows say that Eastern India can produce a maximum of 200 MT and import a maximum of 70 MT of coal in the summer of 2021, and that India can produce and import at most 40 BCM each in 2025[6].

3.3 DEC_Info.csv

Directory: `Root/Carriers`

Columns: `EnergyCarrier, G*, T*, FixedTaxOHDom, ImportPrice, AVTaxOHImp, FixedTaxOHImp`

For each physical or non-physical derived energy carrier (DEC), this file provides some inputs regarding the DEC. These inputs are provided at the granularity given in `EC_InfoGranularity` for this EC. The number of columns that `G*` stands for is the maximum of the corresponding columns required for all derived carriers as determined by the specified granularities in `EC_InfoGranularity`. The corresponding column headings would be from `ModelGeography, SubGeography1, SubGeography2, SubGeography3` for `G*` and `YEAR, SEASON, DAYTYPE, DAYSLICE` for `T*`. The information expected in the columns is as follows:

- `EnergyCarrier`: the name of the EC
- `G*,T*`: the number of geography and time columns in the file would be the maximum of the corresponding columns required for all derived carriers as determined by the specified granularities in `EC_InfoGranularity`. The columns contain the geographic and temporal units for which the various input parameters are being specified. If the columns are not relevant to some carrier, they should be left blank.
- `FixedTaxOHDom`: the fixed taxes and overheads to be applied to this EC when produced domestically. The unit for the `FixedTaxOHDom` column is (currency unit / physical unit) if the DEC is physical, else it is (currency unit / energy unit).
- `ImportPrice`: the unit price of this EC if it is imported, i.e. obtained from outside the modelled geography. The unit is (currency unit / physical unit) if the DEC is physical, else it is (currency unit / energy unit). Typically, this should represent the 'landed price' of the EC.
- `AVTaxOHImp`: the ad valorem taxes and overheads to be applied to this EC when it is imported. It is a non-negative real number, which is multiplied with the imported price.
- `FixedTaxOHImp`: the fixed taxes and overheads to be applied to this EC when imported. The unit for this column is (currency unit / physical unit) if the DEC is physical, else it is (currency unit / energy unit).

Example:

```
ELECTRICITY, INDIA, EAST, BR, 2024, 0, 5.41, 0, 0
```

[6] In all examples, it is assumed that the corresponding units are correctly given in the common inputs. For example, here, it is assumed that the physical units for coal and natural gas are tonnes and million cubic metres respectively. The units used across the various examples may not be mutually consistent.

`MS, INDIA, , , 2025, 26.89, 76.70, 0.025, 26.89`

3.4 DEC_ImpConstraints.csv

Directory: `Root/Carriers`

Columns: `EnergyCarrier, G*, T*, MaxImport`

This file specifies the limits on how much quantity of a derived energy carrier can be imported into the geographic area from outside the model geography in a given time unit. The `MaxImport` column is in the physical units of the EC if EC is physical or in energy unit otherwise. `MaxImport` is provided for each DEC at the granularity specified for that DEC in `EC_ConstraintsGranularity` where, as usual, `G*, T*` will expand to the maximum number of columns required across all DECs and entries for irrelevant columns for some DECs should be left blank. If for any `G*, T*` combination, `MaxImport` is not provided then `MaxImport` is taken as zero by default. This parameter is optional. If this parameter is not provided then no derived energy carrier will be imported.

Example:

`ELECTRICITY, INDIA, SOUTH, UK, , 2023, S01Apr, 0.588`

`MS, INDIA, , , 2026, , 5`

The above rows indicate that maximum import of electricity in UK (Uttarakhand) in 2023 must be 0.588 GWh, and the maximum import of MS (petrol) to India in 2026 must be 5 million tonnes.

4 Energy conversion technology details

Energy conversion technologies (ECTs) take one (primary or derived) energy carrier (EC) as input and convert it into one derived energy carrier (DEC). The input and/or the output carriers can be physical or non-physical. Currently, each technology can only have one ‘input’ carrier and one ‘output’ carrier. For such ECTs, various kinds of information are required regarding its characteristics including aspects such as their efficiency, costs, operating characteristics, ‘legacy’ information and so on. This section describes all such information that is required for ECTs. All these inputs are provided in the `Root/Technologies` directory.

4.1 EnergyConvTechnologies.csv

Directory: `Root/Technologies`

Columns: `EnergyConvTech, CapacityUnit, InputEC, OutputDEC, AnnualOutputPerUnitCapacity`

This file provides the basic information regarding the various ECTs that are being modelled. The information to be provided in the columns respectively are:

- A string giving the name of the ECT
- A string giving the units in which the capacity of an installation of the ECT is measured
- The name of the input energy carrier to this ECT
- The name of the output energy carrier from this ECT.
- The maximum quantity/energy of output EC that can be generated by a unit capacity of this ECT over a year. In other words, this represents the total output that would be produced from a unit capacity of this ECT if it ran throughout the year[7]. If the output EC is physical, then the unit of this input is (physical unit of output EC / capacity unit of the ECT). If the output EC is non-physical, then the unit of this input is (energy unit of output EC / capacity unit of the ECT). This input is required since Rumi does not have prior knowledge about any ECTs and the relationship between its installed capacity and output energy. Note that this factor needs to be specified carefully if the capacity unit happens to be measured in terms of the *input* to the ECT rather than the output[8].

Example:

`ELECTRICITY_SUPERCRIT, MW, COAL, ELECTRICITY, 8760`: This states that a 1 MW coal-based supercritical electricity generation plant can generate at most 8760 MWh in a year if it ran throughout the year at 100% utilization (assuming that the energy unit of electricity is MWh)

`ELECTRICITY_LH, MW, WATERFLOW, ELECTRICITY, 8760`: The same as above but for a large hydro-electricity plant that uses a non-physical input energy carrier

`MS_REFINERY, MTPA, CRUDE, MS, 0.9628`: This states that a 1 MTPA (million tonnes per annum) refinery that produces petrol (MS) can produce at most 0.9628 million tonnes of MS in a year, since the energy density of crude is 0.9628 times that of MS (assuming that the quantity units of both crude and MS are million tonnes).

4.2 ECT_CapAddBounds.csv

Directory: `Root/Technologies`

Columns: `EnergyConvTech, G*, Year, MaxCapacity, MinCapacity`

This input gives the upper and lower bounds on the capacity of an ECT that can be added in each year. The geographic granularity at which this input is given for each ECT is as defined in `ECT_InputsGranularity` for that ECT. The number of geography columns in the file corresponding to `G*` are the maximum number required for any ECT as determined by the geographic granularities

[7] To be precise, it is the output from the ECT if it ran for 100% of time in a year at 100% utilization.

[8] For example, refinery capacities are typically given in terms of the quantity of crude it can process.

specified in `ECT_InputsGranularity`, with the entries for columns that are not required for some ECT being blank as usual.

The `MaxCapacity` column indicates the maximum capacity that can be added of this technology in this geographic area in the given year, while the `MinCapacity` gives the minimum capacity that must be added in the area and year. The latter is useful to indicate what is the capacity of some technology that must be installed – either because it is already under construction or because of government mandates. A value of `-1` in the `MaxCapacity` column is interpreted as there being no limit to capacity addition of that ECT in that year and geography. Such an input specification also allows for the gestation period for any new capacity to come up. Note that even though this input may be given at finer geographic granularity than the ECT's output EC's balancing area, the actual capacity addition by Rumi would be at the output EC's balancing area.

Example: The following lines state that, in western India, in 2023, a maximum of 5000 MW and a minimum of 500 MW of supercritical electricity generation capacity can come up, while in 2023, a maximum of 4 MTPA of petrol refining capacity can come up and no capacity is mandated to come up. The last line says that, in 2031, there is no limit on wind capacity addition in North India.

```
ELECTRICITY_SUPERCRIT, INDIA, WEST, 2023, 5000, 500

MS_REFINE, INDIA, , 2023, 4, 0

ELECTRICITY_WIND, INDIA, NORTH, 2031, 0, -1
```

4.3 ECT_LifeTime.csv

Directory: `Root/Technologies`

Columns: `EnergyConvTech, Year, Lifetime`

For each ECT, this input captures the lifetime of an installation of the ECT. The `Year` column indicates the year of installation of the ECT (which should be within the model period) and the `Lifetime` column gives the lifetime in years as a positive integer. Lifetime of a technology is not assumed to vary by location and hence no geography element is part of this input. Giving this input by installation year helps to give differing lifetimes for fast-evolving technologies whose lifetimes may increase with each new year.

Example:

```
ELECTRICITY_SUPERCRIT, 2021, 40

ELECTRICITY_SUPERCRIT, 2025, 40

ELECTRICITY_SPV, 2021, 25

ELECTRICITY_SPV, 2030, 28
```

4.4 ECT_OperationalInfo.csv

Directory: `Root/Technologies`

Columns: `EnergyConvTech, InstYear, CapacityDerating, SelfCons, MaxRampUpRate, MaxRampDownRate`

This file provides some of the operational characteristics of each ECT that is being modelled. Since this information often changes by year of installation, it is accepted accordingly. Note that, in this case, the installation year can also be the 'base year' of the model (i.e. model start year minus one), which is applicable to the 'legacy' capacity, or the capacity of this ECT that existed before the model period. The following information must be provided for each ECT in the last four columns respectively:

- The rate at which the installed capacity gets 'de-rated' annually as a fraction in [0, 1], that is, the effectively available capacity of the technology would be the previous year's effective capacity multiplied by (1 – the given de-rating). This input helps to capture the aging effect on technologies. If it is given as 0, of course, no derating occurs.
- Self or auxiliary consumption by the technology, given as a fraction in [0, 1], to be applied to the currently effective capacity. This enables estimation of the amount of net useful energy that this technology can supply out of its gross generation.
- The maximum rate at which this technology can 'ramp up' the active (operational) capacity from one time unit to the next, specified as a fraction in [0, 1] to be applied to the currently effective capacity installed in the year specified in the `InstYear` column.
- The maximum rate at which this technology can 'ramp down' the active (operational) capacity from one time unit to the next, specified as a fraction in [0, 1] to be applied to the currently effective capacity installed in the year specified in the `InstYear` column.
- The `MaxRampUpRate, MaxRampDownRate` columns are interpreted as follows for different balancing time granularities of the output carrier of the ECT:
    - If the granularity is `DAYSLICE`, and there are more than one `DAYTYPE` given, then this input is ignored and it is assumed that the technology can ramp up or down at any rate[9]. If only a single `DAYTYPE` is given, then the given fraction represents the fraction of the effective capacity that can be either brought into production or backed down from production *per hour.* The Rumi platform ensures that various boundary cases are handled correctly. For example, when all days of a season are to be treated identically, the ramp-rate of the first day-slice of a day is constrained by both the 'last slice' of the previous season as well as by the 'last slice' of the same season, as both these could 'precede' the first day-slice. Similarly, the ramp rates in the first slice of the model period or the installation year of an ECT are left unconstrained, since there is no 'previous' day-slice in such cases.
    - If the granularity is `DAYTYPE` and there are more than one `DAYTYPE` given, then this input is ignored and it is assumed that the technology can ramp up or down at any rate. If

[9] This is because, in the presence of multiple `DAYTYPEs`, it is not possible to sequence days and hence apply a ramping constraint on the 'previous' day.

there is only one `DAYTYPE`, this input represents the fraction of effective capacity that can be either brought into production or backed down from production *per day.*
- If the granularity is `SEASON`, they represent the fraction of the effective capacity that can be either brought into production or backed down from production *per season.*
- If the granularity is `YEAR`, then this fraction is currently ignored.

Example:

`ELECTRICITY_SUPERCRIT, 2021, 0.005, 0.08, 0.1, 0.1`: to indicate that supercritical capacity installed in 2021 has a 0.5% derating per year, 8% auxiliary consumption, and 10% per hour ramp-up and ramp-down capability (because electricity is balanced at a day-slice).

`MS_REFINERY, 2023, 0, 0.003, 1, 1`: to indicate that a petrol refinery installed in 2023 does not derate, has a 0.3% self-consumption, and can ramp-up and ramp-down fully over the year (the ramp-up and ramp-down parameters are anyway irrelevant for this since the balancing time is a year).

4.5 ECT_EmissionDetails.csv

Directory: `Root/Technologies`

Columns: `EnergyConvTech, InstYear, EmissionType, DomEmissionFactor, ImpEmissionFactor`

This is an optional parameter. In some cases, the emissions arising out of an ECT may be different from the emissions arising out of the input EC of the ECT. This input captures this information in such cases. Naturally, it is only relevant when the input EC is a physical EC. This information must be given by installation year of the ECT (including the 'legacy' year) and is independent of the geographic area. One row needs to be given for each emission type whose emissions from this ECT are different from the default values given for the input EC of the ECT. The last two columns indicate the per-unit emissions when the domestic and imported variants of the input energy carrier are used (the imported emission value is ignored if the input EC is a derived EC). The units for the last two columns are (emission units per physical unit) of the input EC.

Example:

`ELECTRICITY_SUPERCRIT, 2021, CO2, 1800, 2200`: to indicate that there are 1800 and 2200 CO2 units per unit of input coal when used in super-critical generation installed in 2021, for domestic and imported coal respectively.

4.6 ECT_EfficiencyCostMaxAnnualUF.csv

Directory: `Root/Technologies`

Columns: `EnergyConvTech, G*, InstYear, Year, ConvEff, FixedCost, VarCost, MaxAnnualUF`

This file captures details regarding the efficiency, costs, and maximum annual usage factor of each conversion technology. This information can vary by geography, installation year (including the 'legacy' year) as well as usage year and is hence given for all such combinations. Only rows where `Year` is greater than or equal to `InstYear` are processed and the rest ignored, as they are not meaningful. As usual, the number of columns corresponding to `G*` is based on the ECT with the finest geographic granularity as specified in `ECT_InfoGranularity`. The values for the last four columns respectively are interpreted as described below.

- The conversion efficiency is represented as the amount of output energy produced by the ECT per unit of input energy. This is a dimension-less value and it is a fraction in [0, 1], to indicate the share of the input energy that is available as output energy. This input is not relevant when the input EC is a non-physical PEC and is ignored in such cases (but is nevertheless required to be provided for technical reasons).
- The fixed cost is the amount to be paid in `Year` per unit capacity of the ECT installed in `InstYear`, and its units are (currency-units / capacity-unit). This represents the annualized costs of building any new capacity of the ECT.
- The variable cost is the cost of 'processing' or 'handling' one unit of the input EC. Its unit is (currency-units / physical-unit) if the input EC is physical else (currency-units / energy-unit). This represents the cost of working with the input EC, and is additional to the landed cost of the input EC itself. Depending on the amount of data and information available, the modeller has the choice of intelligently using some combination of `FixedCost` (which is specified per unit capacity) and `VarCost` (specified per unit of input EC) to approximately reflect the actual cost (over and above the cost of the input EC) of production using this ECT.
- The last column, given as a value in the closed interval [0, 1], indicates the maximum extent to which the ECT can be used in the usage year. This is helpful to provide inputs that reflect the fact that ECTs must be non-operational for some part of the year for, say, routine maintenance. In effect, the product of this value and `AnnualOutputPerUnitCapacity` (in `EnergyConvTechnologies`) defines the maximum amount of energy that can be produced in a year from a unit capacity of this ECT.

Example:

`ELECTRICITY_SUPERCRIT, INDIA, WEST, 2021, 2023, 0.33, 2000000, 100, 0.85`: to say that a 2021 installed super-critical plant when used in 2023 has an efficiency of 33%, a fixed cost of 20 lakh rupees / MW, a variable cost of Rs 100 / ton of coal and it can produce at most 85% of the `AnnualOutputPerUnitCapacity` per unit capacity in 2023.

`MS_REFINERY, INDIA, , 2023, 2024, 0.99, 10000000, 50, 0.98`: to say that a petrol refinery installed in 2023 and used in 2024 has 99% efficiency, 1 crore rupees / MTPA fixed cost, 50 Rs / kg of crude as variable cost and a maximum usage of 98% in the year.

4.7 ECT_Max_CUF.csv

Directory: `Root/Technologies`

Columns: `EnergyConvTech, InstYear, G*, T*, MaxUF`

This input gives information about the maximum usage factor of the technology at finer geographic and temporal units if it is relevant. For example, this is crucial for intermittent renewable electricity generation technologies. For each ECT and each installation year, this information is given for the combination of geographic and time units at the granularity specified in `ECT_InfoGranularity` with the number of columns represented by `G*, T*` being, as usual, the maximum required among all the ECTs. Note that, in this case, the `InstYear` column would also include the 'legacy' year to indicate the usage factors applicable to pre-existing capacity. The `MaxUF` value is a fraction in [0, 1]. Only rows where `Year` in `T*` is greater than or equal to `InstYear` are processed and the rest ignored, as they are not meaningful. Default value of MaxUF is 1.0, if not specified.

If particular ECT has the same MaxUF value for all values of either `InstYear` or some component of `G*` or some component of `T*`, then instead of creating a separate row for each such `InstYear` or `G*` element or `T*` element, only one row can be created with the `ALL` keyword in the corresponding column. One of the examples below elaborates it.

Example:

`ELECTRICITY_SUPERCRIT, 2021, INDIA, , 2023, , , , 1`: to say that a 2021 installed super-critical coal plant can be used fully (100%) in any time-slice of 2023

`ELECTRICITY_SOLARPV, 2022, INDIA, EAST, 2023, SUMMER, SEASONDAY, MID, 0.45`: to say that a solar plant installed in 2022 in East India has a 45% CUF in 2023 summer mid-day

`ELECTRICITY_SOLARPV, 2023, INDIA, EAST, 2023, SUMMER, SEASONDAY, MID, 0.48`: to say that a solar plant installed in 2023 in East India has a 48% CUF in 2023 summer mid-day

`ELECTRICITY_WINDON, 2023, INDIA, ALL, 2023, SUMMER, SEASONDAY, MID, 0.24`: to say that an on-shore wind generator installed in 2023 in 'all' regions in India has a 24% CUF in 2023 summer mid-day

4.8 ECT_LegacyCapacity.csv

Directory: `Root/Technologies`

Columns: `EnergyConvTech, G*, LegacyCapacity`

The last two parameters related to ECTs are about the legacy or pre-existing capacity that exists and its retirement schedule. This parameter defines how much pre-existing capacity is available of this ECT in the geographic area of interest, with geographic granularity as defined in `ECT_InputsGranularity`. The number of columns of `G*` is, as usual, defined by the maximum geographic granularity of all ECTs in `ECT_InputsGranularity`. The `LegacyCapacity` parameter indicates the pre-existing capacity in this geographic area in the capacity units of the ECT. If this row is missing for some ECT-geography combination, it is assumed that no legacy capacity exists for that combination.

Example:

`ELECTRICITY_SUBCRIT, INDIA, WEST, 53000`: to indicate 53 GW of sub-critical coal capacity in West India

`ELECTRICITY_SOLARPV, INDIA, WEST, 20000`: to indicate 20 GW of solar PV capacity in West India

4.9 ECT_LegacyRetirement.csv

Directory: `Root/Technologies`

Columns: `EnergyConvTech, G*, Year, RetCapacity`

This file provides the retirement schedule of the legacy capacity defined in the previous parameter. For each ECT and geographic area, and for each year in the model period, it provides the amount of legacy capacity that retires in that year. The geographic granularity at which this input is specified for an ECT is as per that specified in `ECT_InputsGranularity`. If this input is not given for any ECT-geography-year combination, it is assumed that no capacity is retiring in that combination. Naturally, the total amount of `RetCapacity` for an ECT across the various model years cannot exceed its legacy capacity. Since no capacity of any ECT may retire at all during the model period, this input file is optional.

Example: The following lines indicate that in West India, 1000, 2000 and 3000 MW of sub-critical coal capacity retires in 2021, 2022 and 2026 respectively.

```
ELECTRICITY_SUBCRIT, INDIA, WEST, 2021, 1000

ELECTRICITY_SUBCRIT, INDIA, WEST, 2022, 2000

ELECTRICITY_SUBCRIT, INDIA, WEST, 2026, 3000
```

5 Energy storage specifications

This section is regarding inputs related to energy storage technologies (ESTs). Many of these inputs are similar to the inputs required for ECTs – for example, efficiency, charge and discharge rates, legacy details etc. All storage related inputs are provided in the `Root/Storage` directory.

5.1 EnergyStorTechnologies.csv

Directory: `Root/Storage`

Columns: `EnergyStorTech, StoredEC, DomOrImp, MaxChargeRate, MaxDischargeRate, StorPeriodicity`

This file provides the basic information related to the ESTs being modelled. This includes the name of the storage, the energy carrier being stored, whether a domestic or imported variant of the EC is being stored, the maximum 'charge' rate of the EST, the maximum 'discharge' rate of the EST, and the frequency at which the storage should be reset to zero. The stored energy carrier cannot be a non-physical primary energy carrier.

The unit of measurement of the storage's capacity is, by definition, the same as the physical unit of the stored EC if it is a physical carrier, else it is the energy unit of the stored EC. The `DomOrImp` column is required because the energy densities of domestic and imported variants of physical primary carriers could be different and hence relevant for energy accounting. The string values used to signify the domestic and imported variants are respectively `EC_DOM` and `EC_IMP`. If the stored EC is a derived carrier, then it must be given as `EC_DOM`. The maximum charge and discharge rates should be positive real numbers in [0,1], and represent the maximum fraction of the storage's capacity that can be charged or discharged in any hour.

The storage reset periodicity is used to tell Rumi that an EST should forcibly be reset (i.e. 'discharge completely) at a specific frequency. In the absence of this, each time unit (e.g. the various days in a season) would have to be treated differently, as the amount of storage available for each such time unit may be different even though all other aspects (e.g. demand) are identical. This is because storage is 'stateful,' i.e. the amount of energy stored at some point (say, end of a day) determines the supply characteristics of the subsequent points (say, the next day). Allowing the storage to reset eliminates this problem by allowing each time unit (say, day) to begin from the same 'state'. If all ESTs have their storage reset periodicity specified such that time units can be abstracted (rather than dealt with individually), this would help reduce computation effort. This parameter can take on four string values namely `DAILY, SEASONAL, ANNUAL` and `NEVER`. The following are the rules governing this input:

- The storage reset periodicity must be strictly coarser than the balancing time of the stored EC, otherwise it would be impossible to charge the storage in a time unit and discharge in another. The meanings of each of the four values is self-explanatory.
- If the stored EC has a balancing time of `DAYSLICE`, and the storage reset periodicity is anything other than `DAILY`, then there can only be at most one `DAYTYPE`, since each day must be tracked separately which is not possible for multiple day types (see the documentation on common inputs).
- If the stored EC has a balancing time of `DAYTYPE`, then this parameter must be `SEASONAL`, `ANNUAL` or `NEVER`, i.e. it is coarser than or equal to a season. This too implies that there can be only one `DAYTYPE`.
- If the stored EC has a balancing time of `SEASON` or `YEAR`, then there are no restrictions on `DAYTYPE`, since individual days do not need to be tracked.

Example: In the following, the four-hour and six-hour batteries have their charge and discharge rates as 1/4 and 1/6 respectively to indicate that not more than a fourth or sixth of the maximum capacity of the battery can be charged or discharged in any hour. Note that storage technologies can store any energy carrier, other than a non-physical primary energy carrier.

```
FOURHRBATTERY, ELECTRICITY, EC_DOM, 0.25, 0.25, DAILY

SIXHRBATTERY, ELECTRICITY, EC_DOM, 0.1667, 0.1667, NEVER

PUMPEDSTORAGE, ELECTRICITY, EC_DOM, 0.20, 0.20, SEASONAL

CRUDE_RESERVE1, CRUDE, EC_DOM, 0.002, 0.002, NEVER

CRUDE_RESERVE2, CRUDE, EC_IMP, 0.002, 0.002, ANNUAL
```

5.2 EST_Lifetime.csv

Directory: `Root/Storage`

Columns: `EnergyStorTech, Year, LifetimeYears, LifetimeCycles`

This file provides the lifetime related information of new EST installed in a year. In the case of ESTs, lifetime consists of two separate components – the number of years and the number of charge/discharge cycles it supports. `Year` ranges over the years in the model period. `LifetimeYears` is a positive integer and `LifeTimeCycles` is a positive real number greater than or equal to 1. The EST is considered unusable if/when it exceeds either of the two limits.

Example:

```
FOURHRBATTERY, 2025, 10, 3800

SIXHRBATTERY, 2028, 12, 4000

PUMPEDSTORAGE, 2022, 60, 25000
```

5.3 EST_CapAddBounds.csv

Directory: `Root/Storage`

Columns: `EnergyStorTech, G*, Year, MaxCap, MinCap`

This input is similar to `ECT_CapAddBounds`, in that it defines the maximum and minimum capacity of an EST that can be added in a geography in a year. The geographic granularity is as defined in `EST_InputsGranularity`, with the number of `G*` columns corresponding to the EST with the finest geographic granularity specified in `EST_InputsGranularity`. `Year` ranges over the years in the model period. A value of `-1` in the `MaxCap` column is interpreted as there being no limit to capacity addition of that storage type in that year and geography.

Example: The following indicates that, in 2026, up to 200 MWh of four-hour battery can be installed in Maharashtra (assuming electricity's unit is MWh) and, in 2022, exactly 100 MWh of pumped storage would be installed in North India (since the minimum and maximum are both equal to 100 MWh). The last line says that in 2031, there is no limit on addition of six-hour battery in Karnataka.

```
FOURHRBATTERY, INDIA, WEST, MH, 2026, 200, 0

PUMPEDSTORAGE, INDIA, NORTH, , 2022, 100, 100

SIXHRBATTERY, INDIA, SOUTH, KA, 2031, 0, -1
```

5.4 EST_DeratingDepthOfDischarge.csv

Directory: `Root/Storage`

Columns: `EnergyStorTech, InstYear, CapacityDerating, DepthOfDischarge`

This input gives some operational details of an EST, such as how the capacity degrades over time and what is its 'depth of discharge', i.e. how much of the storage is accessible or usable. This information is provided by year of installation of the storage, where the year includes the 'legacy' year. Both the inputs are given as a fraction in [0, 1] and are applied to the currently effective capacity of the storage. Thus, the available capacity in any year is the derated capacity multiplied by the depth of discharge.

Example: These indicate that for the listed storage technologies installed in 2025, the capacity must be de-rated by 0.5%, 0.4% and 1% every year, and that the depth of discharge is 90%, 92% and 85% respectively.

```
FOURHRBATTERY, 2025, 0.005, 0.9

SIXHRBATTERY, 2025, 0.004, 0.92

PUMPEDSTORAGE, 2025, 0.01, 0.85
```

5.5 EST_EfficiencyCost.csv

Directory: `Root/Storage`

Columns: `EnergyStorTech, G*, InstYear, Year, FixedCost, Efficiency`

This input captures the storage cost and efficiency details. For each storage technology, in each geographic unit, by year of installation (including the 'legacy year') and for each model year, the annual cost per unit of the storage capacity and the round-trip efficiency of the storage are the inputs to be provided. As with ECTs, only the rows when the year is greater than or equal to the installation year are relevant, the rest are ignored. The geographic granularity is as given in `EST_InfoGranularity`. The number of `G*` columns are determined by the EST with the finest geographic granularity in `EST_InfoGranularity`. The fixed cost input is similar to the fixed cost for an ECT and is in the units of (currency-unit / unit-storage-capacity). The round-trip efficiency represents how much of the energy that is 'sent in' to the storage is actually stored, and is a number in [0, 1].

Example:

`FOURHRBATTERY, INDIA, WEST, 2027, 2028, 200000, 0.8`

`PUMPEDSTORAGE, INDIA, , 2019, 2022, 100000, 0.75`

5.6 EST_LegacyDetails.csv

Directory: `Root/Storage`

Columns: `EnergyStorTech, G*, LegacyCapacity, BalLifeTime, BalCycles`

The last input on ESTs is about legacy EST capacity and their retirement. This input is optional as there may be no legacy storage capacity. For each EST with some legacy capacity, the quantity of legacy or pre-existing capacity at model start, the remaining lifetime (in years) of that technology and optionally, the remaining number of charging cycles are to be given. These inputs have to be provided at a geographic unit that is the same as the balancing area of the stored EC. The legacy capacity is a non-negative real number, the balance life time is a non-negative integer and balance cycles is a non-negative real number.

Example:

`PUMPEDSTORAGE, INDIA, SOUTH, 100, 34, 100000`

6 Inter-geography energy flows

Energy carriers typically need to be transferred from the place of production or storage to the place of consumption, conversion or storage. Such energy flows involve both a cost and a transfer loss. Moreover, infrastructure requirements to enable such flows may impose a restriction on how much energy can flow between specific geographies. This input captures such information.

6.1 EC_Transfers.csv

Directory: `Root/Transfers`

Columns: `EnergyCarrier, G*Src, G*Dest, Year, TransitCost, TransitLoss, MaxTransit`

The energy transfer information for an EC is given between source and destination geographies that are specified at the balancing area level of the EC. Note that the source and destination geographies can be the same – in such cases, the given values correspond to intra-geography energy transfers. This information is provided at an annual temporal granularity as it is unlikely that it would change within a year. The explanation of the columns in the file is given below.

- `EnergyCarrier, Year`: Name of the energy carrier and the year for which the input is being given. `EnergyCarrier` cannot be a non-physical primary energy carrier. `Year` ranges over the years in the model period.

- `G*Src, G*Dest`: These represent the source and destination geographies of the transfer being described, and are similar to the `G*` columns in the other files. However, since each row in this file describes two geographies, the column headers are suffixed by `Src` or `Dest` to indicate whether it is the source or destination geography. Thus, the source geography column headers would be `ModelGeographySrc, SubGeography1Src` etc. while the destination geography column headers would be `ModelGeographyDest, SubGeography1Dest` etc. As usual, the number of columns in the file is decided by the energy carrier with the finest geographic balancing area, and the column entries for energy carriers for which the columns are irrelevant are left blank.
- `TransitCost`: Transit cost is specified as currency units per unit of EC, which is applied to the quantity of EC that is supplied (i.e. before the loss). The EC unit is the physical unit of EC if the EC is physical, else it is an energy unit. This transit cost represents the cost of supplying from 'anywhere within the source' to the 'boundary of the destination' if the two geographies are different and from 'anywhere to anywhere within the geography' if the source and destination are identical. In other words, for energy transfer across two distinct geographies, both the inter-regional cost of getting to the boundary of the destination geography and intra-regional cost of getting from the boundary to the 'actual destination' contribute to the total transit cost.
- `TransitLoss`: Transit loss is specified as a fraction in [0, 1], to be applied to the quantity being supplied. As with `TransitCost`, this also refers to the loss incurred in supplying from 'anywhere within the source' to the 'boundary of the destination' if the two geographies are different and the loss incurred in supplying from 'anywhere to anywhere within a geography' if the two are identical. Similarly, the actual losses applicable for energy transfer across distinct regions is the compounded effect of the inter-regional loss and intra-regional loss.
- `MaxTransit`: This defines the maximum amount of energy that can be transferred across the two geographies, where the limit is applied on the energy that is supplied (i.e. before any transit losses). A value of -1 will be interpreted as the equivalent of no restriction in supply (i.e. permitting infinite supply in any time unit) between these geographies. The unit of this input is (physical unit per unit time) for physical ECs and (energy unit per unit time) for non-physical ECs. The unit time considered depends on the balancing time of the energy carrier as described below. This value will be divided pro-rata among sub-time-intervals or aggregated up to the required balancing time as appropriate.
    - If the EC's balancing time is `DAYSLICE`, then the unit of this column is (EC units / hour).
    - If the EC's balancing time is `DAYTYPE`, then it is (EC units / day)
    - If the EC's balancing time is anything else, then it is (EC units / year).
- If a row is not provided for some pair of from-to-geographies for some EC, it would be assumed that this EC cannot be supplied from that geography to the other. That is, demand for this EC in the destination geography cannot be met through supply coming from this source geography.
- The above point implies that, for a specific geography, if there is no row with the geography as both source and destination (or if the row is present but with a value is zero for `MaxTransit`), then demand in that geography cannot be met at all, since such demand has to at least flow through the geography itself, which is prohibited by the missing row. Hence, in such cases, an error will be issued.

Example:

`ELECTRICITY, INDIA, WEST, GJ, INDIA, EAST, BR, 2023, 0.8, 0.04, 1000:` indicates 4% electricity transmission losses from GJ to BR at 0.8 Rs / kWh with a 1000 MW[10] limit in 2023.

`ELECTRICITY, INDIA, SOUTH, KA, INDIA, SOUTH, KA, 2027, 2, 0.18, -1:` indicates 18% (distribution) loss and 2 Rs / kWh for electricity (distribution) within KA in 2027, with no limit on how much electricity can flow.

`COAL, INDIA, EAST, , INDIA, NORTH, , 2021, 1200, 0.01, 100000000:` indicates that coal transfer from East to North in 2021 costs Rs 1200 / tonne, with 1% transit loss, and an annual transfer limit of 100 MT[11].

- Example cost calculation: Assume that 100 units of some EC are supplied from geography A to geography B (where A ≠ B). Also assume that the A->B transit cost is Rs 0.5 / unit and transit loss is 4%, and B->B transit cost is Rs. 2/unit with a transit loss of 15%. This means that these 100 units from A can meet 81.6 units of demand in B (100*0.96*0.85) at a cost of Rs 242 (100*0.5 + 96*2).
- Example `MaxTransit` use: For an EC with balancing time `SEASON` and physical units MT, if the max transit input is given as 1000, and a particular season occupies 0.28 of the year, then this translates to a transfer limit of 280 MT in that season. Similarly, for an EC with balancing time as `DAYSLICE`, and energy unit kWh, a max transit input of 1000 translates to a flow limit of 3 MWh for a day-slice that is 3 hours long (1000 kWh * 3).

7 EndUseEnergyDemand.csv

Directory: `Root`

Columns: `EnergyCarrier, G*, T*, EndUseDemandEnergy`

This file is typically produced by Rumi's demand processing component[12] and copies are produced in the `Demand/Output` and `Root` folders. The file contains the energy demand for each energy carrier (that is not a non-physical primary carrier) specified at time and geographic granularity coarser than or equal to balancing time and balancing geography of the carrier. . If energy demand is specified at a coarser than balancing granularity, it is assumed that any distribution of the demand across the finer balancing granularities is acceptable to the modeller. The modeller has the option of directly supplying this file

[10] MW, because it's assumed that MWh is the unit of electricity and also that its balancing time is day-slice (and hence the unit is per-hour).

[11] Assuming that the physical unit for coal is tonne and that the balancing time for coal is year.

[12] The file currently produced by the demand module contains an extra column (`TotalEnergyDemand`) which is ignored by the supply module.

(rather than relying on Rumi's demand module). In such a case, the modeller has to ensure that it contains all the relevant rows and columns, and at permitted granularities.

Please note that a file can contain multiple entries/rows for the same energy carrier with different time and geographic granularity. However, duplicate rows with the same energy carrier and time and geography are not allowed[13]. For demand entries, where time and geographic granularity is coarser than balancing time or geography, the columns not relevant can be left blank.

The `EnergyCarrier` column has the name of the energy carrier whose demand is being specified. The `G*, T*` columns indicate the geographic and time units for which the demand is being specified. As usual, the number of columns for `G*, T*` in the file would be the maximum of the columns required for the balancing units of all the relevant carriers and, if the columns are not relevant to some carrier, they should be left blank. The `EndUseDemandEnergy` column indicates the demand for the energy carrier in that geographic and time unit, expressed in the energy units of that carrier.

For demand entries, where time and geographic granularity is coarser than balancing time or geography, demand will be redistributed to the constituent balancing time and geography elements in a least cost manner during the process of optimization.

Example

```
ELECTRICITY, 2011, SUMMER, ALLDAY, MORNING, INDIA, KA, 60.6

ELECTRICITY, 2011, , , , INDIA, , 211468.9

STEAM COAL, 2011, , , , INDIA, , 530.11
```

In the above example, balancing time and geography of `ELECTRICITY` is `DAYSLICE` and `SUBGEOGRAPHY1`. For a particular demand sector, say residential, the example gives an energy demand of 60.6 GWh at the balancing time and geography. However, for another demand sector, say agriculture, demand of 211468.9 GWh has been provided at `YEAR` and `MODELGEOGRAPHY` which is coarser than the balancing time and geography. Columns which are not relevant are kept blank. For `STEAM COAL`, the balancing time and geography are `YEAR` and `MODELGEOGRAPHY`, hence energy demand of 530.11 is provided at the same granularity and other columns are kept empty.

[13] This is ensured by the Rumi demand module, if the file is produced by Rumi. If it is provided by the modeller, it is the modeller's responsibility.

8 UserConstraints.csv

Directory: `Root`

Based on parameter inputs provided by the user, Rumi defines constraints to find an optimal solution. In addition, Rumi provides a facility for users to create custom constraints. These constraints, which should be linear since Rumi is a linear programming-based model, are primarily intended to provide targets based on policy mandates that the model should try to achieve. Typical examples can be defining energy generation targets for specific ECTs to meet renewable energy generation requirements. In addition, users can define other constraints as required if they are not covered by the existing Rumi supply module.

A typical linear constraint has the following structure

```
Lower_BOUND  <=  VARIABLE_1[IndexValue1,IndexValue2..]*MULTIPLIER_1 +
                 VARIABLE_2[IndexValue1,IndexValue2..]*MULTIPLIER_2 +
                 ……
                 VARIABLE_N[IndexValue1,IndexValue2..]*MULTIPLIER_N <= UPPER_BOUND
```

All such constraints are provided through this single parameter file located in the `Root` directory.

This Input CSV contains header less columns and order of columns is relevant.

Each constraint contains three types of rows: a `COMMENT` row, a set of rows representing the linear combination of variables and constants, and a `BOUNDS` row representing the lower and upper bounds on the constraint.

The `COMMENT` row is identified by the keyword `COMMENT` in the first column. The purpose of this row is to provide a human-readable explanation of the constraint in the subsequent column(s) and is ignored by Rumi.

The `COMMENT` row should be followed by rows which define the linear combination of variables that define the constraint. The first column of each such row should contain the name of a variable. This should be followed by n columns that contain values for all the indices of the given variable, where n is the number of indices the variable has. After the columns with index values, the final column in the row has a constant multiplier with which the variable's indexed value would be multiplied.

Rumi provides some additional flexibility and convenience regarding how index values can be given.

1. Each index column can contain a list of possible values the index can take. This is specified as a list separated by commas, and the entire list should be within double quotes (refer to the example below for details). For each such value in the list, Rumi will expand it to addition of each instance of variable corresponding to each index value in the list.

   For example VARIABLE[“IndexValue1,IndexValue2”]*multiplierValue

   Will be expanded to VARIABLE[IndexValue1]* multiplierValue + VARIABLE[IndexValue2]* multiplierValue

2. If a particular index can take all possible values applicable for that index, then the `ALL` keyword can be used instead of listing out all possible values of the index.

   For example VARIABLE[ALL]*multiplierValue

   will be expanded to VARIABLE[IndexValue1]* multiplierValue + VARIABLE[IndexValue2]* multiplierValue, if the applicable values for the index of VARIABLE are IndexValue1 and IndexValue2

3. Similar to the `ALL` keyword, a range of integers can be specified in the StartInt-EndInt format when the index value is of type integer. For example, multiple years for indexes ‘Year’ or ‘InstYear’ can be specified in format StartYear-EndYear. Thus, if a user wants to include all the years from 2020 to 2035 for index ‘Year’, then it can be specified as ‘2030-2035’ instead of specifying individual rows with each year value as index. Please note that there should not be any spaces in the range specification.

   VARIABLE[2030-2032]*multiplier is expanded to VARAIABLE[2030]*multiplier + VARAIABLE[2031]*multiplier + VARAIABLE[2032]*multiplier by Rumi.

Please refer to the Annexure for the list of variables and applicable indices that can be used in constraint definition.

The constraint definition will be concluded by the keyword `BOUNDS` in the first row of the column, followed by upper and lower bound values in the subsequent two columns, where the upper and lower bound values are real numbers. Alternately, the keyword `NONE` can be used for either the lower or upper bound to indicate that the constraint is not bounded on the lower or upper side.

The following examples illustrate how constraints can be used.

Example 1

Suppose the user wants to provide the constraint that the sum of renewable energy generation capacity in the country for the year 2030 should be greater than 500 GW. Such a constraint can be defined as below, assuming solar PV, wind, small hydro and biomass are the only renewable technologies. `EffectiveCapacityExistingInYear` is the variable that represents the effective generation capacity of any energy conversion technology that exists in a year, and it has indices corresponding to the energy conversion technology, the year of operation and the sub-geographies where the capacity is installed. Since this constraint is applicable to the total capacity in the entire model geography, it can be written as follows

$$500 \leq \sum_{t\,\in\{\,SOLAR\_PV, WIND, SMALL\_HYDRO, BIOMASS\}} EffectiveCapacityExistingInYear[t, 2030, INDIA, ALL] \leq \infty$$

The Rumi parameter corresponding to this can be provided as follows

```
COMMENT,"Effective capacity that exists in 2030 in all of India of all renewable technologies >= 500 GW "

EffectiveCapacityExistingInYear,"EG_SOLARPV,EG_WIND,EG_SH,EG_BIOMASS",2030,INDIA,ALL,1

BOUNDS,500,NONE
```

The second row contains the variable name `EffectiveCapacityExistingInYear` in the first column, which is participating in the constraint definition. The first index of this variable is an `ECT`, which for the required constraints takes the values of all renewable technologies such as Solar PV, Wind, Small hydro, Biomass etc. The third column corresponds to the index `YEAR`, which has the value 2030 since the constraint is only for 2030. Since, we want to sum up the capacity across all regions (`SUBGEOGRAPHY1`), the third index (corresponding to `ModelGeography`) takes the value `INDIA` and the fourth index (corresponding to `SubGeography1`) takes the value `ALL` which allows the capacity in all `SubGeography1` regions to be added up.

After the indexes, the last column in the variable row contains the value `1` which is a multiplier of the variable `EffectiveCapacityExistingInYear`. As it is a simple summation of all capacities without any special weight to any particular ECT or region, the multiplier value is 1.

The third row has the keyword `BOUNDS`, where the subsequent column contains values 500 and None which implies that the constraint has a lower bound of 500 and no upper bound.

Blank rows in the file are ignored.

Example 2

Suppose we have to define technical minimum for the coal generation fleet for the year 2025, which will be applicable for all capacities installed from 2023 to 2025. The linear constraint for this is

$$\sum_{2023 \le InstYr \le 2025} OutputFromECTiy(InstYr, ECT\_COAL\quad T*, G*) \ge 0.4 * \ EffectiveCapacityExistingInYear(ECT\_COAL\quad, 2025, G*)$$

Here 0.4 (40%) is the technical minimum. This equation can be rewritten as below so than user constraint for it can be defined.

$$0 \le \sum_{2023 \le InstYr \le 2025} OutputFromECTiy(InstYr, ECT\_COAL\quad, T*, G*) - \ 0.4 * \ EffectiveCapacityExistingInYear(ECT\_COAL\quad, 2025, G*) \le \infty$$

Thus, the user constraint for it can be defined as below. Please note that this particular constraint is only defined for a particular dayslice of a particular season. Such constraints have to be defined for all dayslices of all seasons.

```
COMMENT, Technical minimum constraint for the coal fleet in Western
region.

OutputFromECTiy,2023-2025,EG_COAL,2025,S03Jun,ALLDAYS,H09,INDIA,WR,1

EffectiveCapacityExistingInYear,EG_COAL,2025,INDIA,WR,-0.4

BOUNDS,0,None
```

The first row of above constraint is the `COMMENT` row. The second row is related to output from the coal fleet which is defined by variable `OutputFromECTiy`. Its first index is `InstYear`. In this example we want all capacity installed from 2023 to 2025, which is specified by the range 2023-2025. The next column is the ECT which `EG_COAL` in this case. Columns '`2025,S03Jun,ALLDAYS,H09`' provide the T* indices and columns '`INDIA,WR`' provide the G* indices. The last column is multiplier which 1 for this variable.

The third row is related to `EffectiveCapacityExistingInYear` which is the installed, effective capacity of the coal-based generation fleet. The first index for this variable is the ECT which in this case is EG_COAL. The next index is YEAR. The columns 'INDIA,WR' give the G* indices and the last column represent the multiplier which is -0.4 for this variable as discussed in the constraint formulation above.

The last row specifies that the lower and upper bounds for this constraint are 0 and infinity.

9 Finding an optimal supply mix

Given all the inputs as described in the previous sections, and given the expected demand for each energy carrier in each balancing geography and balancing time of the carrier, the supply module identifies the supply options that are required to meet the demand in each geography/time unit such that the total cost across all geography/time units is minimised. While doing so, it considers all possible costs that have been modelled and identifies the least cost option with 'perfect foresight' or 'complete knowledge.' Moreover, it also satisfies all constraints on production, imports, energy transfers, operating characteristics (e.g. usage factors, ramp rates etc.) and so on. Note that it may also choose to not meet some demand, if the unmet demand value input for that demand is lower than the best available supply option. In the process, it makes the following decisions:

- Decide between domestic production and imported sources for each EC in each geographic and time unit
- Decide about how much capacity of various ECTs and ESTs should be installed where and when
- Decide about usage / operation of various ECTs and ESTs for each geographic and time unit

10 Outputs of the supply component

The final set of outputs are produced by default in a directory called Supply/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 README.md file available in the root directory of the Rumi platform repository). Under the Supply/Output directory, there is a Run-Inputs directory which contains the actual input parameters used for this supply run as seen by pyomo, and a Run-Outputs directory which contains the outputs produced by the supply run. The following table lists all the output files that are produced and a brief description of the information each file contains.

Appendix

The list of output files / variables and applicable indices

Variable / Output CSV file	Description	Index			
AnnualCost	The total cost for all energy carriers put together in each year	Year			
AnnualCarrierCost	The total cost incurred for all energy carriers, technologies etc. put together in each year	Year			
AnnualECTCost	The total fixed cost for all energy conversion technologies put together in each year	Year			
AnnualStorageCost	The total fixed cost for all storage put together in each year	Year			
CostOfCarrier	The cost of an energy carrier in a year y as built up from ECCostInBT_BA	EnergyCarrier			
ECTFixedCost	The fixed cost of each conversion technology in each year	EnergyConvTech			
CostOfStorage	The fixed cost of each storage type in each year	EnergyStorTech			
TotalECCostInBT_BA	Total cost of an EC in each balancing geography/time, which is the sum of ECCostInBT_BA, ECTransitCost and cost of unmet demand	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)	
ECCostInBT_BA	The cost of an EC being used in a balancing time/geography. It includes PECCostInBT_BA or DECCostInBT_BA as the case may be and also ECTVarCost, the transit cost of this carrier discharged from	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)	

	storage and the cost of unserved demand of this carrier in this balancing time/geography.				
DomECCostInBT_BA	The total cost (i.e. basic carrier cost plus taxes plus transit cost) of the domestic variant of each energy carrier being used in a balancing geography/time	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancin g Area granularity of EC)	
ImpECCostInBT_BA	Same as DomPECCostInBT_BA.csv but for imported primary ECs	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancin g Area granularity of EC)	
ECTInputVarCost	The additional variable cost of processing the input EC for each ECT in each year	EnergyCarrier	Year		
ECTransitCost	The transit cost to supply EC across geographies at balancing geography and time of the EC	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancin g Area granularity of EC)	
UnmetDemand	The quantity of EC whose end-use demand in the balancing geography/time remains unmet or unserved	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancin g Area granularity of EC)	
DomSupplyFromTo	The quantity of domestic variant of an EC supplied from a balancing geography in a balancing time	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancin g Area granularity of EC) From	G*(Balancin g Area granularity of EC) To
ImpSupplyFromTo	Same as DomSupplyFrom.csv but for imported ECs	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancin g Area granularity of EC) From	G*(Balancin g Area granularity of EC) To
TotalSupplyFromTo	The total amount of EC (domestic or imported) supplied from one	EnergyCarrier	T*(Balancing Time	G*(Balancin g Area	G*(Balancin g Area

	balancing geography to another, in each balancing time		granularity of EC)	granularity of EC) From	granularity of EC) To
ECTInputDomOutputGran	The quantity of domestic variant of input EC used by an ECT for each installation year of the ECT in each balancing geography/time of the output EC of the ECT. This is one of the variables used to redistribute input carrier quantum from courser to finer time/area granularity as input and output ECs can have arbitrary granularity	InstYear	EnergyConvTec h	T*(Balancin g Time granularity of output EC)	G*(Balancin g Area granularity of outputs EC)
ECTInputImpOutputGran	Same as 'ECTInputDomOutputGran' but for imported variant of EC.	InstYear	EnergyConvTec h	T*(Balancin g Time granularity of output EC)	G*(Balancin g Area granularity of output EC)
ECTInputDomInputGran	The quantity of domestic variant of input EC used by an ECT for each installation year of the ECT in each balancing geography/time of the input EC of the ECT. This is one of the variables used to redistribute input carrier quantum from courser to finer time/area granularity as input and output ECs can have arbitrary granularity	InstYear	EnergyConvTec h	T*(Balancin g Time granularity of input EC)	G*(Balancin g Area granularity of input EC)
ECTInputImpInputGran	Same as 'ECTInputDomInputGran' but for Impoerted variant of EC	InstYear	EnergyConvTec h	T*(Balancin g Time granularity of input EC)	G*(Balancin g Area granularity of input EC)
ECTInputDomCoarserGran	The quantity of domestic variant of input EC used by an ECT for each installation year of ECT at coarsest	InstYear	EnergyConvTec h	T*(Balancin g Time granularity	G*(Balancin g Area granularity

	time and area granularity among the input or output EC of the ECT. This is intermediate variable to redistribute input carrier quantum from courser to finer time/area granularity as input and output ECs can have arbitrary granularity			of courser of input/ouput EC)	of courser of input/output EC)
ECTInputImpCoarserGran	Same as 'ECTInputDomCoarserGran' but for imported variant of EC	InstYear	EnergyConvTech	T*(Balancing Time granularity of courser of input/ouput EC)	G*(Balancing Area granularity of courser of input/output EC)
DomSupplyFrom	The quantity of domestic variant of an EC supplied from a balancing geography in a balancing time	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC) From	
ImpSupplyFrom	Same as DomSupplyFrom.csv but for imported ECs	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC) From	
DomesticProd	The amount of 'local' production of an energy carrier (primary or derived) in each balancing time/geography	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)	
Import	The quantity of EC imported at the balancing area/time of EC.	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)	
SupplyFromECTiy	The supply of output EC from an ECT by installation year and in each balancing geography/time	InstYear	EnergyConvTech	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)

DomStorDischargedFrom	The quantity of energy carrier discharged from all storage technologies that store the domestic variant of the carrier, from one balancing geography to another in each balancing time of the carrier	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)	
ImpStorDischargedFrom	Same as DomStorDischargedFromTo.csv but for storage of imported ECs	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)	
OutputFromECTiyUsingDomInput	The gross amount of output EC produced from an ECT using domestic input EC, by installation year for each balancing geography/time	InstYear	EnergyConvTech	T*(Balancing Time granularity of output EC)	G*(Balancing Area granularity of output EC)
OutputFromECTiyUsingImpInput	Same as OutputFromECTiyUsingDomInput.csv but using imported input EC	InstYear	EnergyConvTech	T*(Balancing Time granularity of output EC)	G*(Balancing Area granularity of output EC)
OutputFromECTiy	The gross amount of output EC produced from an ECT by installation year in each balancing geography/time	InstYear	EnergyConvTech	T*(Balancing Time granularity of output EC)	G*(Balancing Area granularity of output EC)
EndUseDemandMetByDom	The end-use demand for an EC in a balancing geography/time that is met from domestic sources	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)	
EndUseDemandMetByImp	The end-use demand for an EC in a balancing geography/time that is met from imported sources	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)	

EndUseDemandComponents	Intermediate variable used to redistribute EndUseDemand at balancing geography and time for carriers whose demand is given coarser than the balancing geography/time.	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)	
EndUseDemandVar	EndUseDemand at balancing geography and time distributed in a cost optimal manner for carriers whose demand is given coarser than the balancing geography/time. This is demand calculated by aggregating EndUseDemandComponents for EC at balancing time and geography	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)	
NamePlateCapacity	The "name plate" capacity (i.e. without derating) of ECTs installed in each year	InstYear	EnergyConvTech	Year	G*(Balancing Area granularity of output EC)
EffectiveCapacity	The effective (post derating) capacity of ECTs by installation year in each model year	InstYear	EnergyConvTech	Year	G*(Balancing Area granularity of output EC)
CapacityInstalledInYear	The capacity of each ECT that is added in each year in each balancing geography of the output carrier of the ECT	EnergyConvTech	Year	G*(Balancing Area granularity of output EC)	
RemainingLegacyCapacity	The legacy capacity of each ECT that remains in a balancing geography and year after retirements	EnergyConvTech	Year	G*(Balancing Area granularity	

				of output EC)	
EffectiveCapacityExistingInYear	The effective (post derating) capacity of each energy storage technology (EST) by installation year for each model year	EnergyConvTech	Year	G*(Balancing Area granularity of output EC)	
StorCapacityInstalledInYear	The capacity of each EST freshly installed in a year in each balancing geography	InstYear	EnergyStorTech	G*(Balancing Area granularity of EC)	
StorDischarged	The quantity of EC that is discharged in each EST by installation year, balancing geography/time	InstYear	EnergyStorTech	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)
StorCharged	The quantity of EC that is charged in each EST by installation year, balancing geography/time	InstYear	EnergyStorTech	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)
StorMaxLifetimeCharge	The cumulative quantity of EC that has been charged since its installation in each EST by installation year and balancing geography/time	InstYear	EnergyStorTech	G*(Balancing Area granularity of EC)	
StorChargeLevel	The quantity of EC 'currently' stored in each EST by installation year and balancing geography/time	InstYear	EnergyStorTech	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)
EffectiveStorCapacity	The effective (post derating) capacity of each energy storage technology (EST) by installation year for each model year	InstYear	EnergyStorTech	YEAR	G*(Balancing Area granularity of EC)
StorLifetimeCharge	The cumulative quantity of EC that has been charged since its	InstYear	EnergyStorTech	T*(Balancing Time	G*(Balancing Area

	installation in each EST by installation year and balancing geography/time			granularity of EC)	granularity of EC)
StorCapacityExistingInYear	The effective (i.e. post derating) total capacity of each EST in each balancing geography and year	EnergyStorTech	YEAR	G*(Balancing Area granularity of EC)	
MaxDomesticProdVar	The maximum quantity of primary physical EC that can be produced domestically in each balancing geography/time	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)	
MaxImportVar	The maximum quantity of EC that can be imported at balancing time/geography	EnergyCarrier	T*(Balancing Time granularity of EC)	G*(Balancing Area granularity of EC)	

Note: In time granularity (T*) also contains day number if

1. Time granularity of associate EC is finer or equal to `DayType`.
2. If EC has at least one storage with rest type coarser than `DAILY`