**Model equations of the EPMM model**

**Notation:**

* Indices:
  + t: time, hour
  + r, r’: Region/country;
  + R: all region considered
  + Generator types:
    - th: thermal power plant
    - hs: hydro storage plant, excluding pumped storage and run-off river type
    - es: energy storage power plant
    - dr: demand response
    - res: renewable power plant
    - miss: missing power plant
* **Non-negative variables**, and parameters:
  + General:
    - **P**: Power generation
    - **C**: Power consumption
    - Eff: Efficiency
    - CI: Carbon intensity
    - AVA: Availability
    - SC: Self consumption
  + Demand response:
    - **LC**: Lower consumption due to demand response
    - **CC**: Complementary consumption due to demand response
    - UCAP: Upper capacity level by which demand responder can increase its consumption
    - LCAP: Lower capacity level by which demand responder can decrease its consumption
  + Energy Storage:
    - **STO**: Storage level
    - CCAP: Charging capacity
    - SCAP: Storage capacity
    - DCAP: Discharge capacity
  + Hydro storage:
    - MinCAP: Minimum production capacity of hydro storage
    - MaxCAP: maximum production capacity of hydro storage
  + Thermal generation:
    - **d**: On (d=1) *or* off (d=0) status of the thermal power plant, binary variables
    - UT: up-time of a thermal capacity
  + Cost:
    - Cost(Start): Start-up cost
    - Cost(OM): Operational and Maintenance cost
    - Cost(Fuel): fuel cost
    - Cost(CO2): CO2 price
    - VOLL: Value of Loss Load
    - VOLL(+): Cost of loss of spinning up reserve requirement
    - VOLL(-): Cost of loss of spinning down reserve requirement
  + Interconnection
    - ICAP(r,r’): Interconnector export capacity between r and r’
    - ICAP(r’,r): Interconnector import capacity between r’ and r
    - **Flow(r,r’)**: Electricity export from r to r’
    - **Flow(r’,r)**: Electricity import from r’ to r
  + Reserve:
    - **RSV(+)**: providing upward reserve
    - **RSV(-)**: providing downward reserve
    - RSV(up): upward reserve demand
    - RSV(down): downward reserve demand
    - r\_share(up): upward reserve capability as a percentage of installed capacity
    - r\_share(down): downward reserve capability as a percentage of installed capacity

**Objective function**

**Constraints:**

Energy balance:

The total production and the net import should be equal with the consumption including the storage and demand response in each hour for all countries.

Capacity constraints:

Capacity constraints reflect that the hourly production/consumption (in the case of energy storages) or trade cannot exceed the capacity of the power plant/interconnector.

* Interconnector:
* Thermal power plant: and
* Demand response: ;
* Hydro storage:
* Energy Storage: and and , ,
* Renewable:

Hydro storage:

The total generation of the hydro storage power plants should be equal with the capacity multiply by the availability factor.

Energy storage level:

Demand response:

Thermal power plant

If a thermal power plant decreases its production to zero (it means that it is not online), then for at least for UT hours it cannot increase its production. This is the minimum down-time hour.

Reserve – upward:

Reserve - downward:

* +