RES – INTEGRATION
FP6 509204 RES Integration

DETERMINING OPTIMUM INTEGRATION OF RENEWABLE ENERGY SOURCES (DOIRES) SOFTWARE

Theoritical Backround of Optimisation Process

WP 3 – Deliverable 6

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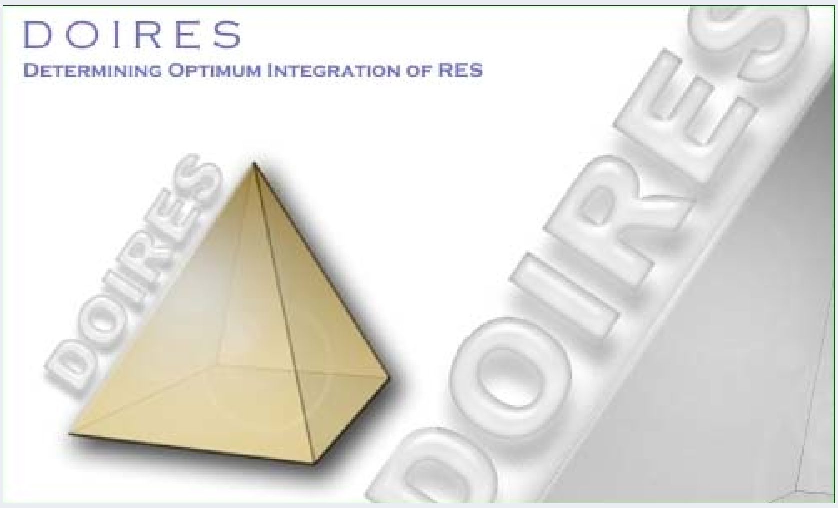
INTRODUCTION TO DOIRES

DOIRES is a mathematical programming optimisation tool with different objectives (minimisation of total cost or total emissions, maximisation of RES share or other indicators) subject to suitable equality and inequality constraints. The model has taken into account appropriate technologies for Integrated RE system and it is designed for an energy planning of a time horizon of up to 20 years.

The model is used for defining the optimum local combination (integration at regional level) of renewable energy technologies according to the specific conditions, needs, particularities of the target region examined at each case. In presence of conflicting objectives, multi-criteria analysis is used to select a compromise option that enhances sustainability. The steps for determining the optimum integration of RE Technologies in specific target regions can be summarised as follows: (a) data collection (energy data, environmental, social, weather data) of the region under study, (b) scenarios based on expectations and system parameters, (c) optimisation resulting in combination of conventional and RE Technologies and (d) multi-criteria analysis that allows for exploration of the proposed solutions, dialog among decision makers and stakeholders aiming at the best compromise.

The inputs to the model pertain with the description of specific scenario to be optimised, based on expectations for the region and the parameters for the system.

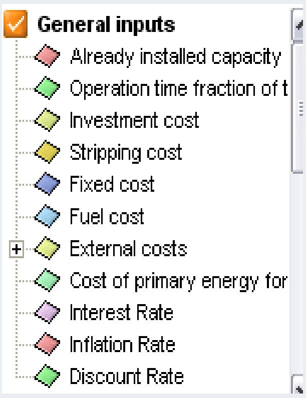
DOIRES allows for an optimisation starting from a base of several possible configurations of potential technologies to be exploited for energy production in the target region under study and leads, under suitable constraints and sustainability indicators, set by the user according to the pursued goal, in an edge of best compromise configuration. This procedure could be pictured as a pyramid, its base being the described scenario to be optimised and its edge, the chosen by DOIRES tool configuration of technologies in operation for a planning horizon of up to 20 years.



The model is formulated according to certain inputs that the user defines through DOIRES environment. These inputs pertain with the definition of the indices, parameters and explanatory variables of the optimisation model, as well as the suitable equality and inequality constraints. The user is advised to follow the specific order in which the inputs are asked by DOIRES in order that no one of them is omitted:

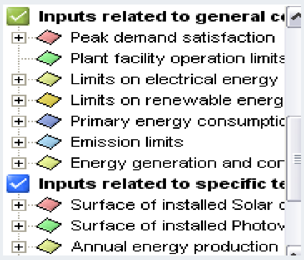
I. Description of scenario to be optimised

II. General Inputs

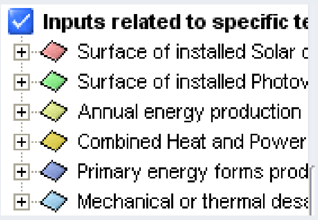


HINT: Inputs that do not apply to the specific case of the user are simply omitted

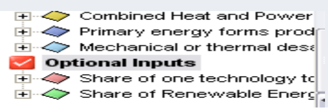
III. Inputs related to general constraints applied for all cases



IV. Inputs related to specific technologies and activities



V. Optional Inputs



Description of scenario to be optimised

Describing the scenario to be optimised gives definition to the indices (sets) of the specific optimisation model case. Different optimised scenarios constitute the alternatives in which the multi-criteria analysis is applied.

First step is to define the list of technologies that are going to be tested and fuels to be used through completing the relevant lists. Also, for each case different energy sectors apply. Energy sectors have the meaning of end-users of the energy produced in the system. The contents of kinds of technologies and kinds of energy sectors are flexible. The user has the ability to fill with different than listed names of technologies and energy sectors according to his specific case.

The second step is to complete four different **tables corresponding to electric, thermal and other power demand**, and also the primary energy source production, if this activity is included in the target region. Other power demand refers to Combined Heat and Power and vehicles engines for transportation and machinery.

In order that the different explanatory scenarios are described explicitly enough, giving all the required information to the optimization model, the following methodology is adapted:

Given a list of technologies that are used as generation options, the energy is produced for specific power demand satisfaction of certain energy sectors (consumers).

The tables to be filled have 20 rows for technologies and 10 columns for energy sectors, for every kind of power demand. What has to be filled is given in appearing boxes for each cell.

How to create different scenarios

Each scenario is described with a pursuing goal, like integration of geothermal district heating, or a second scenario for excluding geothermal heating due to residents' opposition to geothermal energy. Another example could be for maximization of RES share in electricity generation, or introduction of primary energy sources production, in contrast to an alternative described scenario. These pursuing goals contribute to a different layout of the relative tables to be filled of electric, thermal, other power or primary energy sources production.

Hint: In case that no many combinations of different technologies could be tested for a specific region, for any reason, one could be for there is not potential for many technologies that could be incorporated, one way to generate several scenarios could be to exchange thermal with electric power demand tables. This means that two different scenarios could become three if the electric power demand table of the first scenario is used as combination with the thermal power demand table of the second scenario.

After the model has run for one described scenario, reaching to a certain configuration of technologies, the whole procedure could start from this point of describing a second scenario, leading this way to a second comparable configuration. The whole procedure could be repeated for the same specific conditions, needs, particularities of the target region examined at each case, as many times as the user defines possible scenarios for his case under study. Each scenario is saved with a characteristic name in a general folder with the name of the target region, for example Milos case study \ scenario 1: integration of PV

How the tables are filled

Technologies and energy sectors selected in the relevant lists are crossed in the tables with corresponding numbers of Loads for whose satisfaction the technologies are used. Each load number corresponds to a different **Load Duration Curve** **(LDC)**. Same technology may be used for the same energy sector but for satisfaction of a different load. That is why dual cells were made for each combination of technology and energy sector. **Important Note: For describing the distribution of produced power (electric or thermal) to more than one energy sectors by the same technology-(ies) only the numbers of Loads 1 to 3 could be used. The rest numbers of loads 4-10 could be given arbitrarily for loads localized in single energy sectors.**

Loads with the same number participate in the same equation of power generation and consumption balancing, equalized with the same Load Duration Curve (LDC). The same technology (for example fossil fuel boilers) corresponding to different LDCs is categorized in as many categories as the LDCs it corresponds to (categories actually means subsets of j technology in the formulation of the model). This is because as for the example of Thermal power demand and fossil fuel boilers, diesel boilers for industry is a different, in regard to technical and costs characteristics, technology, from domestic diesel boilers.

By corresponding technologies to energy sectors by specific loads generates different subsets of technology set (j), fuels set (i), and energy sectors set (s). The elements required for each table of power demand are:

Electric power demand

Apart from load number for which the corresponding technologies are used, the user gives additional information of whether the power production is centralized or distributed. In order that things are clear enough the following table of electric power demand describes a scenario where:

Electric power

	domestic	industrial	agriculture	transport	desalination	solid waste management	waste water treatment	biogas plant	primary energy source
fossil fuel electricity	centralised 1	centralised 1 distributed 4	centralised 1			centralised 1			
biomass electricity							distributed 2	distributed 2	
biogas generators							distributed 2	distributed 2	
wind turbines	centralised 1	centralised 1 distributed 4	centralised 1		distributed 5	centralised 1			
Photovoltaics					distributed 5		distributed 6		
Hydropower	centralised 1	centralised 1	centralised 1			centralised 1			
Solid waste to energy	centralised 1	centralised 1	centralised 1			centralised 1			

- Centralised electricity production is used, giving electricity to the grid, for the production of which, certain technologies are selected in order that the model decides about their optimum combination according to the constraints that are imposed.

  According to the first table the technologies that are selected are fossil fuel electricity generators, wind turbines, hydro power and solid-to-waste energy (RDF technology) to satisfy electricity demands of domestic, industrial, agriculture and solid waste management energy sectors. That is *Centralised 1* Load duration curve. It means that you will be asked by the model to give the load to be satisfied by these technologies and for these energy sectors.

- Industry sector though, does not satisfy its electric power demands only by the grid, but a distributed energy production is also used, with fossil fuel generators again and also wind turbines are chosen to make an optimum combination. (a substitution of fossil fuel generators may be foreseen). That makes *Distributed 4* Load duration Curve.
- Electricity needs for desalination will be satisfied in this scenario by combination of wind turbines and photovoltaics (*Distributed 5* Load Duration Curve)
- Biomass and biogas generators are used for distributed production for waste water treatment and biogas plant energy sector (*Distributed 2* Load Duration curve). A part though of the load of waste water treatment sector will be satisfied by a stand alone installation of photovoltaics. (*Distributed 6* Load Duration curve).

Thermal power demand

For each technology and energy sector you are asked to select between satisfaction of district heating, space heating, heat demands, sanitary water and other or mix, which will help in the differentiation between different Loads, and Loads in numbers, each of which will correspond again to a different Load Duration Curve.

The following table of thermal power demand describes a scenario where:

Thermal power

	domestic	industrial	agriculture	transport	desalination	solid waste management	waste water treatment	biogas plant
Photovoltaics								
Hydropower								
Solid waste to energy							heat deman 2	heat deman 2
Geothermal heating	district 1		district 1		heat deman 7			
Solar heating	sanitary wa 6				heat deman 7			
Diesel boilers	space heati 1	heat deman 5	heat deman 1					
Biomass heating	district 1		district 1					
Heat pumps			heat deman 4				heat deman 2	space heati 2

- District heating is used for domestic and agriculture energy sectors with technologies to be compared for its production, geothermal and biomass burners. That makes *District 1* Load.

  Space heating of domestic sector is also satisfied by fossil fuel boilers with load name *space heating 1* (it has a different name but the same number with *District 1*). This tells the model the following: Fossil fuel boilers have a separate load duration curve but I want that both loads are incorporated in the same equality and inequality constraints in order that fossil fuel boilers could be substituted by district heating.

  The same is valid for agriculture sector and load *heat demands 1*. Fossil fuel boilers have a separate load duration curve but both loads are incorporated in the same equality and inequality constraints in order that fossil fuel boilers could be substituted by district heating.

- A separate load of heat demand for agriculture (for example for drying) is described by *heat demands 4* with heat pumps use. This means that the power output of heat pumps are equalized with the specific power demand for this load.
- The load *Heat demands 5* describes specific heating needs of industry to be satisfied by fossil fuel boilers.
- For sanitary water needs of domestic sector solar collectors are used under the load *sanitary water 6*. If load number 1 had been given for sanitary water of domestic sector with solar collectors, solar collectors' technology would have participated in the same equation of power generation and consumption balancing, thus acquiring the potential of being partially or totally substituted by other technologies participating in Load 1.
- Heat demands for desalination is proposed to be satisfied by two technologies, the combination of which the model defines: geothermal heating and solar collectors (*heat demands 7*)
- For waste water treatment and biogas plant sectors the heat demands is proposed to be covered by solid waste burning and geothermal heat pumps (*heat demands 2).*The load is given the number 2, as the power produced is distributed to more than one energy sectors. (See Important note above).

Other power demand

Other power demands refer to Combined Heat and Power and vehicles engines for transportation and machinery.

In transportation vehicles and machinery the user has only to select the cells that correspond to diesel engines that burn diesel and otto engines that burn petrol, if this option is examined by the specific case.

Combined Heat and Power have two boxes: Electric Load (left box) and Thermal Load (right box) with numbers of loads already given in electric power and thermal power or not. In the following example gas turbines are used for CHP, giving electricity to the grid (*centralized 1* load) and thermal energy to load 5 (industry *heat demands 5)* load with fossil fuel boilers use). Other loads than the ones already given in electric and thermal power tables, could also been used.

	domestic		industrial		agriculture		transport	desalination		solid waste management	
Photovoltaics											
Hydropower											
Solid waste to energy											
Geothermal heating											
Solar heating											
Diesel boilers											
Biomass heating											
Heat pumps											
Geothermal desalination											
wind desalination											
solar desalination											
diesel engines							✓				
otto engines vehicles							✓				
gas turbines	1		1	5	1					1	
New Technology 2											
New Technology 3											

Primary Energy Source Production

Primary energy source production pertains with the production in the target region of a primary energy product that could be either used for own use in the energy system of the target region and/or exported. For the model's calculations four columns are asked to be completed: source (from a list), product (from a list), productivity of the source in t of product per ha if a crop is the primary energy source or per t waste.day, if the source is a plant of waste management. The following table shows an example, in which vegetable oil production from sunflower crop is foreseen for the target region.

Primary energy source production

	Source	Product	Productivity	Units
1	Sunflower	Vegetable oil	1	t/ha

Model Formulation

INDICES or SETS (symbolism of dimensions)

Set *i* all fuels

- Subsets:

$i_1(i)$ all solid fuels (not participating in mixes)
$i_2(i)$ primary energy products to be produced in the system
$i_3(i)$ fuels 1 of fuel mixes
$i_4(i)$ fuels 2 of fuel mixes
$i_5(i)$ fuels 3 of fuel mixes
$i_6(i)$ biofuels

Set *s* energy sectors / 1 to 10 /
*1 domestic, 2 industrial, 3 agriculture, 4 transport, 5 desalination, 6 solid waste management, 7 waste_water_treatment, 8 biogas plant, 9 primary energy source production, 10 other

- Subsets:

$s_1(s)$ end-use sectors in which electric load 1 is distributed
$s_2(s)$ end-use sectors in which electric load 2 is distributed
$s_3(s)$ end-use sectors in which electric load 3 is distributed
$s_4(s)$ end-use sectors in which thermal load 1 is distributed
$s_5(s)$ end-use sectors in which thermal load 2 is distributed
$s_6(s)$ end-use sectors in which thermal load 3 is distributed

Set *n* load numbers / 1 to 10 /

Set *k* source for primary energy production

Set *t* years /1 to 20 /

Set *p* time intervals / 1 to 8/

Set *r* pollutants

Set *pd* kind of power demand /electric, thermal, other /

Set * upper and lower bounds /upper, lower/

Set *d* /thermal desalination, mechanical desalination/

Set *j* all technologies

- Subsets

$j_1(j)$ technologies for electricity load 1 sectors s_1
$j_2(j)$ technologies for electricity load 2 sectors s_2
$j_3(j)$ technologies for electricity load 3 sectors s_3
$j_4(j)$ technologies for thermal load 1 sectors s_4
$j_5(j)$ technologies for thermal load 2 sectors s_5
$j_6(j)$ technologies for thermal load 3 sectors s_6

$j_7(j)$ technologies using fuels 1 (i3) of mixes
$j_8(j)$ technologies using fuels 2 (i4) of mixes
$j_9(j)$ technologies using fuels 3 (i5) of mixes

$j_{10}(j) – j_{19}(j)$ technologies for **electric load number 1** and sectors 1 to 10 respectively
$j_{20}(j) – j_{29}(j)$ technologies for **electric load number 2** and sectors 1 to 10 respectively

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……………………………………………………………………………………………
$j_{100}(j) - j_{109}(j)$ technologies for **electric load number 10** and sectors 1 to 10 respectively

$j_{110}(j) - j_{119}(j)$ technologies for **thermal load number 1** and sectors 1 to 10 respectively
$j_{120}(j) - j_{129}(j)$ technologies for **thermal load number 2** and sectors 1 to 10 respectively
……………………………………………………………………………………………
……………………………………………………………………………………………
$j_{200}(j) - j_{209}(j)$ technologies for **thermal load number 10** and sectors 1 to 10 respectively
$j_{210}(j) - j_{219}(j)$ technologies for **electric load number 1** of **other power** and sectors 1 to 10 respectively
$j_{220}(j) - j_{229}(j)$ technologies for **electric load number 2** of **other power** and sectors 1 to 10 respectively
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……………………………………………………………………………………………
$j_{300}(j) - j_{309}(j)$ technologies for **electric load number 10** of **other power** and sectors 1 to 10 respectively

$j_{310}(j) - j_{319}(j)$ technologies for **thermal load number 1** of **other power** and sectors 1 to 10 respectively
$j_{320}(j) - j_{329}(j)$ technologies for **thermal load number 2** of **other power** and sectors 1 to 10 respectively
……………………………………………………………………………………………
……………………………………………………………………………………………
$j_{400}(j) - j_{409}(j)$ technologies for **thermal load number 10** of **other power** and sectors 1 to 10 respectively

$j_{410}(j)$ technologies of **other power for electricity** load 1 sectors s_1
$j_{411}(j)$ technologies of **other power for electricity** load 2 sectors s_2
$j_{412}(j)$ technologies of **other power for electricity** load 3 sectors s_3
$j_{413}(j)$ technologies of **other power for thermal** load 1 sectors s_4
$j_{414}(j)$ technologies of **other power for thermal** load 2 sectors s_5
$j_{415}(j)$ technologies of **other power for thermal** load 3 sectors s_6

$j_{416}(j)$ technologies of combined heat and power

$j_{417}(j)$ technologies of other power transports and machinery

$j_{418}(j)$ technologies RES for which power output is asked to reach their potential

$j_{419}(j)$ technology of wind turbines

$j_{420}(j)$ solar thermal technology

$j_{421}(j)$ technology of photovoltaics

$j_{422}(j)$ all technologies used for electricity

$j_{423}(j)$ all technologies used for thermal energy

$j_{424}(j)$ all technologies except technologies used for other power transports and machinery

$j_{425}(j)$ electricity technologies for desalination

$j_{426}(j)$ thermal technologies for desalination

$j_{427}(j)$ technologies RES for which power output is asked to be less equal their potential

$j_{428}(j)$ technologies that use bio-products

$j_{429}(j)$ technologies that use non imported primary energy products

Map for j subsets

Electric Power

		SECTORS									
		1	2	3	4	5	6	7	8	9	10
LOAD	1	j10	j11	j12	j13	j14	j15	j16	j17	j18	j19
	2	j20	j21	j22	j23	j24	j25	j26	j27	j28	j29
	3	j30	j31	j32	j33	j34	j35	j36	j37	j38	j39
	4	j40	j41	j42	j43	j44	j45	j46	j47	j48	j49
	5	j50	j51	j52	j53	j54	j55	j56	j57	j58	j59
	6	j60	j61	j62	j63	j64	j65	j66	j67	j68	j69
	7	j70	j71	j72	j73	j74	j75	j76	j77	j78	j79
	8	j80	j81	j82	j83	j84	j85	j86	j87	j88	j89
	9	j90	j91	j92	j93	j94	j95	j96	j97	j98	j99
	10	j100	j101	j102	j103	j104	j105	j106	j107	j108	j109

Thermal Power

		SECTORS									
		1	2	3	4	5	6	7	8	9	10
LOAD	1	j110	j111	j112	j113	j114	j115	j116	j117	j118	j119
	2	j120	j121	j122	j123	j124	j125	j126	j127	j128	j129
	3	j130	j131	j132	j133	j134	j135	j136	j137	j138	j139
	4	j140	j141	j142	j143	j144	j145	j146	j147	j148	j149
	5	j150	j151	j152	j153	j154	j155	j156	j157	j158	j159
	6	j160	j161	j162	j163	j164	j165	j166	j167	j168	j169
	7	j170	j171	j172	j173	j174	j175	j176	j177	j178	j179
	8	j180	j181	j182	j183	j184	j185	j186	j187	j188	j189
	9	j190	j191	j192	j193	j194	j195	j196	j197	j198	j199
	10	j200	j201	j202	j203	j204	j205	j206	j207	j208	j209

Other Power

		SECTORS									
		1	2	3	4	5	6	7	8	9	10
ELECTRIC LOAD	1	j210	j211	j212	j213	j214	j215	j216	j217	j218	j219
	2	j220	j221	j222	j223	j224	j225	j226	j227	j228	j229
	3	j230	j231	j232	j233	j234	j235	j236	j237	j238	j239

	4	j240	j241	j242	j243	j244	j245	j246	j247	j248	j249
	5	j250	j251	j252	j253	j254	j255	j256	j257	j258	j259
	6	j260	j261	j262	j263	j264	j265	j266	j267	j268	j269
	7	j270	j271	j272	j273	j274	j275	j276	j277	j278	j279
	8	j280	j281	j282	j283	j284	j285	j286	j287	j288	j289
	9	j290	j291	j292	j293	j294	j295	j296	j297	j298	j299
	10	j300	j301	j302	j303	j304	j305	j306	j307	j308	j309

		SECTORS									
		1	2	3	4	5	6	7	8	9	10
THERMAL LOAD	1	j310	j311	j312	j313	j314	j315	j316	j317	j318	j319
	2	j320	j321	j322	j323	j324	j325	j326	j327	j328	j329
	3	j330	j331	j332	j333	j334	j335	j336	j337	j338	j339
	4	j340	j341	j342	j343	j344	j345	j346	j347	j348	j349
	5	j350	j351	j352	j353	j354	j355	j356	j357	j358	j359
	6	j360	j361	j362	j363	j364	j365	j366	j367	j368	j369
	7	j370	j371	j372	j373	j374	j375	j376	j377	j378	j379
	8	j380	j381	j382	j383	j384	j385	j386	j387	j388	j389
	9	j390	j391	j392	j393	j394	j395	j396	j397	j398	j399
	10	j400	j401	j402	j403	j404	j405	j406	j407	j408	j409

EXPLAINED VARIABLES

In each planning study, one or more ‘explained’ variables have to be evaluated by the model within a logical framework. They actually consist the outputs of the model. The level of detail, chosen for the proposed methodology, suggests the adoption of the following ‘explained’ variables:

- **Additional capacity** of the selected technology *j* to be installed in *t* year of the planning horizon in MW. Symbolisation **Add(*j,t*)**
- **Accumulated capacity to be installed** of the selected technology *j* installed in *t* year of the planning horizon in MW. Symbolisation **Addi(*j,t*)**

  $$Addi(j,t) = sum(\tau, Add(j,\tau))$$

  $$\tau = \mathrm{ord}(t)+1$$

- **Power output** of the *j* technology at *t* year and in *p* time interval of the Load Duration Curve in MW. Symbolisation **Pw(*j,t,p*)**
- **Installed capacity of primary energy source** *k* (crop-units ha, or waste management plant-units t waste/day) for the production of primary energy product i_2 at *t* year. Symbolisation $\mathbf{Inb}(k,i_2,t)$
- **Total installed capacity** of the *j* technology at *t* year in MW is the sum of Additional capacity and Already installed capacity of the *j* technology at *t* year. Symbolisation **Tcap(*j,t*)**
- **Surface of solar collectors** in operation for each year *t* is calculated according to their specific technical characteristics and solar radiation of the region in m^2 Symbolisation **Ss(*t*)**

- **Surface of photovoltaics** in operation for each year *t* is calculated according to their specific technical characteristics and solar radiation of the region in m^2 Symbolisation **Spv(*t*)**
- **Recovered heat** from CHP technologies j_{416}, year *t* and time interval *p* of the LDC in MW Symbolisation **Rec(j_{416},*t*,*p*)**
- **Thermal demand satisfied by CHP**, in MW, all chp technologies at *t* year and *p* time interval of the LDC. Symbolisation **Chp(*t*,*p*)**
- **Fresh water quantity from desalination**, produced with **electricity** in year *t*, in m^3. It is set by suitable constraint to be greater than the level of fresh water demand that the user defines. Symbolisation **$Qw_1(t)$**
- **Fresh water quantity from desalination**, produced with **thermal energy** in year *t,* in m^3. It is set by suitable constraint to be greater than the level of fresh water demand that the user defines. Symbolisation **$Qw_2(t)$**
- **Total costs** in M€. It concerns the total actualized cost *CT* of the primary energy conversion over the selected time horizon. Symbolisation **Tc**
- **Total produced energy** in GWh. It concerns the total produced energy over the selected time horizon. Symbolisation **Te**
- **Total produced energy from RES** in GWh. It concerns the total produced energy based on Renewable Energy Sources over the selected time horizon. Symbolisation **Tres**
- **Annual produced energy** in GWh. It concerns the produced energy by each year of the time horizon. Symbolisation **Tea(*t*)**
- **Annual produced energy from RES** in GWh. It concerns the produced energy based on Renewable Energy Sources by each year of the time horizon. Symbolisation **Tresa(*t*)**
- **Total non imported energy produced** in GWh. It concerns the total produced energy based not only on RES but also on energy saving activities over the selected time horizon. Symbolisation **Sec**
- **Annual non imported energy produced** in GWh. It concerns the produced energy based not only on RES but also on energy saving activities for each year of the time horizon. Symbolisation **Seca(*t*)**
- **Total emissions** in kt. It concerns the total emissions per pollutant over the selected time horizon. Symbolisation **Tem(*r*)**

PARAMETERS and EXPLANATORY VARIABLES

Parameters and explanatory variables are actually the inputs the user gives in the model, defining the suitable constraints the model follows for the specific case of the user, and they could be of various dimensions that are defined through the previously reported indices or sets. The inputs are categorised in 4 categories, General Inputs, Inputs related to general constraints applied for all cases, Inputs related to specific technologies and activities and Optional Inputs, of which the first two are obligatory, except of some costs in general inputs that the user chooses to leave out like externalities or stripping cost, and the rest two are optional and they could be omitted if they do not apply to the specific case of the user.

These inputs given by the user contribute in the formulation of the suitable equality or inequality constraints:

Constraints included in the model

Peak demand satisfaction

Plant facility operation limits

Limits on energy generation

Limits on renewable energy potentials

Limits on primary energy consumption

Emissions limits

Energy generation and consumption balancing

Surface of installed Solar Collectors

Surface of installed Photovoltaics

Annual energy production from wind turbines

Combined Heat and Power technologies

Primary energy forms production

Mechanical or thermal desalination

General inputs

This category consists of the following items:

Already installed capacity

Operation time fraction of the Load Duration Curves

Investment cost

Stripping cost

Fixed cost

Fuel cost

+ External costs

- External cost for operation
- External cost for installation
- External cost for stripping
- External cost for fuel consumption

Cost of primary energy form production

Interest rate

Inflation rate

[Discount rate](#)

Already installed capacity (MW)

This is the capacity of technology (*j*) that is already installed in the region **and it is still in operation in year *t***.

Symbolisation **In(*j*,*t*)**

Operation time fraction of the Load Duration Curves (h)

The annual demand of electricity, civil thermal power and every other Load set by the user in description of scenario is represented by a Load Duration Curve (LDC) that is fitted by a step-wise behaviour, as reported in Fig. 1. Each step corresponds to the demand level expected throughout the relevant time interval (*p*). Practical computational reasons allow a maximum of eight time steps for the load duration curve fitting. The first time step of each defined LDC corresponds to the forecasted annual peak load.

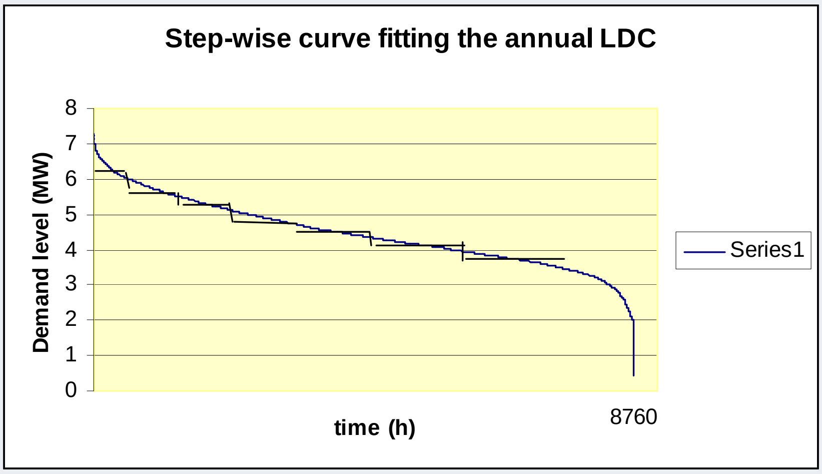

Fig. 1 **Step-wise curve fitting the annual LDC**

Each time step of the Load Duration Curve (*p*) is defined through the operation time fraction in hours. Special attention should be given in order that the sum of all operation time fractions should be equal to the total hours of the year - that is 8760 h. Symbolisation **time(*p*)**

Investment cost (€/MW)

The investment cost is given for each technology *j* and each year *t* of the planning horizon in Euros per MW of installed capacity.

Symbolisation **Inv(*j*,*t*)**

Stripping cost (€/MW)

Stripping cost pertains with all the costs necessary for the installation of one technology, in regard to the Construction unit cost for removal and stockpiling of topsoil in preparation for bulk earthmoving.

The stripping cost is given for each technology *j* and each year *t* of the planning horizon in Euros per MW of installed capacity.

Symbolisation **Str(*j*,*t*)**

Fixed cost (€/MW)

Fixed costs are expenses whose total does not change in proportion to the activity of a business, within the relevant time period or scale of production. For example, a retailer must pay rent and utility bills irrespective of sales volumes. Fixed costs include, but are not limited to, overheads (rent, insurance, and such) and can include direct costs such as payroll (particularly salaries). Capital assets will generally be considered part of fixed costs, but treated differently. Unit fixed costs decline with volume, following a rectangular hyperbola as the inverse of the volume of production.

The fixed cost is given for each technology *j* and each year *t* of the planning horizon in Euros per MW of installed capacity.

Symbolisation **Fx(*j*,*t*)**

Fuel cost (€/t)

The fuel cost is given for each fuel *i* and each year *t* of the planning horizon in Euros per t of fuel used in the energy generation system.

Symbolisation **Fl(*i*,*t*)**

Fuel cost generates variable cost of the energy system of the target region, if multiplied with total fuel consumption, through equation (1).

Variable costs **Var(*j*,*t*)** by contrast to the fixed costs change in relation to the activity of a business such as sales or production volume. In the case of an energy system variable costs are primarily the costs of energy production. In manufacturing, direct material costs are an example of a variable cost.

Var(*j*,*t*)=sum((*i*,*p*), Fl(*i*,*t*)*spec(*i*,*j*)*time(*p*)*Pw(*j*,*t*,*p*))   (1)

i, p, t, j: fuel, time interval, year, technology sets respectively
Fl(*i*,*t*) fuel cost
spec(*i*,*j*) specific fuel consumption
time(*p*) operation time fraction
Pw(*j*,*t*,*p*) power output for each technology, year and time interval

External costs

The external costs consist in the economical estimation of burdens occurred to people and environment because of energy chains including the life-cycle both of primary energy sources and power generation plants. As a source of external costs the following link is given: http://externe.jrc.es/

External cost for operation (€/MW)

External cost for operation pertains with the impacts related with the operative life of the *j*-th generation option in the *t*th year. Symbolisation **Exo(*j*,*t*)**

External cost for installation (€/MW)

External cost for installation pertains with the impacts related with the installation of the *j*-th generation option in the *t*th year. Symbolisation **Exi(*j*,*t*)**

External cost for stripping (€/MW)

External cost for stripping pertains with the impacts related with the stripping procedure of the *j*-th generation option in the *t*th year. Symbolisation **Exs(*j*,*t*)**

External cost for fuel consumption (€/t)

It is the unit cost assessing impacts related to transportation, treatment and utilization of the *i*-th fuel in the *t*-th year. Symbolisation **Exf(*i*,*t*)**

Cost of primary energy form production (€/ha) or (€/t waste.day)

The production of primary energy either from a crop or a waste management plant has a cost that is expressed for each source and product of primary energy and year of time horizon. Symbolisation **$Pr(k,i_2,t)$**

Interest Rate (%)

Interest rate is used optionally for the introduction of amortization factor **AF(*j*)** in the calculation of capital investment cost through equation *(2)*. The user has the option of not including this possibility through leaving empty this box. Symbolisation p

Inflation Rate (%)

Inflation rate is used optionally for the introduction of amortization factor **AF(*j*)** in the calculation of capital investment cost through equation *(2)*. The user has the option of not including this possibility through leaving empty this box. Symbolisation φ

$$AF(j) = \mathrm{sum}(\tau, 1/(1+\frac{\rho-\phi}{1+\phi})^{\tau}) \quad (2)$$

Discount Rate (%)

Discount rate is used optionally for the introduction of discounting in the calculation of all costs through equation *(3)*, that is given as an example for fixed cost. The user has the option of not including this possibility through leaving empty this box. Symbolisation **DR**

Total fixed cost over the planning horizon **TF**:

$$TF = sum((j,t), \frac{1}{(1+DR)^t} Fx(j,t) \cdot Add(j,t)) \qquad (3)$$

Total cost objective function (M€)

Tc = 1/(1+DR)^t * (sum((*j,t*), (Inv(*j,t*) + Var(*j,t*) + Str(*j,t*) + Exi(*j,t*) + Exs(*j,t*))*Add(*j,t*)) + sum((*j,t*), (Fx(*j,t*) + Exo(*j,t*))* (Addi(*j,t*)+In(*j,t*)) + sum((*i,j,t,p*), Exf(*i,t*)*Spec(*i,j*)*time(*p*)*Pw(*j,t,p*))+sum((*k,i2,t*), Pr (*k,i2,t*)*Inb(*k,i2,t*)))/1000000

Where:

DR: Discount rate (%)

AF(*j*) amortization factor

Inv(*j,t*) Investment cost (€/MW)

Str(*j,t*) Stripping cost (€/MW)

Fx(*j,t*) Fixed cost (€/MW)

Var(*j,t*)Variable costs (€/MW)

Exo(*j,t*) External cost for operation

Exi(*j,t*) External cost for installation

Exs(*j,t*) External cost for stripping

Exf(*i,t*) External cost for fuel consumption (€/t)

Pr(*k*,i_2,*t*) Cost of primary energy form production (€/ha) or (€/t waste.day)

Addi(*j,t*) accumulated capacity to be installed of the *j* technology and at *t* year

In (*j,t*) already installed capacity of the *j* technology and at *t* year

Pw(j,t,p) the power output of the j generation option at the t year and p time interval of LDC

Inb(*k*, i_2, *t*) Installed capacity of primary energy source *k* (crop-units ha, or waste management plant-units t waste/day) for the production of primary energy product i_2 at *t* year. Explained variable – output of the model.

Inputs related to general constraints applied for all cases

The optimisation procedure has to run within a logical framework that drives the evaluation of the explained variables. To this purpose, the definition of the following relationships is needed.

These kinds of inputs are related with the general conditions of the model in which the case has to comply with. For this purpose the user is strongly advised that gives the necessary data for the formulation of the relative constraints.

The general constraints consist of the following items:

+ Peak demand satisfaction
  - corrective factor

Plant facility operation limits

+ Limits on energy generation
  - availability factor
+ Limits on renewable energy potentials
  - renewables potential
+ Primary energy consumption
  - specific fuel consumption
  - fuel mixes / biofuels share
  - lower and upper fuel bounds
+ Emission limits
  - Pollutant factors of fuels
  - Pollutants tolerance
+ Energy generation and consumption balancing
  + Demands
    - Demands for LDCs of electric power
    - Demands for LDCs of thermal power
    - Demands for other power (diesel engines)
    - Demands for other power (otto engines)
  + Purchased power
    - Purchased power for loads of electric power
    - Purchased power for loads of thermal power

  Transmission losses factor

Peak demand satisfaction (Constraint No 1)

The first time step of each defined LDC corresponds to the forecasted annual peak load. Then the total electricity or thermal energy generation capacity in this period has to cover, with a suitable reserve margin, the internal load demand and the exported power. Constraint No 1 is expressed by the following equations:

(4) Sum (j_{422}, (Addi (j_{422}, t) + In(j_{422}, t))+ (1-hpr('*1*'))*sum(j_{416},(Addi(j_{416}, t) + In (j_{416}, t)))) =g= (1 + corr)* (sum((n,s), demande(n,s,t,'*1*')) + sum(n, Expe(n, t,'*1*')))

(5) Sum (j_{423}, (Addi (j_{423}, t) + In (j_{423}, t))+ hpr('*1*')*sum(j_{416}, (Addi(j_{416}, t) + In(j_{416}, t))) $\geq$ (1 + corr)* (sum((n,s), demandth(n,s,t,'*1*')) + sum(n, Expth(n, t,'*1*')))

where:
$\mathbf{j}_{422}$: technologies for electric power, j_{423}: technologies for thermal power, j_{416}: technologies for chp

t, n, s, p sets for years of planning horizon, number of loads, energy sectors and time intervals of LDC respectively

Addi(*j,t*) accumulated capacity to be installed of the *j* technology and at *t* year

In (*j,t*) already installed capacity of the *j* technology and at *t* year

demande(*n,s,t,'1'*) electric power demand

demandth(*n,s,t,'1'*) thermal power demand

Expe(*n,t,p*) exported electric power of *n* load at the *t* year and *p* time interval of the LDC

Expth(*n,t,p*) exported thermal power of *n* load at the *t* year and *p* time interval of the LDC

Corr corrective factor taking into account a reserve margin on annual peak load

Corrective factor (no units- dimensionless)

This factor takes into account a reserve margin on annual peak load

Exported electric power (MW)

The model provides the potential of exporting produced power through the electric grid. The user defines the amount of such exported power of *n* load for each year *t* of the planning horizon and time interval *p* of the LDC. Symbolisation **Expe(*n,t,p*)**

Exported thermal power (MW)

The model provides the potential of exporting produced thermal power through a grid connecting different end-use sectors. The user of the model defines the amount of such exported power of *n* load for each year *t* of the planning horizon and time interval *p* of the LDC. Symbolisation **Expth(*n,t,p*)**

Plant facility operation limits (Constraint No 2)

The net power output of each generation option cannot exceed the relevant installed capacity. This is expressed by the following equation:

$$(6) \qquad \mathrm{Pw}(j,t,p) \leq \mathrm{In}(j,t) + \mathrm{Addi}(j,t)$$

Where:
Pw(j,t,p) the power output of the j generation option at the t year and p time interval of LDC

Addi(*j,t*) accumulated capacity to be installed of the *j* technology and at *t* year

In (*j*,*t*) already installed capacity of the *j* technology and at *t* year

Limits on energy generation (Constraint No 3)

Through the availability factor *Av(j)* (hours/year), maintenance and failure periods are defined and, contemporaneously, the maximum energy production is obtained for each generation option. The constrain is described by the equation:

(7) $\text{sum}(p, Pw(j,t,p)*time(p)) \leq Av(j)*(In(j,t)+Addi(j,t))$

Where:

Pw(*j*,*t*,*p*): the power output of the j generation option at the t year and p time interval of LDC

time(*p*) operation time fraction of the LDC

Av(*j*) availability factor of the *j* technology

Addi(*j*,*t*) accumulated capacity to be installed of the *j* technology and at *t* year

In (*j*,*t*) already installed capacity of the *j* technology and at *t* year

Availability factor (h/year)

The availability factor depicts the maintenance and failure periods in hours per year for each technology j, that cannot be in operation. Symbolisation **Av(*j*)**

Limits on renewable energy potentials (Constraints No 4)

Limits on energy production (heat and/or power) from renewable and local energy sources have to be considered (≤ available energy potential). This is expressed by the equations:

(7) $\text{sum}(p, Pw(j_{427},t,p)*time(p)) \leq Pot\,(j_{427},t)$

if the power output of renewables is asked to be less equal of their potential

or *(8)* $\text{sum}(p, Pw(j_{418},t,p)*time(p)) = Pot\,(j_{427},t)$

if the power output of renewables is asked to reach their potential

Where:

j Sets j_{418} technologies RES for which power output is asked to reach their potential and

j_{427} technologies RES for which power output is asked to be less equal their potential

Pw(*j*,*t*,*p*) the power output of the j generation option at the t year and p time interval of LDC

time(*p*) operation time fraction of the LDC

Pot(*j,t*) renewables potential for *t* year in MWh

Renewables potential (MWh)

The Renewables in the system under study have a specific potential depended on the particular characteristics of the target region. This potential is given for each renewable technology *j* and year *t* of the time horizon. Symbolisation **Pot(*j,t*)**

Primary energy consumption (Constraint No 5)

Fuel consumption is related to plant/facilities energy production. The whole sum of these contributions, for the *i*-th fuel at the *t*-th year, has to be comprised between suitable lower and upper boundaries that the user sets according to what is pursued for. Given the different subsets of the i set of fuels, constraint no 5 is expressed by the following equations:

$\text{Fuel}(i_1, t, \text{'lower'}) \leq \text{sum}((j,p), \text{Pw}(j,t,p)*\text{time}(p)*\text{Spec}(i_1,j)) \leq \text{Fuel}(i_1, t, \text{'upper'})$ *(9)*

$\text{Fuel}(i_3, t, \text{'lower'}) \leq \text{sum}((j_7,p), \text{Pw}(j_7,t,p)*\text{time}(p)*\text{Fm1}(j_7,i_3,t)*\text{Spec}(i_3,j_7)) \leq \text{Fuel}(i_3, t, \text{'upper'})$ *(10)*

$\text{Fuel}(i_4, t, \text{'lower'}) \leq \text{sum}((j_8,p), \text{Pw}(j_8,t,p)*\text{time}(p)*\text{Fm2}(j_8,i_4,t)*\text{Spec}(i_4,j_8)) \leq \text{Fuel}(i_4, t, \text{'upper'})$ *(11)*

$\text{Fuel}(i_5, t, \text{'lower'}) \leq \text{sum}((j_9,p), \text{Pw}(j_9,t,p)*\text{time}(p)*\text{Fm3}(j_9,i_5,t)*\text{Spec}(i_5,j_9)) \leq \text{Fuel}(i_5, t, \text{'upper'})$ *(12)*

Where:
i_1, i_3,, i_4, i_5 subsets of of the i set of fuels

j_7, j_8, j_9 subsets of the j set of technologies

Pw(*j,t,p*) the power output of the *j* generation option at the *t* year and *p* time interval of LDC

time(*p*) operation time fraction of the LDC

Fm(*j,i,t*) fuel mixes – percentages of specific fuels in energy production of specific generation options j at t year

Spec (*i,j*) specific fuel consumption of the *i* fuel for *j* technology

Fuel(*i, t,* '*') lower and upper bounds of fuel consumption

Specific fuel consumption (t / MWh)

Each technology j participating in the system is characterized by a specific fuel i consumption, expressed with tones of fuel per unit of energy produced, MWh. This generates the total fuel consumption according to the power output of this technology and operation time fraction of the LDC. Symbolisation **Spec(*i,j*)**

Fuel mixes / biofuels share (%)

In the energy generation process, various fuels could participate in different kinds of fuel mixes. This option is given by the model, moreover, the user being able to vary these shares from year to year, by completing the relevant tables for each combination of fuel *i* and technology *j* and for each year *t* of the time horizon. Symbolisation **Fm(*i,j,t*)**

Lower and upper fuel bounds (t)

The whole sum of the *i*-th fuel at the *t*-th year contribution to the energy production is comprised between suitable lower and upper boundaries that the user sets according to what is pursued for. He could pursue for a minimisation of fossil fuels and maximisation of biofuels for the generation options *j* that burn fuel mixes in the depth of the planning horizon, as the upper and lower bounds are given for each year of the time horizon. Symbolisation **Fuel(*i,t,'*'*)**, ***/upper, lower/**

Emission limits (Constraint No 6)

The unit consumption of an energy form is related to pollutants emission through suitable emission factors. The total annual emission of the *r*-th pollutant has to be up to the emission limits. Constraint no 6 is expressed through the equation:

(13) $\text{sum}\ ((i,j,p),\ \text{Pw}(j,t,p)*\text{time}(p)*\text{Spec}\ (i,j)*\text{Em}(i,r)) \leq \text{Tol}(r,t)$

Where:

Pw(*j,t,p*) the power output of the *j* generation option at the *t* year and *p* time interval of LDC

time(*p*) operation time fraction of the LDC

Spec (*i,j*) specific fuel consumption of the *i* fuel for *j* technology

Em(*i, r*) pollutant factor of *r* pollutant and *i* fuel

Tol(*r,t*) pollutants tolerance at *t* year of the time horizon

Pollutant factors of fuels (t / t)

Emissions factor is of *i* fuel for *r* pollutant in t of air pollutant per t of fuel consumed. Symbolisation **Em(*i,r*)**

Pollutants tolerance (t)

Pollutants tolerance is an environmental parameter setting limits to the r pollutant in the t year of the planning horizon. Symbolisation **Tol(*r,t*)**

Energy generation and consumption balancing (Constraint No 7)

The balance among the electricity or thermal energy generation, the internal consumption and the net power exchange with the grid has to be satisfied. The constraint is formulated according to the input tables of the user (description of scenario), where he has defined what numbers of loads correspond to which sectors and which technologies have been suggested for the satisfaction of these loads, these constituting the j subsets as referred below in the equations. Each number of load corresponds to a separate LDC and consequently to a separate equation through constraint No 7. The sum of purchased power from a grid and the power generated by intercrossed technologies, including also Combined Heat and Power technologies that contribute to the specific loads and sectors, has to balance (be equal) with the electric, thermal or other power demand as case (equations *(14)* – *(213)* and). Moreover, centralised power for the grid and self produced power by individual energy sectors, has to balance (be equal) with the sum of purchased power by all sectors purchasing for the specific number of load, and any exported power set by the user (equations *(214)* to *(219)*).

The above are expressed through the following forms of equations:

$$Purel('1','1',t,p)+ sum(j_{10}, Pw(j_{10},t,p))+ sum(j_{210}, Pw(j_{210},t,p)) - Sp('1','1',t,p) = Deme('1','1',t,p) \quad (14)$$

$$Purel('1','2',t,p)+ sum(j_{11}, Pw(j_{11},t,p))+ sum(j_{211}, Pw(j_{211},t,p)) - Sp('1','2',t,p) = Deme('1','2',t,p)$$

....(15)

$$Purel('3','10',t,p)+ sum(j_{39}, Pw(j_{39},t,p))+ sum(j_{239}, Pw(j_{239},t,p)) - Sp('3','10',t,p) = Deme('3','10',t,p)$$

$$Purel('4','1',t,p)+sum(j_{40},Pw(j_{40},t,p))+sum(j_{240},Pw(j_{240},t,p))=Deme('1','2',t,p) \quad (17)$$

....

$$Purel('10','10',t,p)+ sum(j_{109}, Pw(j_{109},t,p))+ sum(j_{309}, Pw(j_{309},t,p)) = Deme('10','10',t,p) \quad (113)$$

$$Purth('1','1',t,p)+sum(j_{110},Pw(j_{110},t,p))+sum(j_{310},Pw(j_{310},t,p)) = Demth('1','1',t,p) \quad (114)$$

$$Purth('1','21',t,p)+sum(j_{111},Pw(j_{111},t,p))+sum(j_{311},Pw(j_{311},t,p)) = Demth('1','2',t,p) \quad (115)$$

....

$$Purth('10','10',t,p)+sum(j_{209},Pw(j_{209},t,p))+sum(j_{409},Pw(j_{409},t,p)) = Demth('10','10',t,p) \quad (213)$$

$$(1-a('1','electric'))*(sum(j_1, Pw(j_1,t,p))+ sum(j_{410}, Pw(j_{410},t,p)) + sum(s, Sp('1',s,t,p))) = sum(s_1, Purel('1',s_1,t,p)) + Expe('1',t,p) \quad (214)$$

$$(1-a('2','electric'))*(sum(j_2, Pw(j_2,t,p))+ sum(j_{411}, Pw(j_{411},t,p)) + sum(s, Sp('2',s,t,p))) = sum(s_2, Purel('2',s_2,t,p)) + Expe('2',t,p) \quad (215)$$

$(1-a('3','electric'))*(sum(j_3, Pw(j_3,t,p))+ sum(j_{412}, Pw(j_{412},t,p)) + sum(s, Sp('3',s,t,p))) = sum(s_3, Purel('3',s_3,t,p)) + Expe('3',t,p)$ *(216)*

$(1-a('1','thermal'))*(sum(j_4, Pw(j_4,t,p))+ sum(j_{413}, Pw(j_{413},t,p))) = sum(s_4, Purel('1',s_4,t,p)) + Expth('1',t,p)$ *(217)*

$(1-a('2','thermal'))*(sum(j_5, Pw(j_5,t,p))+ sum(j_{414}, Pw(j_{414},t,p))) = sum(s_5, Purel('2',s_5,t,p)) + Expth('2',t,p)$ *(218)*

$(1-a('3','thermal'))*(sum(j_6, Pw(j_6,t,p))+ sum(j_{415}, Pw(j_{415},t,p))) = sum(s_6, Purel('3',s_6,t,p)) + Expth('3',t,p)$ *(219)*

Where :
Purel(*n,s,t,p*) is the purchased power for electric load *n*, by energy sector *s* or sum of sectors as subsets of s set at year *t* and time interval *p* of LDC

Purth(*n,s,t,p*) is the purchased power for thermal load *n*, by energy sector *s* at year *t* and time interval *p* of LDC

Pw(*j,t,p*) the power output (for the corresponding to loads and sectors *j* set) of the *j* generation option at the *t* year and *p* time interval of LDC

Deme(*n,s,t,p*) Electric demand level for load *n*, energy sector *s* at year *t* and time interval *p* of LDC

Demth(*n,s,t,p*) Thermal demand level for load *n*, energy sector *s* at year *t* and time interval *p* of LDC

Expe(*n,t,p*) exported electric power of *n* load at the *t* year and *p* time interval of the LDC

Expth(*n,t,p*) exported thermal power of *n* load at the *t* year and *p* time interval of the LDC

a(*n,pd*) transmission losses factor of *n* load and electric or thermal kind of power demand – *pd* set

Sp(*n,s,t,p*) Self produced electric power for only electric loads *1*, *2* or *3* by individual energy sectors *s* at *t* year and *p* time interval of LDC

For the case of Combined Heat and Power technologies certain equations are applied that are described in Combined Heat and Power technologies constraint.

For other power demand, constraint No7 is only applicable for the vehicles engines for transportation and machinery, as CHP is distributed to corresponding electric or thermal loads in the above equations (*(14)* to *(219)*)

The balance of diesel engines and otto engines power output and the internal consumption has to be satisfied. The constraint is formulated according to the input table of the user (scenario definition), in which the intercrossed energy sectors have been selected.

Energy generation and consumption balancing for other power is expressed by the following two equations:

Pw('*diesel eng*',*t*,*p*) = sum(*s*, Demod (*s*,*t*,*p*)) *(220)*

Pw('*otto eng*',*t*,*p*) = sum(*s*, Demot (*s*,*t*,*p*)) *(221)*

Where:

Pw(*j*,*t*,*p*) the power output of the *j* generation option (diesel or otto engines) at the *t* year and *p* time interval of LDC

Demod (*s*,*t*,*p*) Diesel demand level of energy sector *s* at year *t* and time interval *p* of LDC

Demot (*s*,*t*,*p*) Otto demand level of energy sector *s* at year *t* and time interval *p* of LDC

Demands (MW)

All demands of electric and thermal power are given for separate load number *n*, sector *s*, year *t* and time interval *p* of the Load Duration Curves that arise from the Description of Scenarios to be optimized, as set by the user. They depict the Load Duration Curves of the specific load they correspond to. Other power demands concern only the vehicles engines for transportation and machinery, as CHP is distributed to corresponding electric or thermal demands.

Demands for LDCs of electric power (MW)

Electric power demand is given for separate load number *n*, sector *s*, year *t* and time interval *p* of the Load Duration Curves that arise from the Description of Scenarios to be optimized, as set by the user. They depict the Load Duration Curves of the specific load they correspond to. Symbolisation **Deme(*n*,*s*,*t*,*p*)**

Demands for LDCs of thermal power (MW)

Thermal power demand is given for separate load number *n*, sector *s*, year *t* and time interval *p* of the Load Duration Curves that arise from the Description of Scenarios to be optimized, as set by the user. They depict the Load Duration Curves of the specific load they correspond to. Symbolisation **Demth(*n*,*s*,*t*,*p*)**

Demands for other power (diesel engines) (MW)

Diesel engines power demand concerns diesel engines, i.e. engines that burn diesel, and is given for each energy sector s, year t and time interval p of the LDC according to other power demand description, made in description of scenario. Demands for diesel vehicles and machinery are expressed in MW. Symbolisation **Demod(*s*,*t*,*p*)**

Demands for other power (otto engines) (MW)

Otto engines power demand concerns otto engines, i.e. engines that burn petrol, and is given for each energy sector s, year t and time interval p of the LDC according to other power demand description, made in description of scenario. Demands for otto vehicles are expressed in MW. Symbolisation **Demot(*s,t,p*)**

Purchased power (MW)

Purchased power pertains with the power purchased by an end user (energy sector *s*) from a grid distributing power of specific load number *n* at year *t* and *p* time interval of LDC. Energy sectors purchasing power are considered those energy sectors that do not produce by their own power, but power produced by a central generation plant is distributed to more than one energy sectors. Particular notice must be taken in order that the values given for purchased power are less equal the respective power demand (of same load number *n* and end-use sector *s*). For example if Deme('1','1',t,p) = 7 MW, then Purel('1','1',t,p) can be up to 7 MW.

Purchased power for loads of electric power (MW)

Purchased electric power is the power purchased by an end user (energy sector *s*) from a grid distributing power of specific load number *n* at year *t* and *p* time interval of LDC. Particular notice must be taken in order that the values given for purchased power are less equal the respective power demand (of same load number *n* and end-use sector *s*). For example if Deme('1','1',t,p) = 7 MW, then Purel('1','1',t,p) can be up to 7 MW. Symbolisation **Purel(*n,s,t,p*)**

Purchased power for loads of thermal power (MW)

Similarly to purchased electric power, purchased thermal power is the power purchased by an end user (energy sector *s*) from a grid distributing thermal power of specific load number *n* at year *t* and *p* time interval of LDC. Particular notice must be taken in order that the values given for purchased power are less equal the respective power demand (of same load number *n* and end-use sector *s*). For example if Demth('1','1',t,p) = 7 MW, then Purth('1','1',t,p) can be up to 7 MW. Symbolisation **Purth(*n,s,t,p*)**

Self-produced electric power and transmitted to the grid (MW)

Self produced electric power could be by any energy sector *s*, but for the loads 1 to 3 load numbers *n* that are used for describing the distribution of produced power (electric or thermal) to more than one energy sectors through a grid. The self produced power is given for each year *t* and time interval *p* of the LDC. Symbolisation **Sp(*n,s,t,p*)**

Transmission losses factor (no units < 1)

Transmission losses factor pertains with the energy transmission line losses and is applicable for only for the numbers of Loads 1 to 3, used for describing the distribution of produced power *pd* (electric or thermal applies) to more than one energy sectors. Symbolisation **a(*n,pd*)**

Inputs related to specific technologies and activities

These kinds of inputs are related with the specific conditions applied for specific technologies of the model in which the case has to comply with. For this purpose the user is advised to give the necessary data applied to the technologies that he has selected in description of scenario definition for the formulation of the relative constraints.

The general constraints consist of the following items:

+ Surface of installed Solar collectors
  - annual solar radiation
  - efficiency of solar collectors
+ Surface of installed Photovoltaics
  - annual solar radiation
  - efficiency of photovoltaics
  - electric transmission losses in the system
  - coefficient of temperature correction
+ Annual energy production from wind turbines
  - annual factor of wind availability
  - mean coefficient of wind power
+ Combined Heat and Power technologies
  - Heat to Power ratio for CHP technologies
+ Primary energy forms production
  - demand level of the primary energy form
+ Mechanical or thermal desalination
  - energy consumption for mechanical and/or thermal desalination
  - level of fresh water demand

Surface of installed Solar collectors (Constraint No 8)

Annual energy production from solar collectors is related to surface of installed collectors, their efficiency, annual solar radiation and availability throughout the year. The installed capacity of Solar collectors is restricted according to the following equation:

$$Ss(t) = \text{sum}((j_{420},p), Pw(j_{420},t,p)*\text{time}(p))/Rad*Effsc \qquad (222)$$

Where:
j_{420} j subset for solar thermal collectors technology

Pw(*j,t,p*) the power output of the *j* generation option at the *t* year and *p* time interval of LDC

time(*p*) operation time fraction of the LDC

Rad Annual solar radiation

Effsc Efficiency of solar collectors

Additional constraint for the surface of installed solar collectors is constraint no 3 through the availability factor, which is for this case the hours of sunshine of the region.

Annual solar radiation (MWh/m^2)

It pertains with the local annual solar radiation on horizontal surface in MWh per sq m. Symbolisation **Rad**

Efficiency of solar collectors (no units <1)

The efficiency of a collector can be described in general by n = Q_A/G, where Q_A is the available thermal power (W/m^2), and G is the irradiance incident on the glass pane (W/m^2). The available thermal power is the available irradiance in the absorber, converted into heat, minus the thermal losses through convection, conduction and radiation. This parameter is normally given by the manufacturer of the collectors. Symbolisation **Effsc**

Surface of installed Photovoltaics (Constraint No 9)

Annual energy production from PV is related to surface of installed panels, their efficiency, annual solar radiation, coefficient of temperature correction, transmission losses and availability throughout the year. The installed capacity of photovoltaics is restricted according to the following equation:

$$Spv(t) = sum((j_{421},p), Pw(j_{421},t,p)*time(p))/Rad*Effpv*Tc*(1-At) \qquad (223)$$

Where:

j_{421} *j* subset for photovoltaics technology

Pw(*j,t,p*) the power output of the *j* generation option at the *t* year and *p* time interval of LDC

time(*p*) operation time fraction of the LDC

Rad Annual solar radiation

Effpv Efficiency of photovoltaics

Tc Coefficient of temperature correction

At Electric transmission losses in the system

Additional constraint for the surface of installed PV is constraint no 3 through the availability factor, which is for this case the hours of sunshine of the region.

Annual solar radiation (MWh/m^2)

It pertains with the local annual solar radiation on horizontal surface in MWh per sq m. Symbolisation **Rad**

Efficiency of photovoltaics (no units <1)

The efficiency of solar cells and PV modules can be described in general by n = P_{MPP}/G*A, where P_{MPP} is the maximum power point, the point on the characteristic curve at which the solar cell works with maximum power. It is given in units of watt peak (W_p). G is the irradiance incident on the glass pane (W/m^2) and A is the surface area of the solar cell in m^2. On the data sheets, the efficiency is always specified under standard test conditions. This coefficient is normally given by the manufacturer of the photovoltaics. Symbolisation **Effpv**

Coefficient of temperature correction (no units <1)

This coefficient of temperature correction is used for other than the standard test conditions. Its value is equal to1 for the standard conditions of 20^0 C (solar cells temperature = ambient temp + 30^0 C) and is diminishing for every increase of 1^0 C by 0.005. Symbolisation **Tc**

Electric transmission losses in the system (no units <1)

With this coefficient additional electric transmission losses in the system (battery banks, inverters etc.) are taken into account for the transmission of power from PV generators to the end-users. Symbolisation **At**

Annual energy production from wind turbines (Constraint No 10)

Annual energy production from wind turbines cannot exceed the expected annual energy production according to wind data of the region and technical characteristics of the wind turbine. This is expressed through the following equation:

$$\text{sum}(p, \text{Pw}(j_{419},t,p)*\text{time}(p)) \leq 8760*\text{delta}(t)*\text{omega}(t)*\ (\text{In}(j_{419},t)+\text{Addi}(j_{419},t)) \quad (224)$$

where:

j_{419} j subset for wind turbines

Pw(*j*,*t*,*p*) the power output of the *j* generation option at the *t* year and *p* time interval of LDC

time(*p*) operation time fraction of the LDC

Addi(*j*,*t*) accumulated capacity to be installed of the *j* technology and at *t* year

In (*j*,*t*) already installed capacity of the *j* technology and at *t* year

delta(*t*) annual factor of wind availability

omega(*t*) mean coefficient of wind power

Annual factor of wind availability (no units <1)

The annual factor of wind turbines availability is similar to the availability factor of all technologies and depicts the maintenance and failure periods of wind turbines that cannot be in operation. Symbolisation **delta(*t*)**. Its value is around 0.9

Mean coefficient of wind power (no units <1)

Mean coefficient of wind power is a parameter that predicts the power output of the wind turbine according to the characteristic functional curve of the wind turbine and the probability density of wind velocity occurrence. Symbolisation **omega(*t*)-ω(*t*)**
Omega is calculated through the equations:

$$\omega = \omega_1 + \omega_2$$

$$\omega_1 = \int_{V_C}^{V_R} \frac{N(V)}{N_0} \cdot f(V) \cdot dV$$

$$\omega_2 = \int_{V_R}^{V_F} \frac{N(V)}{N_0} \cdot f(V) \cdot dV$$

$$or - else$$

$$\omega_1 = \exp\left[-(V_C / C)^k\right] - \exp\left[-(V_R / C)^k\right]$$

$$\omega_2 = \exp\left[-(V_R / C)^k\right] - \exp\left[-(V_F / C)^k\right]$$

Where:

V_C: lowest wind velocity where wind turbine functions
V_R: mean wind velocity in the site
V_F: wind velocity where wind turbine stops functioning
N(V): Power of wind turbine from the characteristic functional curve
N_0: Nominal power of wind turbine
f(V): probability density of wind velocity occurrence

C: Scale parameter of Weibull distribution
k: Shape Parameter of Weibull distribution
For Milos case study C = 6 m/sec and k = 1.5

The value of omega could vary from 0.15 for the most pessimistic scenario to 0.6 for the most optimistic.

Combined Heat and Power technologies (Constraint No 11)

Recovered heat from CHP production is related to HP ratio and is equalised with a heat demand, set as variable (equations *(225)* and *(226)*). Then recovered heat from CHP has to follow the equation *(227)* and produced electric power has to follow equation *(228)*

sum(j_{416}, Rec(j_{416},*t*,*p*)) ≤ hpr(*p*)*sum(j_{416}, Pw(j_{416},*t*,*p*)) *(225)*

sum(j_{416}, Rec(j_{416},*t*,*p*)) = Chp(*t*,*p*) *(226)*

where :
j_{416}: CHP technologies *j* subset

Rec(j_{416},*t*,*p*) Recovered heat from CHP technologies

Pw(j_{416},*t*,*p*) the power output of the CHP generation option at the *t* year and *p* time interval of LDC

Chp(*t*,*p*) Thermal demand satisfied by CHP

hpr(*p*) Heat to Power ratio at the *p* time interval of the LDC

$hpr(p)*sum(j_{416}, Pw(j_{416},t,p)) = sum(j_{413},Pw(j_{413},t,p))+sum(j_{414},Pw(j_{414},t,p))+sum(j_{415},Pw(j_{415},t,p)) +sum(j_{310},Pw(j_{310},t,p))+sum(j_{311},Pw(j_{311},t,p))+sum(j_{312},Pw(j_{312},t,p))+sum(j_{313},Pw(j_{313},t,p))+sum(j_{314},Pw(j_{314},t,p))+sum(j_{315},Pw(j_{315},t,p))+sum(j_{316},Pw(j_{316},t,p))+\ldots\ldots\ldots+sum(j_{402},Pw(j_{402},t,p))+sum(j_{403},Pw(j_{403},t,p))+sum(j_{404},Pw(j_{404},t,p))+sum(j_{405},Pw(j_{405},t,p))+sum(j_{406},Pw(j_{406},t,p))+sum(j_{407},Pw(j_{407},t,p))+sum(j_{408},Pw(j_{408},t,p))+sum(j_{409},Pw(j_{409},t,p))$ *(227)*

$(1- hpr(p)*sum(j_{416}, Pw(j_{416},t,p)) =sum(j_{410},Pw(j_{410},t,p))+sum(j_{411},Pw(j_{411},t,p))+sum(j_{412},Pw(j_{412},t,p)) +sum(j_{210},Pw(j_{210},t,p))+sum(j_{211},Pw(j_{211},t,p))+sum(j_{212},Pw(j_{212},t,p))+sum(j_{213},Pw(j_{213},t,p))+sum(j_{214},Pw(j_{214},t,p))+sum(j_{215},Pw(j_{215},t,p))+sum(j_{216},Pw(j_{216},t,p))+\ldots\ldots\ldots+sum(j_{302},Pw(j_{302},t,p))+sum(j_{303},Pw(j_{303},t,p))+sum(j_{304},Pw(j_{304},t,p))+sum(j_{305},Pw(j_{305},t,p))+sum(j_{306},Pw(j_{306},t,p))+sum(j_{307},Pw(j_{307},t,p))+sum(j_{308},Pw(j_{308},t,p))+sum(j_{309},Pw(j_{309},t,p))$ *(228)*

Where:

j_{410} to j_{415} j subsets of CHP demand for sum of sectors of electric and thermal load numbers 1 to 3

j_{210} to j_{409} *j* subsets of CHP demand as the map of j subsets for CHP describes

Heat to Power ratio for CHP technologies (no units <1)

Heat-to-power ratio is the ratio of thermal power output to the electric power output (MWt/MWe) of CHP technologies at the *p*-th time interval of the load duration curve. Symbolisation **hpr(*p*)**

Primary energy forms production (Constraint No 12)

Required installed capacity of the source for primary energy production is related to the demand level of the primary energy form (product) and productivity of the source.

$Inb(k, i_2, t) = Demop(k,i_2,t)/pr(k,i_2)$ *(229)*

Where:

Inb(*k*, i_2, *t*) Installed capacity of primary energy source *k* (crop-units ha, or waste management plant-units t waste/day) for the production of primary energy product i_2 at *t* year. Explained variable – output of the model.

Demop(*k*,i_2,*t*) Demand level of the primary energy form in t

pr(*k*,i_2) productivity of the source in t/ha for crops or t/t waste.day for waste management, as defined in primary energy source description of scenario

Demand level of the primary energy form (t)

The user defines what level of demand for primary energy production in tones of product i_2 corresponding to *k* source for each year *t* of the planning horizon would like the model to take into account for the relevant calculations. Symbolisation **Demop(*k*,*i*$_2$,*t*)**

Mechanical or thermal desalination (Constraint No 13)

Energy production of technologies for desalination is restricted according to specific energy consumption for fresh water production and demand level for fresh water. The quantities of fresh water produced from mechanical and/or thermal desalination with electricity or thermal energy supply ($Qw_1(t)$ and $Qw_2(t)$ respectively) is set by suitable constraint to be greater than the level of fresh water demand that the user defines. This is expressed through the equations:

$$(sum(p,\ (sum(n,\ Purel(n,'5',t,p)*time(p)))+(Sum(j_{425},\ time(p)*Pw(j_{425},t,p)))))=Ecdes('mechanical',\ 'electric')*Qw_1(t) \quad (230)$$

$$(sum(p,\ (sum(n,\ Purth(n,'5',t,p)*time(p)))+(Sum(j_{426},\ time(p)*Pw(j_{426},t,p)))))=(Ecdes('mechanical',\ ''thermal')+Ecdes('thermal',\ ''thermal'))*Qw_2(t) \quad (231)$$

$$Qw_1(t)+Qw_2(t) \geq Qw(t) \quad (232)$$

Where :

Pw(*j*$_{425}$,*t*,*p*) the power output of the desalination generation option through electricity ***j***$_{425}$ or thermal energy ***j***$_{426}$ production at the *t* year and *p* time interval of LDC

Purel(*n*,'5',*t*,*p*) is the purchased power for electric load *n*, and energy sector '5', which is the desalination end-user sector at year *t* and time interval *p* of LDC

Purth(*n*,'5',*t*,*p*) is the purchased power for thermal load *n*, and energy sector '5', which is the desalination end-user sector at year *t* and time interval *p* of LDC

Ecdes (*d*,*pd*) Energy consumption for *d* kind of desalination (mechanical or thermal) and of *pd* kind of power (electric or thermal).

$Qw_1(t)$ Fresh water quantity from desalination, produced with **electricity** in year *t,* in m^3. It is an explained variable– output of the model.

$Qw_2(t)$ Fresh water quantity from desalination, produced with **thermal energy** in year *t,* in m^3. It is an explained variable– output of the model.

Qw(*t*) Level of fresh water demand from desalination

Energy consumption for mechanical and/or thermal desalination (MWh/m^3)

Energy consumption for *d* kind of desalination (mechanical or thermal) and of *pd* kind of power (electric or thermal). Symbolisation **Ecdes(*d*,*pd*)**. In fact the possible cases could be only three Ecdes (*'mechanical', 'electric'*), Ecdes (*'mechanical', ''thermal'*) and Ecdes (*'thermal', ''thermal'*)

Level of fresh water demand (m^3)

The user defines the minimum level of demand for fresh water that he wants the system to satisfy. Then fresh water quantity from desalination either produced from electricity supply and/or thermal energy supply has to comply with this demand level (be greater than), as described in Constraint No 13.

Optional Inputs

Optional inputs pertain with constraints that are included in the optimization process only if the user chooses to. Such constraints have to do with shares of either specific technologies (Constraint No 14) or renewable, in general, technologies (Constraint No 15) participation in the system.

Share of one technology to satisfaction of specific load level (Constraint No 14)

Specific *j* technology's power output is set to be up to one percentage of total power output from the sum of technologies that participate in the load satisfaction, to which the particular technology corresponds. This has especial meaning for wind turbines that are integrated in an electric grid and particular care must be taken for electric power pitches. The wind turbines share that usually has no affect in electric power pitches is less than 30%. For other reasons the same constraint could apply to any other technology. This concept is formulated though the following equations *(233)* to *(641)*.

The relevant ***j*** **subsets** can be found in j subsets and j mapping tables

Per (*j*) is the Percentage of technology *j* that contributes to the satisfaction *n* load number

For electric load 1

$$Pw(j_1,t,p) \leq Per(j_1) * (sum(j_1, Pw(j_1,t,p)) + sum(j_{410}, Pw(j_{410},t,p))) \quad (233)$$

$$Pw(j_{10},t,p) \leq Per(j_{10}) * (sum(j_{10}, Pw(j_{10},t,p)) + sum(j_{210}, Pw(j_{210},t,p))) \quad (234)$$

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$$Pw(j_{19},t,p) \leq Per(j_{19}) * (sum(j_{19}, Pw(j_{19},t,p)) + sum(j_{219}, Pw(j_{219},t,p))) \quad (243)$$

For electric load 2

$$Pw(j_2,t,p) \leq Per(j_2) * (sum(j_2, Pw(j_2,t,p)) + sum(j_{411}, Pw(j_{411},t,p))) \quad (244)$$

$$Pw(j_{20},t,p) \leq Per(j_{20}) * (sum(j_{20}, Pw(j_{20},t,p)) + sum(j_{220}, Pw(j_{220},t,p))) \quad (245)$$

....

$$Pw(j_{29},t,p) \leq Per(j_{29}) * (sum(j_{29}, Pw(j_{29},t,p)) + sum(j_{229}, Pw(j_{229},t,p))) \quad (254)$$

For electric load 3

$Pw(j_3,t,p) \leq Per\ (j_3)^*\ (sum(j_3,\ Pw(j_3,t,p))+sum(j_{412},\ Pw(j_{412},t,p)))$
(255)

$Pw(j_{30},t,p) \leq\ Per(j_{30})^*\ (sum(j_{30},\ Pw(j_{30},t,p))+sum(j_{230},\ Pw(j_{230},t,p)))$
(256)

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$Pw(j_{39},t,p) \leq\ Per(j_{39})^*\ (sum(j_{39},\ Pw(j_{39},t,p))+sum(j_{239},\ Pw(j_{239},t,p)))$
(265)

For electric load 4

$Pw(j_{40},t,p) \leq\ Per(j_{40})^*\ (sum(j_{40},\ Pw(j_{40},t,p))+sum(j_{240},\ Pw(j_{240},t,p)))$
(266)

$Pw(j_{41},t,p) \leq\ Per(j_{41})^*\ (sum(j_{41},\ Pw(j_{41},t,p))+sum(j_{241},\ Pw(j_{241},t,p)))$
(267)

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$Pw(j_{49},t,p) \leq\ Per(j_{49})^*\ (sum(j_{49},\ Pw(j_{49},t,p))+sum(j_{249},\ Pw(j_{249},t,p)))$
(275)

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For electric load 10

$Pw(j_{100},t,p) \leq\ Per(j_{100})^*\ (sum(j_{100},\ Pw(j_{100},t,p))+sum(j_{300},\ Pw(j_{300},t,p)))$
(326)

$Pw(j_{101},t,p) \leq\ Per(j_{101})^*\ (sum(j_{101},\ Pw(j_{101},t,p))+sum(j_{301},\ Pw(j_{301},t,p)))$
(327)

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$Pw(j_{109},t,p) \leq\ Per(j_{109})^*\ (sum(j_{109},\ Pw(j_{109},t,p))+sum(j_{309},\ Pw(j_{309},t,p)))$
(335)

For thermal load 1

$Pw(j_4,t,p) \leq Per\ (j_4)^*\ (sum(j_4,\ Pw(j_4,t,p))+sum(j_{413},\ Pw(j_{413},t,p)))$
(336)

$Pw(j_{110},t,p) \leq\ Per(j_{110})^*\ (sum(j_{110},\ Pw(j_{110},t,p))+sum(j_{310},\ Pw(j_{310},t,p)))$
(337)

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$Pw(j_{119},t,p) \leq\ Per(j_{119})^*\ (sum(j_{119},\ Pw(j_{119},t,p))+sum(j_{319},\ Pw(j_{319},t,p)))$
(345)

For thermal load 2

$Pw(j_5,t,p) \leq Per\ (j_5)^*\ (sum(j_5,\ Pw(j_5,t,p))+sum(j_{414},\ Pw(j_{414},t,p)))$
(346)

$Pw(j_{120},t,p) \leq\ Per(j_{120})^*\ (sum(j_{120},\ Pw(j_{120},t,p))+sum(j_{320},\ Pw(j_{320},t,p)))$
(347)

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$Pw(j_{129},t,p) \leq Per(j_{129}) * (sum(j_{129}, Pw(j_{129},t,p)) + sum(j_{329}, Pw(j_{329},t,p)))$ *(355)*

For thermal load 3

$Pw(j_{6},t,p) \leq Per(j_{6}) * (sum(j_{6}, Pw(j_{6},t,p)) + sum(j_{415}, Pw(j_{415},t,p)))$ *(356)*

$Pw(j_{130},t,p) \leq Per(j_{130}) * (sum(j_{130}, Pw(j_{130},t,p)) + sum(j_{330}, Pw(j_{330},t,p)))$ *(357)*

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$Pw(j_{139},t,p) \leq Per(j_{139}) * (sum(j_{139}, Pw(j_{139},t,p)) + sum(j_{339}, Pw(j_{339},t,p)))$ *(365)*

For thermal load 4

$Pw(j_{40},t,p) \leq Per(j_{40}) * (sum(j_{40}, Pw(j_{40},t,p)) + sum(j_{340}, Pw(j_{340},t,p)))$ *(366)*

$Pw(j_{141},t,p) \leq Per(j_{141}) * (sum(j_{141}, Pw(j_{141},t,p)) + sum(j_{341}, Pw(j_{341},t,p)))$ *(367)*

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$Pw(j_{149},t,p) \leq Per(j_{149}) * (sum(j_{149}, Pw(j_{149},t,p)) + sum(j_{349}, Pw(j_{349},t,p)))$ *(375)*

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For thermal load 10

$Pw(j_{200},t,p) \leq Per(j_{200}) * (sum(j_{200}, Pw(j_{200},t,p)) + sum(j_{400}, Pw(j_{400},t,p)))$ *(426)*

$Pw(j_{201},t,p) \leq Per(j_{201}) * (sum(j_{201}, Pw(j_{201},t,p)) + sum(j_{401}, Pw(j_{401},t,p)))$ *(427)*

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$Pw(j_{209},t,p) \leq Per(j_{209}) * (sum(j_{209}, Pw(j_{209},t,p)) + sum(j_{409}, Pw(j_{409},t,p)))$ *(435)*

For CHP electric load 1

$Pw(j_{410},t,p) \leq Per(j_{410}) * (sum(j_{1}, Pw(j_{1},t,p)) + sum(j_{410}, Pw(j_{410},t,p)))$ *(436)*

$Pw(j_{210},t,p) \leq Per(j_{210}) * (sum(j_{10}, Pw(j_{10},t,p)) + sum(j_{210}, Pw(j_{210},t,p)))$ *(437)*

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$Pw(j_{219},t,p) \leq Per(j_{219}) * (sum(j_{19}, Pw(j_{19},t,p)) + sum(j_{219}, Pw(j_{219},t,p)))$ *(446)*

For CHP electric load 2

$Pw(j_{411},t,p) \leq Per\ (j_{411})^*\ (sum(j_2,\ Pw(j_2,t,p))+sum(j_{411},\ Pw(j_{411},t,p)))$

(447)

$Pw(j_{220},t,p) \leq Per(j_{220})^*\ (sum(j_{20},\ Pw(j_{20},t,p))+sum(j_{220},\ Pw(j_{220},t,p)))$

(448)

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$Pw(j_{229},t,p) \leq Per(j_{229})^*\ (sum(j_{29},\ Pw(j_{29},t,p))+sum(j_{229},\ Pw(j_{229},t,p)))$

(457)

For CHP electric load 3

$Pw(j_{412},t,p) \leq Per\ (j_{412})^*\ (sum(j_3,\ Pw(j_3,t,p))+sum(j_{412},\ Pw(j_{412},t,p)))$

(458)

$Pw(j_{230},t,p) \leq Per(j_{230})^*\ (sum(j_{30},\ Pw(j_{30},t,p))+sum(j_{230},\ Pw(j_{230},t,p)))$

(459)

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$Pw(j_{239},t,p) \leq Per(j_{239})^*\ (sum(j_{39},\ Pw(j_{39},t,p))+sum(j_{239},\ Pw(j_{239},t,p)))$

(468)

For CHP electric load 4

$Pw(j_{240},t,p) \leq Per(j_{240})^*\ (sum(j_{40},\ Pw(j_{40},t,p))+sum(j_{240},\ Pw(j_{240},t,p)))$

(469)

$Pw(j_{241},t,p) \leq Per(j_{241})^*\ (sum(j_{41},\ Pw(j_{41},t,p))+sum(j_{241},\ Pw(j_{241},t,p)))$

(267)

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$Pw(j_{249},t,p) \leq Per(j_{249})^*\ (sum(j_{49},\ Pw(j_{49},t,p))+sum(j_{249},\ Pw(j_{249},t,p)))$

(478)

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For CHP electric load 10

$Pw(j_{300},t,p) \leq Per(j_{300})^*\ (sum(j_{100},\ Pw(j_{100},t,p))+sum(j_{300},\ Pw(j_{300},t,p)))$

(529)

$Pw(j_{301},t,p) \leq Per(j_{301})^*\ (sum(j_{101},\ Pw(j_{101},t,p))+sum(j_{301},\ Pw(j_{301},t,p)))$

(530)

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$Pw(j_{309},t,p) \leq Per(j_{309})^*\ (sum(j_{109},\ Pw(j_{109},t,p))+sum(j_{309},\ Pw(j_{309},t,p)))$

(538)

For CHP thermal load 1

$Pw(j_{413},t,p) \leq Per\ (j_{413})^*\ (sum(j_4,\ Pw(j_4,t,p))+sum(j_{413},\ Pw(j_{413},t,p)))$

(539)

$Pw(j_{310},t,p) \leq Per(j_{310})^*\ (sum(j_{110},\ Pw(j_{110},t,p))+sum(j_{310},\ Pw(j_{310},t,p)))$

(540)

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$Pw(j_{319},t,p) \leq Per(j_{319})^* (sum(j_{119}, Pw(j_{119},t,p))+sum(j_{319}, Pw(j_{319},t,p)))$
(549)

For CHP thermal load 2

$Pw(j_{414},t,p) \leq Per (j_{414})^* (sum(j_5, Pw(j_5,t,p))+sum(j_{414}, Pw(j_{414},t,p)))$
(550)

$Pw(j_{320},t,p) \leq Per(j_{320})^* (sum(j_{120}, Pw(j_{120},t,p))+sum(j_{320}, Pw(j_{320},t,p)))$
(551)

....

$Pw(j_{329},t,p) \leq Per(j_{329})^* (sum(j_{129}, Pw(j_{129},t,p))+sum(j_{329}, Pw(j_{329},t,p)))$
(560)

For CHP thermal load 3

$Pw(j_{415},t,p) \leq Per (j_{415})^* (sum(j_6, Pw(j_6,t,p))+sum(j_{415}, Pw(j_{415},t,p)))$
(561)

$Pw(j_{330},t,p) \leq Per(j_{330})^* (sum(j_{130}, Pw(j_{130},t,p))+sum(j_{330}, Pw(j_{330},t,p)))$
(562)

....

$Pw(j_{339},t,p) \leq Per(j_{339})^* (sum(j_{139}, Pw(j_{139},t,p))+sum(j_{339}, Pw(j_{339},t,p)))$
(571)

For CHP thermal load 4

$Pw(j_{340},t,p) \leq Per(j_{340})^* (sum(j_{40}, Pw(j_{40},t,p))+sum(j_{340}, Pw(j_{340},t,p)))$
(572)

$Pw(j_{341},t,p) \leq Per(j_{341})^* (sum(j_{141}, Pw(j_{141},t,p))+sum(j_{341}, Pw(j_{341},t,p)))$
(573)

....

$Pw(j_{349},t,p) \leq Per(j_{349})^* (sum(j_{149}, Pw(j_{149},t,p))+sum(j_{349}, Pw(j_{349},t,p)))$
(581)

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For CHP thermal load 10

$Pw(j_{400},t,p) \leq Per(j_{400})^* (sum(j_{200}, Pw(j_{200},t,p))+sum(j_{400}, Pw(j_{400},t,p)))$
(632)

$Pw(j_{401},t,p) \leq Per(j_{401})^* (sum(j_{201}, Pw(j_{201},t,p))+sum(j_{401}, Pw(j_{401},t,p)))$
(633)

....

$Pw(j_{409},t,p) \leq Per(j_{409})^* (sum(j_{209}, Pw(j_{209},t,p))+sum(j_{409}, Pw(j_{409},t,p)))$
(641)

Percentage of technology to load number and kind of power demand (%)

Specific j technology's power output is set to be up to one percentage of total power output from the sum of technologies that participate in the load satisfaction, to which the particular technology corresponds. The percentage is given for each technology j that contributes to the satisfaction of n load number. Symbolisation **Per(*j*)**

Share of Renewable Energy produced in the system (Constraint No 15)

The model has the potential of taking into account a minimum RES share that the user sets as prerequisite. The power output of RES technologies is given then greater than the lower bound of this minimum res share in the total power output in the system (transportation has not been taken into account in this total power output as it would much diminish the potential res share in the system) . The value of RES share is given for each year. The equation followed in this constraint is as follows:

$$\text{sum}((j_{418},p),\ \text{time}(p)*\text{Pw}(j_{418},t,p)) + \text{sum}((j_{427},p),\ \text{time}(p)*\text{Pw}(j_{427},t,p)) \geq \text{sh}(t)*\text{sum}((j_{424},p),\ \text{time}(p) * \text{Pw}(j_{424},t,p)) \quad (642)$$

where:

j_{418}(j) technologies RES for which power output is asked to reach their potential

j_{424}(j) all technologies except technologies used for other power transports and machinery

j_{427}(j) technologies RES for which power output is asked to be less equal their potential

Pw(*j,t,p*) the power output of the j generation option at the t year and p time interval of LDC

time(*p*) operation time fraction of the LDC

sh(*t*) Minimum Res share in the planning horizon

Minimum Res share in the planning horizon (%)

The model has the potential of taking into account a minimum RES share that the user sets as prerequisite. The power output of RES technologies is given then greater than the lower bound of this minimum res share in the total power output in the system. This share is given with a prospect of the 20 years of the planning horizon. Symbolisation **sh(*t*)**