Nord Pool TIMES Model

Norwegian, Swedish and Finnish Power sector

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Contents

INTRODUCTION

In the Nordic Countries many factors affect the power prices. The main price drivers in particular are the weather (if the temperature is low the demand rises causing an increase of prices. This is especially true in Nord Pool because in the Nordic area many houses are heated electrically), the transmission capacity of the interconnectors, the status of the hydro reservoirs, the wind speed in Denmark and the rainfall levels.

In order to explore the future power exchange between Denmark and the rest of the Nordic Countries a TIMES model of the Swedish, Norwegian and Finnish power system was created. Such TIMES-NPM model can be run together with TIMES-DK with different scenarios. This allows assessing power exchange between the Nordic countries under different assumptions, which may involve more countries at the same time. In fact TIMES-NPM makes possible to analyze the effect of an environmental and energy policies implemented in any of the Nordic Countries on the rest of the states. It also permits to analyze power trade in the Nordic area modifying the conditions of the main price drivers in any of the countries analyzed.

MODEL STRUCTURE

The TIMES Nord Pool model (TIMES-NPM) is a multiregional model that includes the description of the Norwegian, Swedish and Finnish electrical systems. Such regions are electrically interconnected by means of transmission lines represented as endogenous trade processes. They are also electrically connected to the neighbouring countries and such links are represented by means of exogenous trade processes.
The model was built in such a way so as to be able to run it hard-linked with TIMES-DK model or in stand-alone mode. In the first case the model becomes a five-region model and the prices and volumes of the electricity traded are endogenously determined by the model, while in the second case the power exchange with Denmark is exogenously defined according to price related criteria.

The technologies and commodities considered in the model are only those related to the supply, production and transmission electricity in the Nordic Countries. Each of the three countries described in the model is represented as one single region. This spatial resolution doesn't allow analysing the power exchange and the bottlenecks inside the countries, nor to catch the differences of hydrology, biomass, solar, wind potential and demand among the Countries' counties.
The one-country one-region focus was adopted because TIMES-NPM was created mainly to be run together with TIMES-DK, which remains the core and the focus of the analyses. This focus is adequate to analyse the global electricity exchange between the Nordic countries and the need for new interconnectors, but still keeps the model size manageable.

In order to be able to run TIMES-NPM together with TIMES-DK the same time structure was adopted. In fact as base year 2010 was set and TIMES-NPM optimizes energy-technology related decisions over a time horizon of forty years, from 2010 to 2050. The time horizon is divided in periods that are represented by some milestones, which are: 2010, 2012, 2015, 2020, 2030, 2040 and 2050.

Moreover, TIMES-NPM is built with the same time slices as TIMES-DK. In this model each time slice represents a set of hours with similar characteristics.

First the years were divided into the four seasons, then into working day (WD) or not working day (NW) and finally each hour of the year was allocated to one of the following classes, which represent critical combinations of renewable energy production and power demand in Denmark:

- High wind availability, low power demand (A)
- High power demand, low wind availability (B)
- Photovoltaic peak (C)
- Rest of hours (D)

This division ends up with making the time structure of the model divided in 32 time slices. Figure 1 shows the acronyms of the time slices in summer.

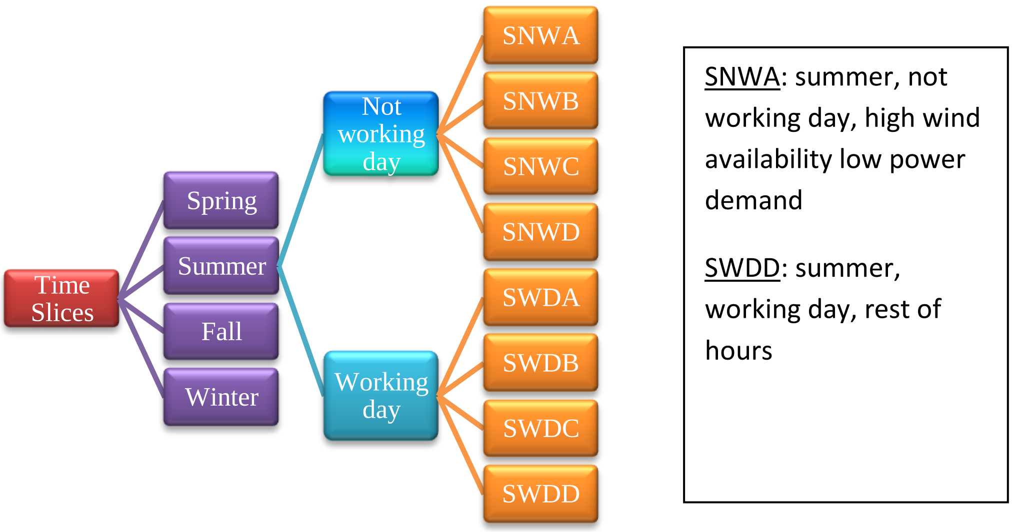

Figure 1: Time structure acronym example

The allocation to the proper class is done using a workbook called "Time Slice Tool", which groups each hour of the year into 32 time slices by comparing the time profile of the energy content of Danish photovoltaic, wind and demand with some user-established thresholds (LARSEN).

The time structure of the model is described in the workbook called "SysSetting", which contains the settings of the model. Here is declared the division in seasons, working and not working day and in the critical combination A,B,C,D. Moreover though the attribute "YRFR" it is also described the time fraction of each time slice, as visible in table 1.

Table 1: Year fraction of some time slices

~TFM_INS		
TimeSlice	Attribute	AllRegions
RWDA	YRFR	0.0011
RWDD	YRFR	0.1315
RWDC	YRFR	0.0134

The unit used for the capacity of the generating technologies is the MW, while that for the demand technologies and supply technologies is the PJa. The activity of all the processes is expressed in PJ.

The currency of the model is the Danish Crown. In case the cost of a technology is expressed in a different currency, this is converted in the Danish Crown according to its value in 2010. This is done by means of the currency conversion factors declared in the "SysSettings" workbook and that were computed starting from "Valuta5_2013" workbook (by P. E. Grohnheit).

The rate used by TIMES to discount all the costs occurred in the various years to the base year 2010 is 4%.

BASE YEAR TEMPLATES

ENERGY RESOURCES SUPPLY

In TIMES-NPM the workbook "VT_NPM_SUP" is dedicated to the description of the supply of the primary resources needed to operate the power systems of the Nordic Countries. In fact the supply commodities described in the model are all the resources requested by the power plants located in Sweden, Norway and Finland for producing power.

The workbook "VT_NPM_SUP" includes various sheets:

- Sheet COMM: It lists all the primary commodities needed by the power systems. For each commodity the relative unit (PJ) and set membership is shown. As visible from figure 2 the primary commodities are: natural gas, coal, heavy fuel, diesel, biogas, waste, wood pellet, wood chip, wood gas, peat, uranium, sun, wind and water.

~FI_Comm				
CSet	Region	CommName	CommDesc	Unit
*Commodity Set Membership	Region Name	Commodity Name	Commodity Description	Unit
NRG		COA	Coal	PJ
		NGA	Natural Gas	PJ
		WST	Waste	PJ
		BGA	Biogas	PJ
		WIN	Wind	PJ
		HYD	Hydro	PJ
		HFO	Heavy Fuel Oil	PJ
		SUPELC	Electricity SUP	PJ
		WPE	Wood Pellet	PJ
		WCH	Wood Chips and Waste	PJ
		PET	Peat	PJ
		URN	Uranium	PJ
		DSL	Diesel	PJ
		WOG	WoodGas	PJ
		SOL	Solar	PJ
ENV		SUPCO2	Supply sector CO2	kt

Figure 2: Supply commodities

- Sheet PROC: It includes the list of all the processes that make these commodities available. These processes are only of two kinds: import technologies ("IMP") and extraction technologies ("MIN"). The proper supply processes have been associated to each commodity in accordance to the National Energy Balance elaborated by (U.S ENERGY INFORMATION ADMINISTRATION, 2015)
- Sheet MIN-IMP-EXP: It describes the relationship between supply commodities and supply processes. In particular it includes for every supply process the exogenous definition of the future trend of mining/import cost, expressed as million of Danish Crowns in 2010 per Petajoule.
  These costs have been taken from RAMSES database. In case they were not available, they have been taken from TIMES-DK and then they have been differentiated for Sweden, Norway and Finland according to their relative wealth compared to Denmark. This has been calculated as the ratio between the GDP of the country and the GDP of Denmark in 2010 (EUROSTAT, 2015).
  If a certain supply commodity doesn't exist in a country, to that commodity in that specific country a constraint that maintains zero the extraction and import per year was associated.

POWER GENERATION SYSTEM

In the Nordic power system many generating sources are used, mainly hydro, nuclear, fossil, biomass and wind. The energy sources are not equally distributed between the different Nordic countries, but instead power systems differ greatly from one country to another. In fact in Norway power is produced using almost exclusively hydro, while Sweden and Finland mainly produce power with a mix of nuclear and hydro.
In 2013 the total power production in Norway, Sweden, Finland and Denmark was 380 TWh and the total consumption was 380.5 TWh. Such consumption is divided between the four Nordic countries in the following way: Sweden consumed 137.5 TWh, Norway 128.1 TWh, Finland 81.4 TWh and Denmark 34 TWh.
At the beginning of 2010 in the Nordic countries the total installed capacity was 83.8 GW. Of this capacity 36 GW were installed in Sweden, around 16 GW were installed in Finland and the rest 31.8 GW were installed in Norway. Inside the single countries, the power capacity is split as shown in the following pie charts.

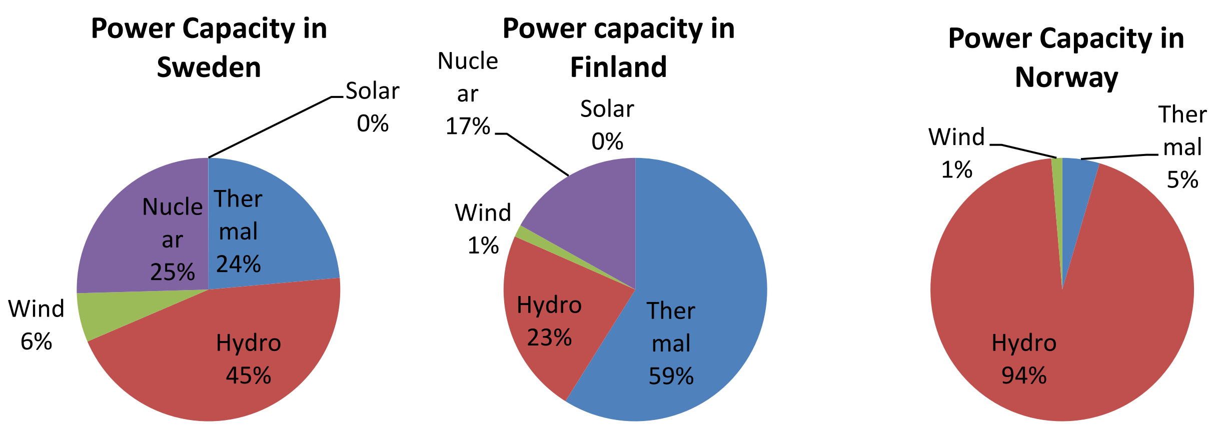

Figure 3: Power capacity division in the Nordic Countries

The Nordic power generation system has been described in a workbook denominated "VT_NPM_ELC": it includes many sheets describing the commodities consumed/transformed/generated for producing power and the existing/under construction technologies employed in the power generation sector.
All the information needed for a relevant description of the status of the Nordic power system in the base year and in the following two milestone years (2012 and 2015) have been organized in the following sheets:

- Sheet COMM: It lists all the commodities consumed/produced/emitted in the power production sector with the related units (PJ and kt) and set membership (NRG and ENV). In particular to the commodities heat and electricity the highest time resolution as been associated, which is the time slice level (denominated "DAYNITE" in TIMES)
- Sheet PROC: Here all the existing and under construction power plants have been listed and provided of some parameters. These describe the capacity unit (MW), the activity unit (PJ), the region of location and the set membership
- Sheets NOR, SWE, FIN: In these three sheets the power plants installed and under construction in the Nordic countries have been organized according to the region of location. The definition of the characteristics of the power plants was realized by means of "~FI_T" tables

  In these sheets are described the commodities input and output to the power generating technologies installed in each country, thus defining the network of energy flows, energy commodities and power plants. The technical parameters associated to the power plants include the efficiency (EFF), availability factor (AF, AFA), the contribution to the power peak (PEAK) and conversion factor between capacity and activity (CAP2ACT). The economic parameters include investment fixed O&M cost (FIXOM) and variable O&M cost (VAROM). Moreover by means of the parameter STOCK for every power plant is defined the retirement profile
- Sheet EMIS: It contains the emissions factors (unit of pollutant per unit of activity) associated to the commodities consumed by the plants. In particular only CO_2 has been considered
- Sheet FUEL TECH: It contains some dummy processes that don't represent real energy transformations, but which are needed for modelling. In fact they make available the primary commodities to the power sector. Such processes have associated efficiency equal to one and therefore they don't have any influence on the overall energy system operation.

POWER DEMAND

In 2010 the domestic net consumption of electricity was 413 PJ in Norway, 300 PJ in Finland and 474 PJ in Sweden (IEA, 2014). The total power demand has been split in four energy sectors: residential, industrial, transport and commercial (that includes agriculture and fishing too). The contributions of these sectors to the total final power demand in the base year are described in figure 4.

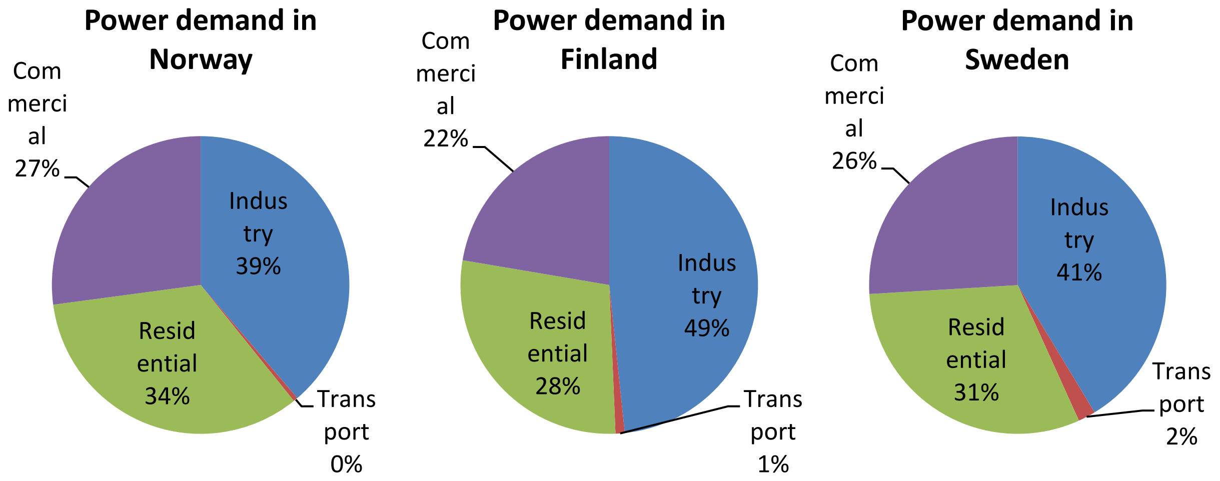

Figure 4: Power demand per sector in 2010

In TIMES-NPM the demand for energy services in the Nordic Countries in the base year is given exogenously in a workbook called "VT_NPM_DEM". Such demand is inelastic and the solver chooses which technologies to operate for its satisfaction without limitations neither of cost nor of system efficiency

In order to model the division of the total power demand between the energy sectors considered four commodities have been used (described in the sheet "Commodities"): one relative to industry (DINDELC), one to transport (DTRAELC), one to the residential sector (DRESELC) and one to the commercial sector (DCOMELC). These commodities flow out of four processes denominated "Demand Technologies", listed in the sheet "Processes". The technological description of such processes is in the sheet "DemTechs", which describes that the commodity electricity (ELCC) is converted in electric services. Since the conversion efficiency of these processes is equal to one, they work as dummy processes representing the fulfilment of the energy services. The exogenously given data regarding the amount of electric service to be met yearly is described in the sheet "Demands".

FUTURE TECHNOLOGIES

In TIMES models the main decision variable is the capacity to be installed in order to meet the demand. Until 2015 the existing or under construction plants are described and fixed in the workbook "VT_NPM_ELC", so that the solver is limited to determine the optimal use of the installed plants in terms of activity (electric energy production, in PJ). On the contrary, from 2015 on the solver determines which technologies to install to ensure that the electricity demand is satisfied in each time slice.

In order to ensure that the demand is met throughout the time horizon, from 2015 the solver both selects the optimal technology mix for replacing and/or complementing the existing stock and quantifies the optimal use of the already existing and new-installed plants.

The solver establishes which new technologies to install by selecting them from the workbook "SubRes_NewELCTechs", which includes the list of power plants available in the future in the Nordic Countries. They are described by means of technological, environmental and economical parameters.
The format of this workbook is very similar to that of the base year workbook, but it presents some extra attributes needed to better characterize the investment: INVCOST (investment cost, which is divided in many annual payments over the lifetime of the plant), START (year when the technology becomes commercially available), ILED (year it takes to build the technology)

The technologies considered in "SubRes_NewELCTecs" are those which are likely to be part of the future power generation mix in the Nordic region. This set of new available processes doesn't include any coal or fuel-oil power plants and future investments in natural gas fuelled power plants are possible only if equipped with carbon capture and storage (CCS). This was done in order to maintain consistency with the energy policies and laws existing in the Nordic region (NORDEN & IEA, 2013).
The technologies taken into account for future investments are presented in table 2

Table 2: Overview of future available technologies, potential and investment cost

Technology
Gas turbine combined cycle with CCS
Waste to energy CHP
Photovoltaic
Peat CHP
Wood chips and waste CHP
Straw CHP
Wood pellet CHP
Nuclear plant
Wind turbine large on-shore
Wind turbine medium on-shore
Wind turbine off-shore
New DAM hydro
New ROR hydro
Expanded and upgraded DAM hydro
Expanded and upgraded ROR hydro
Decommissioned and rebuilt DAM hydro
Decommissioned and rebuilt ROR hydro

Such technologies don't have infinite potential, but the yearly power production is limited by the availability of the energy source that has to be converted in electricity. However, the declaration of the maximum yearly activity was not reported in the SubRes but in some specific Scenario files, described in the relative chapter.

The SubRes is intended as a list of technologies with standard characteristics available for all the regions of the model, to be adjusted by means of ad-hoc commands.
The workbook "SubRES_NewELCTecs_Trans" is used for adjusting the description of the power plants available in the future by region. In fact not all the technologies described in "SubRes_NewELCTecs" exist

in every country and furthermore they don't have the same techno-economical characteristics in all the countries.

In the sheet "AVA" an availability-table declares if a power plant is not available in a certain country, thus excluding it from the list of the technologies available in the future in that specific country. Such declaration is visible in table 3.

Table 3: Availability of future technologies per region

~TFM_AVA

Pset_Set	Pset_PN	AllRegions	NOR	FIN	SWE
	*	1			
	ECWSTBPC3N		0		
	ECSTRBPD1N		0		
	ECPETBPC3N			0	
	ECPETEXC3N		0	0	
	ECWPEBPC3N		0	0	
	ECWCHBPC3N		0	0	
	ETURNBWR3N		0		
	ERSOLPVO3N		0	0	
	ERHYDELCDAM1N			0	
	ERHYDEXPUPDAM1N			0	
	ERHYDDAM3N			0	0
	ERHYDROR3N				0
	ERWINFRSWON		0	0	

Moreover in the sheet "Regional Costs" a transformation-update table is used for multiplying the installation, fixed O&M and variable O&M costs by the relative wealth of the different countries, as shown in table 4. In this way the future technologies present different costs in the various countries depending on their GDP compared to the Danish GDP.

Table 4: Regional costs of future technologies

~TFM_UPD

Attribute	FIN	NOR	SWE	Pset_Set
INVCOST	*0.802298850574713	*1.52183908045977	*0.905747126436782	CHP, ELE
FIXOM	*0.802298850574713	*1.52183908045977	*0.905747126436782	CHP, ELE
VAROM	*0.802298850574713	*1.52183908045977	*0.905747126436782	CHP, ELE

SCENARIO FILES

Scenario files are used to provide the underlying energy system with changing input data or with specific energy or environmental policies or with further constraints that make the representation of the energy system more exact.

In this chapter the description of the Scenario files created for the TIMES-NPM is given.

DEM_FR-PROJ-2DS

This scenario file was created with the purpose of adding more information to the demand commodities: the load profile and the power projection.

The power demand isn't constant over the day or over the year but instead is characterized by a strong variation. With the purpose of catching this variation, a description of the load profile of the various countries modelled in TIMES-NPM has been included. By means of the attribute "COM-FR" (fraction of the total demand) it has been possible to associate a share of the total annual power demand to each one of the 32 time slices. The 32 shares have been calculated inputting to the "Time slice tool" the historical load profile of Norway, Finland and Sweden taken from (STATNETT, 2015a), (ENERGIATEOLLISUUS, 2015) and (SVENSKA KRAFTNAT, 2015)

Part of the definition of the load profile in the model is shown in table 5.

Table 5: Demand Fraction

TimeSlice	LimType	Attribute	Year	Cset_SET	Cset_CN	NOR	FIN	SWE
RWDA		COM_FR	2010	DEM	D*ELC	0.0009	0.0009	0.0008
RWDD		COM_FR	2010	DEM	D*ELC	0.1299	0.1311	0.1296
RWDC		COM_FR	2010	DEM	D*ELC	0.0144	0.0140	0.0146
RWDB		COM_FR	2010	DEM	D*ELC	0.0257	0.0253	0.0260
RNWA		COM_FR	2010	DEM	D*ELC	0.0005	0.0005	0.0005
RNWD		COM_FR	2010	DEM	D*ELC	0.0716	0.0711	0.0718

The projections of energy demand deeply influence the need for new installed capacity and the future energy system in general. Therefore, when dealing with energy models, it is important to use reliable and trustworthy data regarding future power demand projection. In the demand workbook "VT_NPM_DEM" only the power demand in 2010 has been described. Separately in the DEM_FR-PROJ-2DS scenario file the demand projection described in (IEA, 2014) has been described, by means of the commodity "COM_PROJ", as shown in table 6.

Table 6: Demand projection

~TFM_INS

Attribute	Year	NOR	FIN	SWE	Cset_Set	Cset_CN
COM_PROJ	2011	161.4	145.8	196.3	DEM	DINDELC
COM_PROJ	2012	162.8	146.2	196.6	DEM	DINDELC
COM_PROJ	2013	164.2	146.6	197.0	DEM	DINDELC
COM_PROJ	2014	165.5	147.1	197.4	DEM	DINDELC

AVERAGE_INFLOW

This scenario file is used for describing the hydropower production in the Nordic Countries in a year of normal rainfall. The generation by reservoir hydro and run-of-river hydro has been modelled by describing for every time slice the availability factor of the commodity electricity (ELCC) coming out from such plants.

Such availability factors have been calculated starting from the historical water inflow series using the "Time slice feeder" tool.
For ROR hydro there isn't any possibility to store water, so power production is the same as the water inflow (expressed as energy inflow rather than as mass flow rate) that arrives to the plant, except in a few hours when the inflow is higher than the discharge capacity of the hydro turbine. For reservoir-hydro instead the power generation is set equal to the water inflow only over the entire year, while at time slice level the power production and the water inflow can be different, because this kind of plants has the possibility to store water.

In order to check that the model is well calibrated, for 2010 and 2012 the availability factors relative to hydropower production have been calculated from the water inflow in 2010 and 2012 rather than from the average water inflow series.

Moreover in this scenario file a set of constraints on the total yearly generation has been described: they ensure that the total yearly hydropower generation is lower or equal to the energy content of the total water inflow to the hydro-stations. The constraints on the maximum hydropower production (PJ) have been set for each region by means of user constraints and have been interpolated over the entire time horizon of the model. The constraints for Finland have been taken from (KAUPPA- JA TEOLLISUUSMINISTERIÖ ENERGIAOSASTO, 2005), from (LESKALA, 2010) and from (WORLD ENERGY COUNSIL, 2013), those for Sweden from (UNIDO & INTERNATIONAL CENTER, 2013), from (RUDBERG, 2013) and from (IEA, 2010) while the maximum power production from the Norwegian hydro was taken from (LIND, ROSENBERG, & SELJOM, 2013).

BIO-THERMAL-SOLAR_POTENTIAL

This scenario file allows inputting in the model the potential for nuclear, fossil, bio-thermal and photovoltaic technologies for each region. The potentials have been inserted by means of user constraints. Some potential are relative to one single power plant (e.g. ECWSTGEEXC1N, which is waste-to-energy CHP), while others are relative to a group of technologies (e.g. ET*,EC* , which is the set of all the thermal electric and CHP plants).
These potential have been input in order the model to take into account the estimated availability of sources (biomass, sun, uranium) that can be destined to power generation in the Nordic Countries. Data for the potential have been taken from the Balmorel model of the Nordic Regions (File Geogr.inc, 2004), from (IEA PV Power Systems programme, 2012) concerning photovoltaic in Sweden, from (IEA Bioenergy, 2012) concerning forestry biomass in Sweden and from (LESKALA, 2010) for biomass in Finland.

WIND_FRACTIONPOTENTIAL

The structure of this scenario file is very similar to that relative to hydropower production. In fact for each wind technology and in each region are specified the availability factors in each time slice.

Different sets of availability factors have been calculated in each country for the currently installed wind turbines, for large wind turbines onshore, for medium wind turbines onshore and for offshore wind turbines (from Balmorel model of the Nordic countries). An example of availability factors relative to the currently existing wind technologies is shown in table 7.

Table 7: Wind technologies AF

~TFM_INS

TimeSlice	Attribute	Year	Cset_CN	Pset_PN	NOR	FIN	SWE
RWDA	AF	2010	ELCC	ERWINWON1*	18%	19%	21%
RWDD	AF	2010	ELCC	ERWINWON1*	24%	20%	21%
RWDC	AF	2010	ELCC	ERWINWON1*	24%	17%	22%
RWDB	AF	2010	ELCC	ERWINWON1*	24%	20%	19%
RNWA	AF	2010	ELCC	ERWINWON1*	20%	16%	18%

Moreover, some user constraints were used to limit in every country the annual power production of a set of wind technologies to the wind potential value. These constraints are relative to 2010 and 2012 (using statistical data) and to future years (based on estimation of the wind potential), as visible in table 8.

Table 8: Wind potential

			~UC_T:UC_RHSRTS~UP			
UC_N	**Pset_PN**	**Pset_CI**	**Year**	**UC_ACT**	NOR	UC_RHSRTS~UP~0
UC_PotentialOnshoreWindNOR	*WINWON*	ELCWIN	2010	1.0	3.2	5.0
	WINWON	ELCWIN	2012	1.0	5.6	
	WINWON	ELCWIN	2015	1.0	45.4	
	WINWON	ELCWIN	2030	1.0	64.1	
UC_FuturePotentialOffshoreWindNOR	*WINWOFF*	ELCWIN	2030	1.0	82.4	5.0

The constraints on the maximum annual power production from wind turbines were taken from (VTT, 2014) for Finland, from (SVENSK VINDENERGI, 28) for Sweden and from (LIND, ROSENBERG, & SELJOM, 2013) for Norway.

KILL-ELCC_IMPEXP_DK

This scenario file is run only when TIMES-NPM is run together with TIMES-DK. In fact when these TIMES models are run together in hard-link mode, the power trade between Denmark and the rest of Nordic countries is described by means of endogenous trade processes, defined in the TIMES-TRADE model. Therefore the scenario KILL-ELCC_IMPEXP_DK is used for eliminating the exogenous trade processes between Denmark and the rest of the Nordic countries, in such a way so as not to compute these exchanges twice.

This is done by setting to zero the activity bound and the capacity bound referred to these exogenous trade processes over the entire time horizon, as shown in table 9.

Table 9: Kill exogenous trade with Denmark scenario

~TFM_INS

LimType	Attribute	Year	AllRegions	Pset_PN
UP	ACT_BND	2010	0	*PELC-DK*
UP	ACT_BND	0	5	*PELC-DK*
UP	CAP_BND	2010	0	*PELC-DK*
UP	CAP_BND	0	5	*PELC-DK*

ENDOGENOUS ELECTRICITY TRADE

In 2010 the status of the interconnectors in the Nordic region was the following: Norway was electrically interconnected to Sweden, Denmark, Netherland, Finland and Russia and the total existing Norwegian transmission capacity summed up to 5450 MW. Sweden was interconnected to Norway, Denmark, Finland, Germany and Poland, with an exporting transmission capacity of 8840 GW and 10540 MW for importing. Finland was interconnected to Norway, Sweden, Russia, and Estonia, with an exporting capacity of 2100MW and an importing capacity of 3420 MW.
Such interconnectors represent an alternative way to fulfil the power demand in an efficient way: instead of starting an expensive plant in the peak hours or instead of using water stored in the reservoirs in periods of drought, power can be imported from the surrounding countries which in that moment are producing power at cheaper cost.

In TIMES-NPM the interconnectors between the modelled regions (Norway, Sweden and Finland) are represented as endogenous trade processes, while the interconnectors between these regions and the surrounding countries are represented as exogenous trade processes.

The definition of the endogenous trading processes between Norway, Sweden and Finland is given in the scenario trade file denominated "Trade_Links" by means of the electricity trade matrix. Since power can flow in both directions, the bi-lateral electricity trade matrix was used. It is shown in table 10, where exporters are by rows and importers by columns.

Table 10: Bi-lateral power trade matrix

~TradeLinks

ELCC	NOR	SWE	FIN
NOR		1	1
SWE	1		
FIN	1	1	

This trade matrix is used by VEDA-FE to automatically create the endogenous trade process called "TB_ELCC_NOR_SWE", "TB_ELCC_NOR_FIN" and "TB_ELCC_SWE_FIN". These processes are recognized by TIMES as IRE processes, which mean endogenous trade processes: power exchange flows are not based on exogenously defined price related criteria, but instead the trading prices and volumes are determined by the model itself.

The technical description of these interconnections is realized in a scenario trade file called “Trade_Data” by means of a transformation-insert table, which contains the availability factor (0.95), the efficiency (0.97) and the CAP_BND constraints for the base year and for some future years, as visible in table 11.

Table 11: Endogenous trade processes characteristics

~TFM_INS

LimType	Attribute	Year	AllRegions	NOR	FIN	SWE	Pset_PN
	EFF	2010	0.97				TB_ELCC*
	AFA		0.95				TB_ELCC*
	CAP2ACT		0.032				TB_ELCC*
UP	CAP_BND	0	5				TB_ELCC*
UP	CAP_BND	2010		3600		3600	TB_ELCC_NOR_SWE_01
UP	CAP_BND	2010		70	100		TB_ELCC_NOR_FIN_01
UP	CAP_BND	2010			1650	2050	TB_ELCC_FIN_SWE_01
UP	CAP_BND	2012			2450	2850	TB_ELCC_FIN_SWE_01
UP	CAP_BND	2019		3600		3600	TB_ELCC_NOR_SWE_01
UP	CAP_BND	2020		5000		5000	TB_ELCC_NOR_SWE_01

EXOGENOUS ELECTRICITY TRADE

The exchange flows between the countries modelled in TIMES-NPM (Norway, Sweden and Finland) and the neighbouring countries (Denmark, Germany, Poland, Lithuania, Russia, Estonia, Netherlands and United Kingdom) is modelled by means of exogenous trade processes.

The list of the exogenous trade processes is given in the workbook “SubRES_ELC-IMPEXP”, together with the associated life time (parameter “LIFE”), availability factor (“AFA”), efficiency (“EFF”) and year of installation (“START”).

In order to specify in which regions the exogenous trade processes are available a transformation availability table was created in the workbook “SubRES_ELC-IMPEXP_Trans”.

In the same workbook, in the sheet “New-LineCap” the transmission capacity associated to each trade process in the various years of the time horizon is given. This information is expressed as maximum activity (PJ) over the year rather than as installed capacity and is given by means of a transformation-insert table, as shown in table 12.

The values of the current maximum transmission capacity were taken from (ENTSO-E, 2011) and from (ENTSO-E, 2014), while data about future planned maximum transmission capacity were taken from (STATNETT, SVENSKA KRAFTNAT, ENERGINET.DK, FINGRID , 2012).

Table 12: Transmission capacity of some exogenous trade processes

~TFM_INS

LimType	Attribute	Year	NOR	FIN	SWE	Pset_PN
UP	CAP_BND	0	5	5	5	IMPELC*,EXPELC*
FX	NCAP_BND	2010	22			IMPELC-NL
FX	NCAP_BND	2010	2			IMPELC-RU-Murmansk
FX	NCAP_BND	2010	22			EXPELC-NL
FX	NCAP_BND	2010		41		IMPELC-RU-Vyborg
FX	NCAP_BND	2010		11		IMPELC-ES

The computation of the exchange flows for these processes is based on price related criteria exogenously defined in the model. In every year and in every time slice TIMES compares the endogenously calculated equilibrium price in each region with the cost of importing and exporting from the interconnected countries.
If the equilibrium price is higher than the import cost the model will import power as long as the new equilibrium price becomes equal to the import cost or as long as all the transmission lines are congested. Instead if the equilibrium price in the region is lower than the export cost then it will export as long as the new equilibrium price becomes equal to the export cost or as long as all the transmission lines are congested

The import and export costs used by TIMES for the determination of the exchange flows between the countries represented in TIMES-NPM and the surrounding countries are exogenously given in the workbook "SubRES_ELC-IMPEXP_Trans".
In order to obtain the costs of import and export associated to the neighbouring countries, first the trading price profiles were calculated for the base year starting from the hourly power prices in 2010. Then the projections for the future prices were computed by multiplying the price profile in the base year for some coefficients that estimate the evolution of the power prices in the future.
Once calculated all these prices it was possible to declare in the model the import and export costs. For every country and for every time slice the import cost was set equal to its power price, while instead the export cost was set equal to 99% of the import cost.

The description of the import and export costs for the various countries, for the various years and for the various time slices was input in the model in the workbook "SubRES_ELC-IMPEXP_Trans". An extract of the exogenous import and exports cost as it has been input in the model is shown in table 13.

Table 13: Exogenous import cost of Sweden from Denmark East

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TimeSlice	Attribute	Year	SWE	Pset_PN	CURR
RWDA	COST	2010	28.99	IMPELC-DKE	MKr10
RWDD	COST	2010	93.88	IMPELC-DKE	MKr10
RWDC	COST	2010	98.80	IMPELC-DKE	MKr10
RWDB	COST	2010	117.61	IMPELC-DKE	MKr10

RESULTS OF THE MODEL

TIMES-NPM is used for exploring the power generation and the power trade in the Nordic Countries from 2010 to 2050. In order to be sure that the results given by the model are trustworthy and that therefore the estimates that it provides are likely to occur, first the model needs to be validated, which means to check that the results given for 2010 and 2012 are in line with the statistics.

The results of the model in 2010 and 2012 revealed that while the power plants operated are the same as the statistics and the power generated by the various classes of power plants is almost the same as the statistical values, some mismatches have been seen between the power trade computed by the model and the statistics. This problem has been experimented also in a previous version of the model that included only the region Norway. A possible explanation to this mismatch between the results of the model and the statistics is that exogenous power trade introduces some errors which then modify the entire national energy balance.

The comparison between the average results of TIMES-NPM in 2010 and 2012 and the average statistical values in 2010 and 2012 for Norway, Finland and Sweden is shown in the following tables. The major differences between statistics and model results are highlighted in red.

Table 14: Difference between statistics and model results in Finland

FINLAND	Average 2010-2012	
	Statistics	Model results
PRODUCTION	261	265
Hydro power	53	53
Wind power	1	1
Nuclear power	79	79
Co-generation, CHP	92	94
Condense etc.	35	38
IMPORTS	63	71
Sweden	29	27
Norway	0	1
Estonia	4	5
Russia	29	38
EXPORTS	12	10
Sweden	9	0
Norway	0	0
Estonia	3	10
Russia	0	0

Table 15: Difference between statistics and model results in Sweden

SWEDEN	Average 2010-2012

	Statistics	Model results
PRODUCTION	532	525
Hydro power	264	253
Wind power	19	19
Nuclear power	211	219
Thermal	37	33
IMPORTS	50	49
Denmark	11	11
Finland	9	0
Norway	24	33
Poland	1	0
Germany	5	5
EXPORTS	82	51
Denmark	21	0
Finland	30	28
Norway	18	0
Poland	6	13
Germany	7	10

Table 16: Difference between statistics and model results in Norway

NORWAY	Average 2010-2012	
	Statistics	Model results
PRODUCTION	488	476
Hydro power	468	456
Wind power	13	13
Nuclear power	0	0
Thermal	8	8
IMPORTS	34	14
EXPORTS	52	40

As visible from the previous three tables the main differences are that Finland doesn't export to Sweden and that Sweden doesn't export to Norway nor to Denmark.

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