SAFER2028-SINARP2024 Deliverable report,

D1.1.2: Refining the scenarios (T1.1)

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1 Introduction

2024 has witnessed the biggest step change in grid scenario parametrisation for several years (in the COSI→SINARP project context). This is due in particular to an unfunded Master's thesis by a scholarship student, The Phong Nguyen [1]. Under John Millar and Ilkka Jokinen's supervision, Phong analysed a number of data sources, including *Fingrid development plans* [2], to produce a thesis rich with present and future (~2035) scenarios (according to 4 possible development scenarios identified by Fingrid) for both generation and demand. Of relevance to the other tasks in SINARP2024 is a much better present load distribution than has been used previously, a couple of recently commissioned lines and some more wind parks, which are modelled by Floran Martin [3], whose work in modelling Type 4 wind parks with grid-following converters has been continued in 2024 by his exchange student, Pierre Troussard for grid forming converters. These developments have resulted in more realistic load flows at the 400 kV level in Finland. What is more, if we get continuation in 2025, Phong has extended the present model of the grid to a good projection based on Fingrid's expansion plans for 2035, along with four load and generation scenarios. While Fingrid has recently revised their projections, we can quickly update Phong's work if required.

For SINARP2024 we will focus on the present state of the Finnish power system, and for this report we will focus on the relevant part of Phong's work and the work of John Millar billed to the project, whilst acknowledging that parametrisation for the future grid loading and transmission expansion is ready and waiting for work in 2025.

The red comments in Fig. 1 indicate that we are on target with T1.1 (and indeed, the other tasks in WP1).

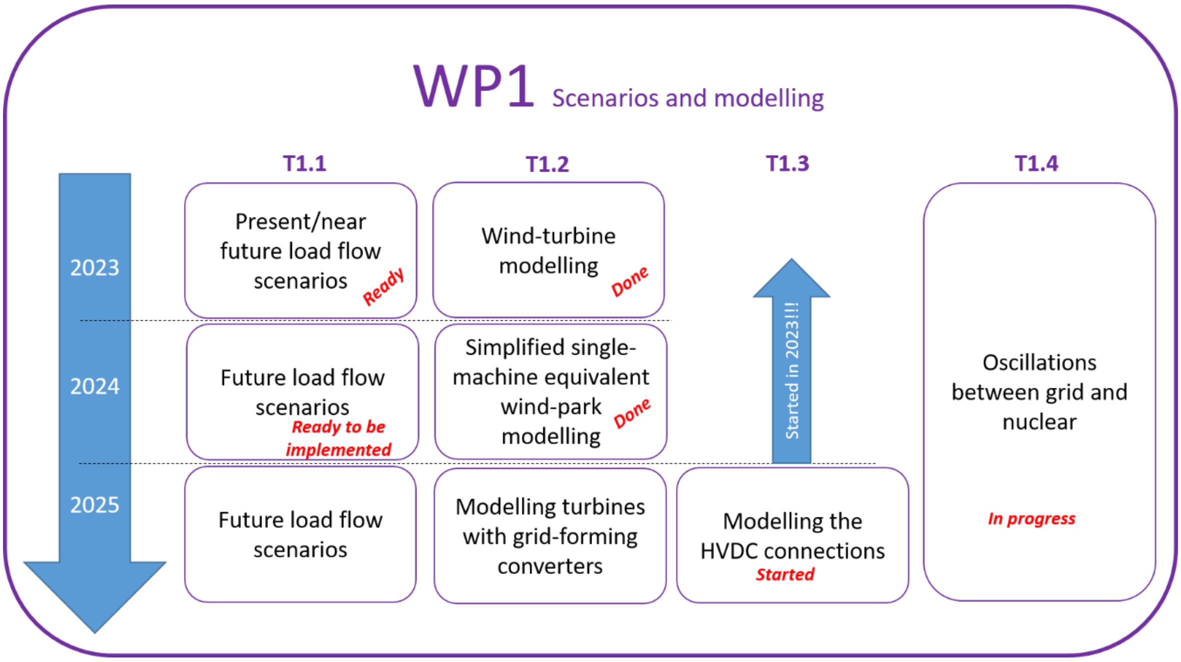

Figure 1 Scenario modelling back on schedule, with present and future load scenarios completed (this figure is modified from Figure 1 in SINARP_Project_plan_2024)

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2 Generation Modelling

Table 1 is taken from Table 34 in Phong's thesis [1], and uses, among other sources, data from [4] lumped to the nearest 400 kV substation. This follows methodology used in previous years of SINARP and COSI, but is somewhat more detailed in Phong's thesis, although net generation has been lumped to each connection point, which is suitable for voltage sources but not for segregating individual generator types. However, Phong has done this segregation in his data files. Solar generation has also been included, although it must be admitted that this is experiencing a sharp increase in 2024, and Phong's data is already out of date! Fingrid's online data portal registers that solar production peaked at 867 MW in July 2024 [2], which is significant, especially given that the sun tends to shine when the energy demand is low in Finland. Wind has also increased by more than 1.5 GW during 2024. A lot more hydro has been added, as well, so that our scaling of hydro more correctly represents the geographical distribution of this resource in Finland. Appendix A shows the parametrising used in the current model. The logic is to represent each generation type present at each 400 kV connection point, as a synchronous generator or wind park digital twin, and as a voltage source (for quicker simulations and checking power flows, etc.).

The implementation of all this in the grid model will be given in more detail in D2.1.1 in December, but Fig. 2 below gives some idea of the implementation in Simscape. Each connection point has blocks for each generation type, in this case an industrial CHP block and a hydro block. The hydro block, as an example, has a synchronous machine block and a voltage source block, one of which is commented out. The synchronous machine block opens up to the subsystems in the lower left of Fig.2, consisting of a synchronous generator in the middle, a power system stabilizer on the right, and a parasitic load and step-up transformer on the left. The parameters of the synchronous generator are shown on the bottom right of the figure. The parameters and the blocks used are controlled in m-files.

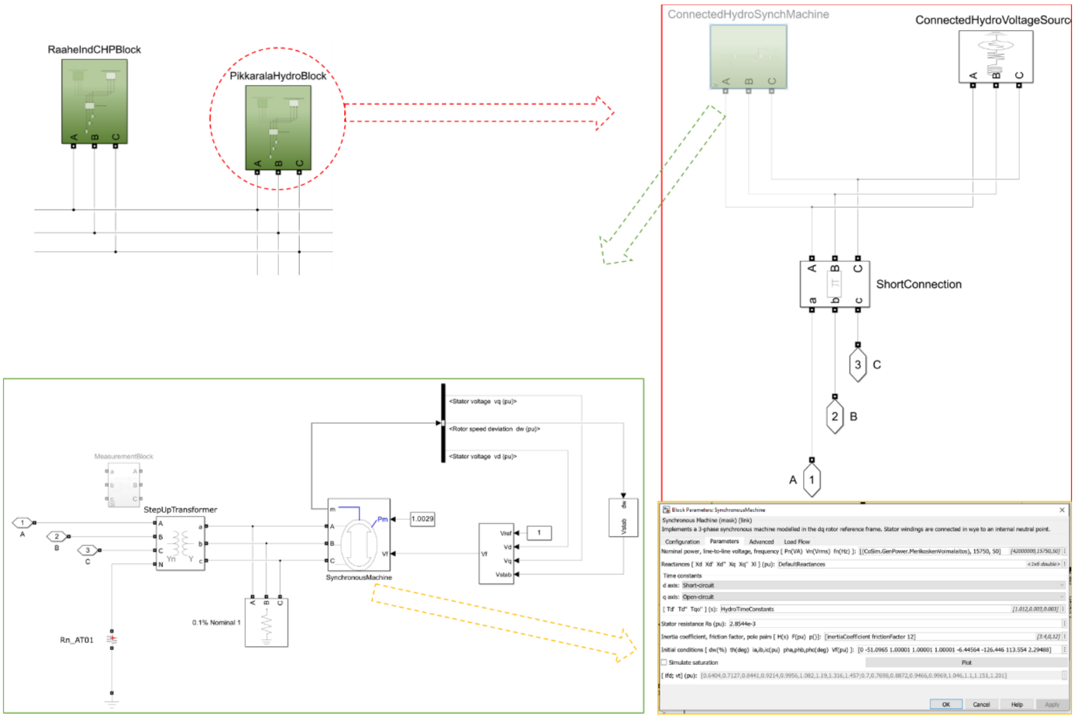

Figure 2 The subsystems and parameter settings that underly a Hydro block

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Table 1 Electricity Generation capacity lumped to nearest 400 kV substation (taken from [1])

Substation	Wind (MW)	Solar (MW)	Nuclear (MW)	Hydro (MW)	Thermal (MW)	Total (MW)
Petäjäkoski	117.25			288.50	0.90	406.65
Pirttikoski	195.80			554.70		750.50
Keminmaa	123.70			11.00	16.00	150.70
Asmunti						
Simojoki	474.90			226.00		700.90
Tuomela						
Isokangas	146.50			311.80		458.30
Pikkarala	37.10	4.90		42.00		84.00
Pyhänselkä				101.70		101.70
Pihlajaranta	68.40					68.40
Valkeus	625.80					625.80
Jylkkä	494.30	10.00				504.30
Uusnivala	55.80			3.50		59.30
Hirvisuo	372.45			12.30		384.75
Vuolijoki	433.40			353.90	1.50	788.80
Pysäysperä	207.70			14.80		222.50
Alapitkä				27.10		27.10
Tuovila	209.00			8.30	41.90	259.20
Alajärvi	142.40			4.50	3.40	150.30
Seinäjoki	176.40	9.00		43.52	3.10	232.02
Kärppiö	480.90			6.30		487.20
Kristinestad	643.65				60.00	703.65
Arkkukallio				1.00		1.00
Ulvila	293.50			105.75	624.30	1023.55
Vihtavuori	69.00			30.40		99.40
Petäjävesi	29.96			4.50	1.20	35.66
Huutokoski	64.50	5.00		192.90	184.80	447.20
Toivila						
Olkiluoto			3380.00		100.50	3480.50
Lavianvuori		3.60				3.60
Rauma						
Huittinen	3.60			79.40		83
Forssa	55.30			8.50	352.00	415.80
Lieto	34.90			4.50	41.10	80.50
Salo	21.00			4.20		25.20
Inkoo	10.00			6.90		16.90
Kangasala				107.50	5.00	112.50
Hikiä		2.31			68.40	70.71
Visulahti		4.00		3.20		7.20
Yllikkälä	21.00			257.50	111.10	389.60
Kymi	31.90			87.43		119.33
Koria	33.00			288.60	1.20	322.80
Loviisa			1014.00	28.50	40.00	1082.50
Nurmijärvi						
Anttila					98.00	98.00
Kopula						
Tammisto				3.00	2.10	5.10
Länsisalmi	3.45				118.00	121.45
Espoo					1.30	1.30
Total	5675.56	38.81	4394.00	3223.70	1857.80	15208.87

The more elaborate modelling of generation allocation to the connection points made available in Phong's Master's thesis [1], and the entire generation parameters currently used in the SINARP grid model can be found in Appendix A, Table A.1 at the end of this document.

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3 Demand modelling

The more accurate assessment of current demand made in Phong's thesis has perhaps given rise to the most profound change to the SINARP grid model. To do this, Phong referred to [5], primarily to give an accurate present foundation to his future modelling, but the present day loading is what is relevant to SINARP2024, and is given in terms of peak demand in Table A.2 in the Appendix.

4 Fault scenario used in 2024 Co-simulations

We have still to finalise the grid events that we will explore, but the main contribution for 2024 is the first, admittedly crude, modelling of subsynchronous harmonics via shunt current sources at the wind park locations. The amplitude of these harmonics are tuned to give the voltage distortion reported by Fingrid. Again, it must be stressed that results for this will be tentative, but they will form the foundation for more accurate modelling in 2025. There has been considerable development by Marius and the team at VTT in the development of the co-simulation platform, and, most significant for the scenarios, a work-around to give the APROS model the same power output that the Loviisa units give in reality. This work will be reported by VTT in D2.3.1 in January 2025.

We will conclude this report with an RMS voltage plot at the 400 kV connection to Loviisa NPP. We have tuned the current sources, which are producing harmonics at 5.5 Hz and 27 Hz with an amplitude of 0.1 pu the amplitude of the RMS current from each wind farm. This would seem quite high distortion, but gives about 1.5 kV distortion at the 400 kV connection point. It remains to be seen what this amount of distortion will do to the pumps, but also the generator and steam turbine shafts. For that we will have to know the forced oscillation frequencies of the shafts.

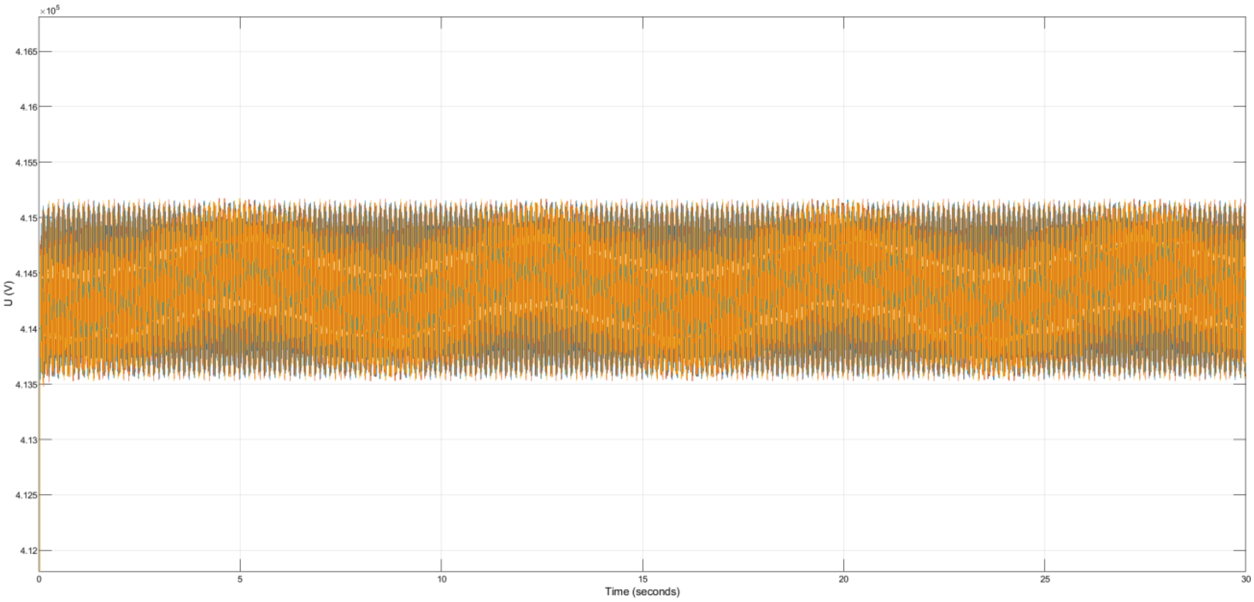

Figure 3 Scenario 10 plots of voltage (above) and frequency (below). It takes about 8 simulated seconds for the model to converge, but harmonics appear when the wind turbines are connected at about 6 seconds.

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5 Discussion

2024 has delivered what was promised in 2023, i.e., refinement of the geographic distribution of demand in Finland, and also produced future scenarios focusing on 2035. We have opened up research into subsynchronous oscillations, and we will also run a couple of winter scenario simulations, with wind and without wind, in the final co-simulations, once the 2024 grid model is ready and delivered to VTT.

References

[1] T. P. Nguyen, "Power system modeling to aid the planning and operation of the Finnish transmission grid in 2035 scenarios," Master's thesis, 31.07.2024, in Master's Programme in Advanced Energy Solutions, https://aaltodoc.aalto.fi/server/api/core/bitstreams/1faa8626-1a00-4f14-951e-c67c1d872610/content

[2] Fingrid. Fingrid's electricity system vision 2022 — draft scenarios for the future electricity system. Available: https://www.fingrid.fi/globalassets/dokumentit/en/news/fingrid_electricity_system_draft_scenarios.pdf

[3] SAFER2028-SINARP deliverable D1.2.1, Digital twin of a wind farm equipped with type IV generator and a grid following controller, Floran Martin, Robert John Millar, and Janne Seppänen

[4] Energiaviraston voimalaitosrekisteri, 14 November, 2023, https://energiavirasto.fi/toimitusvarmuus

[5] Finnish Energy. Electricity consumption by municipality 2007–2022. Available: https://energia.fi/en/statistics/electricity-consumption-by-municipality-2007-2021 [Accessed 31 July 2024].

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Appendix A Generation and demand parameters

Table A1 Generation parameters.

% HVDC links from Sweden	
CoSim.GenPower.Finnbole	800e6
CoSim.GenPower.Dannebo	4.00E+08
% Nuclear	
CoSim.GenPower.Loviisa_1	507000000
CoSim.GenPower.Loviisa_2	507000000
CoSim.GenPower.Olkiluoto_1	890000000
CoSim.GenPower.Olkiluoto_2	890000000
CoSim.GenPower.Olkiluoto_3	1600000000
% Hydro and bio CHP	
CoSim.GenPower.KoriVesivoima	synchScaleFactor * 288.6e6
CoSim.GenPower.Harjavalta	synchScaleFactor * 105e6
CoSim.GenPower.Isohaara	synchScaleFactor * 106e6
CoSim.GenPower.Letsi	synchScaleFactor * 483e6
CoSim.GenPower.Ossauskoski	synchScaleFactor * 120e6
CoSim.GenPower.PetajaskoskiPM1	synchScaleFactor * 56e6
CoSim.GenPower.PetajaskoskiPM2	synchScaleFactor * 56e6
CoSim.GenPower.PetajaskoskiPM3	synchScaleFactor * 56e6
CoSim.GenPower.Pirttikoski1	synchScaleFactor * 84.5e6
CoSim.GenPower.Pirttikoski2	synchScaleFactor * 84.5e6
CoSim.GenPower.Seitakorva	synchScaleFactor * 142.5e6
CoSim.GenPower.Taivalkoski	synchScaleFactor * 133.2e6
CoSim.GenPower.Imatra	synchScaleFactor * 192e6
CoSim.GenPower.PyhakoskiAndMontta	synchScaleFactor * 198e6
CoSim.GenPower.Valajaskoski	synchScaleFactor * 92e6
CoSim.GenPower.Vanttauskoski	synchScaleFactor * 94.4e6
CoSim.GenPower.PamilonVesiVoima-laitos	synchScaleFactor * 85e6
CoSim.GenPower.NuojuaVesiVoima-laitos	synchScaleFactor * 85e6
CoSim.GenPower.MelonVesiVoimalaitos	synchScaleFactor * 70e6
CoSim.GenPower.Tainionkoski	synchScaleFactor * 66e6
CoSim.GenPower.UtanenVesiVoima-laitos	synchScaleFactor * 65e6
CoSim.GenPower.Tainionkoski	synchScaleFactor * 66e6
CoSim.GenPower.RaasakanVesiVoima-laitos	synchScaleFactor * 60e6
CoSim.GenPower.JylhamanVesiVoima-laitos	synchScaleFactor * 55e6
CoSim.GenPower.PallinVesiVoima-laitos	synchScaleFactor * 55e6

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CoSim.GenPower.MontanVesiVoima-laitos	synchScaleFactor * 51e6
CoSim.GenPower.KolsinVesiVoima-laitos	synchScaleFactor * 45e6
CoSim.GenPower.AittoVesiVoimalaitos	synchScaleFactor * 45e6
CoSim.GenPower.PahkaVesiVoimalaitos	synchScaleFactor * 42e6
CoSim.GenPower.MerikoskenVoima-laitos	synchScaleFactor * 42e6
CoSim.GenPower.PorttipahdanVoima-laitos	synchScaleFactor * 40e6
CoSim.GenPower.MaalismaaVoimalaitos	synchScaleFactor * 38.6e6
CoSim.GenPower.KierikinVoimalaitos	synchScaleFactor * 37.5e6
CoSim.GenPower.SeitenoikeanVoima-laitos	synchScaleFactor * 37.9e6
CoSim.GenPower.HaapakoskenVoima-laitos	synchScaleFactor * 32.6e6
CoSim.GenPower.KaltimonVoimalaitos	synchScaleFactor * 32e6
CoSim.GenPower.KuusankoskenVoima-laitos	synchScaleFactor * 30e6
CoSim.GenPower.MankalanVoimalaitos	synchScaleFactor * 30e6
CoSim.GenPower.KurkiaskanVoima-laitos	synchScaleFactor * 26.6e6
CoSim.GenPower.JumiskonVoimalaitos	synchScaleFactor * 27.8e6
CoSim.GenPower.KokkosnivanVoima-laitos	synchScaleFactor * 26e6
CoSim.GenPower.Koivukoski3Voima-laitos	synchScaleFactor * 24.3e6
CoSim.GenPower.Leppikoski	synchScaleFactor * 24e6
CoSim.GenPower.Voikkaa2Voimalaitos	synchScaleFactor * 24e6
CoSim.GenPower.Ahvenkoski	synchScaleFactor * 24e6
CoSim.GenPower.MyllykoskenVoima-laitos3	synchScaleFactor * 23.8e6
CoSim.GenPower.KoriVesivoima	synchScaleFactor * 288.6e6
% Wind Parks	
CoSim.GenPower.MutkalampiWind	windScaleFactor * 426e6
CoSim.GenPower.PiipurinmakiWind	windScaleFactor * 211.5e6
CoSim.GenPower.VihtavuoriWind	windScaleFactor * 151e6
CoSim.GenPower.Pursiala1and2Wind	windScaleFactor * 147.7e6
CoSim.GenPower.KristinestadA	windScaleFactor * 322e6
CoSim.GenPower.KristinestadB	windScaleFactor * 322e6
%CoSim.GenPower.MetsalaWind	windScaleFactor * 117.3e6
CoSim.GenPower.TuovilaWind	windScaleFactor * 209e6
CoSim.GenPower.MustilankangasWind	windScaleFactor * 92.4e6
CoSim.GenPower.OltavaWind	windScaleFactor * 91.2e6
%CoSim.GenPower.KalaxWind	windScaleFactor * 90.3e6
CoSim.GenPower.KarppioWind	windScaleFactor * 481e6
CoSim.GenPower.KeminmaaWindA	windScaleFactor * 248e6
CoSim.GenPower.KeminmaaWindB	windScaleFactor * 248e6

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CoSim.GenPower.ValkeusSurplusWind	windScaleFactor * 510e6
CoSim.GenPower.SimojokiWind	windScaleFactor * 475e6
CoSim.GenPower.VuolijokiSurplusWind	windScaleFactor * 222e6
CoSim.GenPower.HirvisuoWind	windScaleFactor * 373e6
CoSim.GenPower.UlvilaWind	windScaleFactor * 294e6
CoSim.GenPower.PysaysperaWind	windScaleFactor * 208e6
CoSim.GenPower.PirttikoskiWind	windScaleFactor * 196e6
CoSim.GenPower.SeinajokiWind	windScaleFactor * 176e6
CoSim.GenPower.IsokangasWind	windScaleFactor * 147e6
CoSim.GenPower.AlajarviWind	windScaleFactor * 143e6
CoSim.GenPower.PetajaskoskiWind	windScaleFactor * 117e6
% Industrial CHP (Bio etc)	
CoSim.GenPower.AanekoskiInd	industrialSynchScaleFactor * 280e6
CoSim.GenPower.AnjalankoskiInd	industrialSynchScaleFactor * 160.5e6
CoSim.GenPower.KaukopaaInd	industrialSynchScaleFactor * 105e6
CoSim.GenPower.OuluInd	industrialSynchScaleFactor * 100e6
CoSim.GenPower.PietarsaariInd	industrialSynchScaleFactor * 95e6
CoSim.GenPower.RaaheInd	industrialSynchScaleFactor * 94e6
CoSim.GenPower.KuusaanniemiInd	industrialSynchScaleFactor * 87e6
CoSim.GenPower.KuusankoskiInd	industrialSynchScaleFactor * 76e6
CoSim.GenPower.KotkaInd	industrialSynchScaleFactor * 72e6
% Urban CHP	
CoSim.GenPower.VuosaariAandB	urbanCHPscaleFactor * 648e6
CoSim.GenPower.Salmisaari	urbanCHPscaleFactor * 163e6
CoSim.GenPower.VantaanJatevoimala	urbanCHPscaleFactor * 81.4e6
CoSim.GenPower.Suomenoja	urbanCHPscaleFactor * 358e6

Table A2 Demand Parameters

CoSim.Pdemand.Estlink1	350e6
CoSim.QindDemand.Estlink1	0
CoSim.QcapDemand.Estlink1	0
CoSim.Pdemand.Estlink2	650e6
CoSim.QindDemand.Estlink2	0
CoSim.QcapDemand.Estlink2	0
CoSim.Pdemand.Alajarvi	loadScaleFactor * 81e6
CoSim.QindDemand.Alajarvi	60e6
CoSim.QcapDemand.Alajarvi	0
CoSim.Pdemand.Alapitka	loadScaleFactor * 532e6

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CoSim.QindDemand.Alapitka	6e6
CoSim.QcapDemand.Alapitka	0
CoSim.Pdemand.Anttila	loadScaleFactor * 489e6
CoSim.QindDemand.Anttila	1e6
CoSim.QcapDemand.Anttila	0
CoSim.Pdemand.Espoo	loadScaleFactor * 530e6
CoSim.QindDemand.Espoo	60e6
CoSim.QcapDemand.Espoo	0
CoSim.Pdemand.Forssa	loadScaleFactor * 134e6
CoSim.QindDemand.Forssa	6e6
CoSim.QcapDemand.Forssa	0
CoSim.Pdemand.Hikia	loadScaleFactor * 614e6
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CoSim.Pdemand.Hirvisuo	loadScaleFactor * 2895e6
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CoSim.QcapDemand.Hirvisuo	0
CoSim.Pdemand.Huittinen	loadScaleFactor * 254e6
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CoSim.Pdemand.Keminmaa	loadScaleFactor * 812e6
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CoSim.Pdemand.Koria	loadScaleFactor * 575e6
CoSim.QindDemand.Koria	1e6
CoSim.QcapDemand.Koria	0

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CoSim.Pdemand.Kristinestad	loadScaleFactor * 117e6
CoSim.QindDemand.Kristinestad	60e6
CoSim.QcapDemand.Kristinestad	0
CoSim.Pdemand.Kymi	loadScaleFactor * 378e6
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CoSim.QcapDemand.Kymi	0
CoSim.Pdemand.Lansisalmi	loadScaleFactor * 443e6
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CoSim.QcapDemand.Pirttikoski	0
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CoSim.QcapDemand.Pyhanselka	0
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CoSim.QindDemand.Rauma	60e6
CoSim.QcapDemand.Rauma	0
CoSim.Pdemand.Seinajoki	loadScaleFactor * 303e6

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CoSim.QindDemand.Seinajoki	60e6
CoSim.QcapDemand.Seinajoki	0
CoSim.Pdemand.Tammisto	loadScaleFactor * 936e6
CoSim.QindDemand.Tammisto	0
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CoSim.Pdemand.Toivila	loadScaleFactor * 187e6
CoSim.QindDemand.Toivila	6e6
CoSim.QcapDemand.Toivila	0
CoSim.Pdemand.Tuovila	loadScaleFactor * 187e6
CoSim.QindDemand.Tuovila	60e6
CoSim.QcapDemand.Tuovila	0
CoSim.Pdemand.Ulvila	loadScaleFactor * 417e6
CoSim.QindDemand.Ulvila	6e6
CoSim.QcapDemand.Ulvila	0
CoSim.Pdemand.Vuolijoki	loadScaleFactor * 266e6
CoSim.QindDemand.Vuolijoki	60e6
CoSim.QcapDemand.Vuolijoki	0
CoSim.Pdemand.Yllikkala	loadScaleFactor * 1001e6
CoSim.QindDemand.Yllikkala	1e6
CoSim.QcapDemand.Yllikkala	0
CoSim.Pdemand.Visulahti	loadScaleFactor * 228
CoSim.QindDemand.Visulahti	60e6
CoSim.QcapDemand.Visulahti	0

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