Intro to EnergyPLAN

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LOCAL



AALBORG University



EnergyPLAN





EnergyPLAN

- A consistent and comparative analysis of alternatives
- Able to analyse radical technological change

AALBORG UNIVERSITY DENMARK

- Able to provide suitable information for feasibility studies and the design of public regulation measures
- Able to explore a wide range of future options (speed of calculation)



Why to choose EnergyPLAN

<u>User friendly</u> analysis of national / regional and city energy systems Simplified modelling of energy system.

Main focus:

- Design energy systems to accommodate fluctuating renewable energy
- Renewable-energy penetration up to 100% renewable energy
- Long term projections



www.EnergyPLAN.eu



Why to choose EnergyPLAN

- >3,000 users worldwide
- Sharing the data online -<u>http://www.energyplan.eu/us</u> <u>eful_resources/existingmodel</u> <u>s/</u>
- Free-download
- You can create add-on tools





General characteristics

- Analysis of all energy sectors:
 - Electricity
 - Heating
 - Transport
 - Industry
- 1 year in our-by-hour steps
- Aggregated model
 - Does not model each plant individually, but all plants in a system
- Fast simulation the computation of 1 year requires only a few seconds



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EnergyPLAN – Advanced analysis of smart energy systems

ABSTRACT

Check for updates

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Keywords: EnergyPLAN Model description Smart energy systems Energy systems analysis Energy modelling EnergyPLAN is an energy system analysis tool created for the study and research in the design of future sustainable energy solutions with a special focus on energy systems with high shares of renewable energy sources. It has been under development since 1999 and has formed the basis for a substantial number of PhD theses and several hundreds of research papers. EnergyPLAN is designed to exploit the synergies enabled from including the whole energy system, as expressed in the smart energy system concept. Thus, with EnergyPLAN the user can take a holistic approach focusing on the analysis of the cross-sectoral interaction. Traditionally disparate demand sectors, such as buildings, industry and transport, are linked with supply technologies through electricity, gas, district heating and cooling grids. In this way, EnergyPLAN neables the analysis of the conversion of renewable electricity into other energy carriers, such as heat, hydrogen, green gases and electrofuels, as well as the implementation of energy efficiency improvements and energy conservation. This article describes the overall structure of EnergyPLAN and the essential algorithms and computational structure.

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Simulation versus optimization Or operation versus investment optimisation?

- a **simulation model** can be defined as representation of a system used to predict the behaviour of the system under a given set of conditions
- while an **optimization model** is typically used synonymously with mathematical programming to refer to a mathematical formulation in which a formal algorithm is used to compute a set of decision-variable values that minimize or maximize an objective function subject to constrains.









Three different types of analyses

Technical System Analysis with or without CEEP (Critical Excess Electricity Production) Results: Fuel consumption, energy balances, CO₂-emissions etc.

> Market Exchange Analysis Results: Optimal trade strategies, costs and technologies

> > Market economic energy system simulation and feasibility studies Results: Socio-economic costs incl. fuel and CO₂ trade costs



Step by step using EnergyPLAN

- 1. Defining energy demands (electricity, individual and district heating demands)
- 2. Defining energy production
- 3. Balancing and storage



Step 1: Defining electricity demand

Warnings Appear Here: E Overview Electricity Demand and Fixed Import/Export ⊡ Demand Electricit Electricity demand*: 1057,2694 GWh/year Change distribution Hour_electricity.txt - Heating Electric heating (IF included) 0 GWh/year Subtract electric heating using distribution from 'individual' window - Cooling - Industry and Fuel Electric cooling (IF included) 0 GWh/year Subtract electric cooling using distribution from 'cooling' window - Transport --- Water Elec. for Biomass Conversion 0,00 GWh/year (Transfered from Biomass Conversion TabSheet) - Supply (Transfered from Transport TabSheet) Elec. for Transportation 35,47 GWh/year 🗄 - Balancing and Storage 🛓 - Cost Sum (excluding electric heating and cooling) 1092,74 GWh/year - General - Investment and Fixed OM - Heat and Electricity Electric heating (individual) GWh/year 0,00 Renewable Energy Electricity for heat pumps (individual) GWh/year 0.00 Liquid and Gas Fuels Electric cooling GWh/year Heat Infrastructure 0,00 Road Vehicles Other Vehicles Flexible demand (1 day) 1000 0 GWh/year Max-effect k₩ - Water Import/ Flexible demand (1 week) 0 GWh/year Max-effect 1000 k₩ - Additional Export - Fuel Flexible demand (4 weeks) 0 1000 k₩ GWh/year Max-effect fixed and --- Variable OM variable External Electricity Market Change distribution Hour_Tysklandsexport.txt GWh/year Fixed Import/Export 0 Simulation Electricity 🛓 Output demand Total electricity demand* 1092,74 GWh/year



Step 1: Defining heat demands

/arnings Appear Here:									
Overview Overview Demand Electricity	Total Heat Dema	ınd*: 1114,09	Demand Per Bui	lding* : 9191,243	kWh/year Inc	lv. heated h	nouseholds: 121	212 Units	Coal Boiler Heat demand
Heating Cooling Industry and Fuel Transport Water Supply Balancing and Storage	Individual Heatin GWh/year Distribution:	ng: Fuel Efficienc; Input Thermal	 Heat Efficient Demand Electric Heat Hour distributivity 	Estimate cy Capacity Electricit Limit* Producti	d y Heat on Storage*	Solar T Share*	Fhermal Input Output Solar Hour solar1	Resulting Fuel Consumption*	Oil Boiler Heat Ngas Boiler Heat Biomass Boiler Heat Heat demand
 Cost General Investment and Fixed OM Heat and Electricity Renewable Energy Liquid and Gas Fuels Heat Infrastructure Road Vehicles Other Vehicles Other Vehicles Water Additional Fuel Variable OM External Electricity Market Simulation Output 	Coal boiler : Dil boiler : Ngas boiler : Biomass boiler : H2 micro CHP : Ngas micro CHP : Biomass micro CHP Heat Pump : Electric heating : Total Individual	0 0.8 0 0.85 1237.876 0.9 0 0.8 0.5 0.5 0.5	0,00 0,00 1114,09 0,00 0 0,3 0 0,3 0 0,3 0 3 0 3 0 1114,09	1 0.00 1 0.00 1 0.00 1 0.00 1 0.00 10 0.00	0 0 0 0 0 0 0 0 0	1 1 1 1 1 1 1 1 1 1	0 0,00 0 0,00	0,00 0,00 1237,88 0,00 0,00 0,00 0,00	H2 H2 CHP Heat
	District Heating: Production: Network Losses: Heat Demand:	Group 1: Gro 0 0 0.2 0.23 0,00	up 2: Group 3: 0 0,183 0,00 0,00	Total: D 0,00 (0,00	istribution: Change Ho	ur_distr-heat.tx	xt		Electricity Electricity Electricity Heat boiler Heat boiler Heat thermal Heat He



Step 1: Defining transport demands

								-
Varnings Appear Here:								
• • • Overview	GWh/year	Fossil	Biofuel	Waste*	Electrofuel	Total	Distribution	Help to design inputs
Demand Electricity Heating Cooling Industry and Fuel Industry and Fuel Water Water Supply Balancing and Storage Cost General Heat and Fixed OM Heat and Fixed OM Heat and Fixed Parallelectricity Renewable Energy	JP (Jet Fuel) Diesel Petrol Ngas* (Grid Gas) LPG H2 (Produced by Elec Electricity (Dump Chan Electricity (Smart Chan	0 354,638 421,176 0 0 xtrolysers) rge) ge)	0	0,00	0	0,00 354,64 421,18 0,00 0,00 0 35,469 0	Gas H2 Dump Smart	const.txt Hour_transport.txt Hour_transport.txt Hour_transport.txt
Herevsole Lingy High and Gas Fuels Heat Infrastructure Road Vehicles Uther Vehicles Water Additional Fuel Variable OM External Electricity Market Simulation Output	Electric Vehicle Smart Charge Vehi Additional Specific	Specification icles: Max. share Capacity of Share of pa Efficiency (Battery stor ations for Vehic Capacity of Efficiency (of cars during grid to battery rirked cars grid grid to battery age capacity age capacity battery to grid battery to grid	g peak demand: y connection: d connected:) (G): d connection)	0.2 0 0.7 0.9 0 0 0.9	kw Mwh kw		Oil Combustion cars Transport demand Ngas Combustion cars Transport demand Biomass Combustion cars Transport demand Hz storage FC Transport demand Electricity Electric grid Transport demand



Step 2: Defining the production

Warnings Appear Here:			
Overview Overview Overview Overview Overview Overview Overview Overview	Group 1: Group 2: Group 3: Total Electricity Production: District Heating Production: 0,00 0,00 0,00 0,00	Unit: GWh/year	Group 1 represents district heating systems with no CHP Group 2 represents district heating systems based on small CHP plants Group 3 represents district heating systems based on large CHP extraction plants
Cooling Industry and Fuel Transport Water	Boilers Thermal Capacity 0 0	kJ/s	
Heat and Electricity Electricity Only Heat Only	Boiler Efficiency 0.9 0.9 0.9 Fixed Boiler share 0 0	Percent	Central Power Plants Capacity Efficiency Correction Factor: Annual production: Distributions Storage for Dammed Hydro Storage 0 MV/h Storage difference: 0
Fuel Distribution Waste Liquid and Gas Fuels Lo2 Gasencing and Storage Cost	Combined Heat and Power (CHP) CHP Condensing Mode Operation* Electric Capacity (PP1) 0 Electric Efficiency (PP1) 0,45	kW-e	nearing PP1 (CHP3 Condensing Mode)* 0.00 n/a* - Cooling - Industry and Fuel - Industry and Fuel - Transport - Condensing PP2 0 - Water 0 0 - Heat and Electricity - Nuclear - Heat and Electricity - Heat and Electricity - Heat and Electricity - Nuclear - Heat and Electricity - Nuclear
 General Investment and Fixed OM Heat and Electricity Renewable Energy Liquid and Gas Fuels Heat Infrastructure 	CHP Back Pressure Mode Operation* Electric Capacity 0 Thermal Capacity 2161	k₩-e kJ/s	Heat Only - Fuel Distribution - Wate U Liquid and Gas Fuels - CO2 Belancing and Storage Dammed Hydro Water supply* Dammed Hydro Power Dammed Hydro Power Damm
Road Vehicles Other Vehicles Water Additional	Electric Efficiency 0,4 0,4 Thermal Efficiency 0,5 0,5		General G
Variable OM Variable OM Simulation Output	Industrial CHP CHP Electricity 0 0 0,00 CHP Heat Produced 0 0 0,00	GWh/year GWh/year	Heat Infrastructure Energy Source kW share GW/h/year factor production capacity factor - Road Vehicles Wind 0 0 Change Hour_wind_1.txt 0.00 0.00 0.00 - Water - Additional Photo Voltaic 0 0 Change Hour_wind_1.txt 0.00 0.00 0.00 - Fuel Wave Power 0 0 Change Hour_solar_prod1 0.00 0.00 0.00 - Variable OM Externel Restriction Market Forer Hudro 0 0 Change Hour_solar_prod1 0.00 0.00
	CHP Heat Delivered* 0,00 0,00 0,00 0,00	GWh/year Distr	Image: Simulation Image: Simulation Image: Simulation Image: Simulation 0.00 0.00 0.00 0.00 Image: Simulation Image: Simulation Image: Simulation Image: Simulation 0.00 0.00 0.00 0.00 Image: Simulation Image: Simulation Image: Simulation Image: Simulation 0.00 0.00 0.00 0.00 Image: Simulation Image: Simulation Image: Simulation Image: Simulation 0.00 0.00 0.00



Step 3: Balancing and storage

Overview Overview Overview Overview Overview Overview Overview Overview Overview Supply Balancing and Storage Overview Ov	Electric grid stabilisation requirements: Minimum grid stabilisation share* 0.3 Stabilisation share of CHP2 0 Stabilisation share of Waste CHP 0 Stabilisation share smart charge EV and V2G 0 Stabilisation share smart charge EV and V2G 0 Stabilisation share transmission line 0 Stabilisation share transmission line 0 Stabilisation share transmission line 0 Minimum CHP in gr. 3: 300 Minimum PP: 0 CHP3 priority to PP in grid stabilisation No Capacities Charge (electricity) 0 MW Storage loss rate 0.05 Percent per hour Discharge (steam) 0 MW Storage Capacity 1	Critical Excess Electricity Production (CEEP) Critical Electricity Excess Production (CEEP) regulation: Write number: 1: Reducing RES1 and RES2 2: Reducing CHP in gr.2 by replacing with boiler 3: Reducing CHP in gr.3 by replacing with boiler 100 4: Replacing boiler with electric heating in gr.2 with maximum capacity: 100 6: Reducing BES3 100 7: Reducing negative plant in combination with RES1, RES2, RES3 and RES4 8: Increasing CO2Hydrogenation (See Tabsheet Sythetic Fuel) if available capacity 9: Partloading nuclear (speficity partload options in electricity only Tabsheet) Note: Electricity only tabsheet
	Electricity Storage 1 Capacities Efficiencies Fuel Ratio *) Storage Capacity Charge 0 MW 0.8 0 GWh Discharge 0 MW 0.9 0 GWh Allow for simultaneous operation of turbine and pump: No *) Fuel ratio = fuel input / electric output (for CAES technologies or similar)	Electricity Storage 2 Capacities Efficiencies Storage Capacity Charge 0 MW 0.8 0 GWh Discharge 0 MW 0.9 0 Wh

From annual values to hour by hour

- Using the annual value the hour by hour values are calculated
 - Demands

(electricity, district heating, transport etc.)

- RES (wind, PV etc.)
- Fixed import/export



3294

4392 Hours



Results in seconds

New CEESA.txt

Gr.1

2,98 1,25 11,09 24,34 2,07 0,91

Fixed imp/exp. 0,00

Transportation 8.22

35.74

Gr.2

0,00 2,65 9,02 20,78

0,83 TWh/year 0,00 share

4454 MW 12,63 TWh/year 0,00 Grid

10173 MW 41,75 TWh/year 0,00 stabili-5000 MW 6,46 TWh/year 0,00 sation

District Heating

heating Solar CSHP DHP CHP HP ELT Boiler EH

03 717 1189 17 241 237

17 270 144

17 249 205

481 1298 195 729 1552

- - 0,77 1,05

- 0.00 0.00 0.00 0.00 0.00

1,81 8,43 10,60 0,77 1,05 3,81

Productio

0 TWh/year

0 TWh/year

Gr.3 Sum Group 3: CHP

WARNING !!: (1) Critical Excess;

0 620 73 0 783 175

311 74 80

156 105

0 407 74

0 196 48

Maximum 10955 3841 1307 838 2532 3150 0 3720 600 1614 3754 6922 1184 7658 600

3.81

24

10

Minimum 2170 0 1056 16 0 21 0 0 0 -2307 1312 -246 6 0 0 0 0 31

DHP CHP2 CHP3 Boiler2 Boiler3 PP Geo/NuHydro Waste Elc.ly. version Fuel Wind Offsh. PV

38,39 4,22

2,65 31,52

Capacities

3484

7574

Electricity prod. from CSHP Waste (TWh/year)

0.00 0.00

0,00 0,39

0.89 0.72

Consumptio

70 2938

96 3247

lance demandTransn HP trolyser EH

-2 2787 1398 1042 3366 4 2759 1399 1079 4407

11 2001 1422 944 4180 -34 2361 1382 699 4164

28 2307 1394 459 4435 -43 2246 1408 109 4115

-13 2407 1412 256 3732 14 2492 1408 659 5068

-8 2482 1400 599 3999

1 2682 1400 881 4638

10 2683 1378 905 3749 74

CAES BioCon-Synthetic

- -22,85 -0,02

-32,15

- 38,87

-24.78 -10.85 35.63

Elec-

73 175

80

19

105

46

800 2100

MW-e MJ/s elec.

1945 1241 0.58 0.37

2500 1292 0.60 0.31

0,60

Group 2:

Heat Pump 300 1050

Heat Pump

Condensing 10333

Ba- Elec. Flex.&

-33 2060 1411

-35 2349 1389

Whyeer 39.41 4.22 11.38 1.71 6.41 13.63 0.00 1.72 0.40 -0.07 21.80 12.30 5.26 35.13 0.40 0.00 0.00 61.67 0.00 0.00 1.77 11.25 2.28

4,16 3,45

Heatstorage: gr.2:40 GWh

Fixed Boiler: gr.2:0,5 Per cent

CHP

Boiler

Boiler

Gr.1:

Efficiencies

Ther

0.95

0,95

3.50

3.50

gr.10 GWh

gr.0,5 Per cent

Hydro Tur-

0 5913 0 8144

0 7311 0 6858

0 7331 0 7451

0 5751

0 6280

0 6417 0 8798

0 8183

0 5917

0 7021

0 18481

12,63 41,75 6,48 0,79 6,39

Regulation Strate(Technical regulation no. 3 Fuel Price level: Basic

COP KEOL regulation 23458000

Minimum CHP gr 3 load

Maximum import/export

Minimum PP

Gas Storage

Minimum Stabilisation share 0,00

Stabilisation share of CHP 0.00

Heat Pump maximum share 0,50

Distr. Name : Price_DKV_2008.txt

Addition factor 100,00 DKK/MWH Multiplication factor 1,05

Dependency factor 0,02 DKK/MWh pr

6000 GWh

200 2339 385 200 1537 207

200 1744 216 200 1490 223

200 1274 192 204 408 121

205 482 381

205 425 410

200 1323 148 100

202 1281 260

32.15

7.61 -24.78 5.17 3.45 12.63 41.75 6.46 0.79 6.39 32.15 0.92 19.11 138.16 -2.93 135.23

0 200 2458 361 100

0 228 4445 3285 100

201 1028 316 100 200 875 154 100

Average Market Price541 DKK/MWh

Syngas capacity 3522 MW

Biogas max to grid 895 MW

Electricity

Production

Hy- Geo- Waste-

Pump bine RES dro thermal CSHP CHP PP

Electricity demand (TWh/year): Elexible demand4.07

0.00 Total

300 MW

0 MW

0 MW

January 6657 190 1307 446 1331 2693 February 6790 401 1307 391 873 2856

September 3109 581 1300 23 586 629 October 4179 398 1307 150 500 1780

November 5196 216 1307 325 751 2335

December 6024 128 1307 416 1398 2284

8,43 10,60

4028 892 1307 4006 758 1306 2347 824 1270 2347 885 1284 2347 844 1286

5921 454 1307 308 989 2460 4928 692 1307 170 841 1854

Input

Wind

Offshore Wind Photo Voltaic

Wave Power

Hydro Power

Output

March

April

May June July

August

Oil N.Gas

Biomass 1.81

Renewable

Nuclear/CCS Total

H2 etc.

Biofuel

Average 4487

FUEL BALANCE (TWb/year)

Geothermal/Nuclear

Demand

Distr.

Fixed demand 21,80 Electric heating + HP 1,65

District heating (TWh/year)

Industrial CHP (CSHP) 0,00 Demand after solar and CSHP 1,71

District heating demand Solar Thermal

Electric cooling

A Results

EnergyPLAN model 12.0 RESULT: Data-set: Technical regulation no. 1 Critical Recep Regulation Strategy:	Startdata	а
Total Calculation Time Loading of Data Calculating Strategy 1 Calculating Strategy 2 Calculating Heatstorage Calc Calculating Heatstorage	12:00:00 12:00:00 12:00:00 12:00:00 12:00:00 12:00:00 12:00:00	
ANNUAL CO2 EMISSIONS (Mt): CO2-emission (total) CO2-emission (corrected)	9,458 9,458	
SHARE OF RES (incl. Biomass): RES share of FES RES share of elec. prod. RES electricity prod.	28,7 34,6 7,01	percent percent TWh⁄year
ANNUAL FUEL CONSUMPTIONS (TWh/year) Fuel Consumption (total) CAES Fuel Consumption Fuel (cncl Biomass excl.RES) Fuel Consumption (incl. H2) Fuel Consumption (corrected) Coal Consumption 011 Consumption Biomass Consumption Biomass Consumption Waste Input V2G Pre Load Hours	TOTAL: 48,98 0,00 46,56 48,98 47,84 11,64 11,64 11,64 0,00 0,00 0,00	HOUSEHOLDS: 0,00 0,00 0,00 0,00 0,00
ANNUAL COSTS (M DKK) Fuel ex. Ngas exchange Coal FuelOil Gasoil/Diesel Petrol/JP Gas handling Biomass Food income Waste	TOTAL :	VARIABLE: BF 0
Ngas Exchange costs		0
Marginal operation costs		0
Electricity exchange Import Export Bottleneck Fixed imp/exp		-93
CO2 emission costs		0
Variable costs	-93	
Fixed operation costs	0	
Annual Investment costs	0	
TOTAL ANNUAL COSTS	-93	



Household 0.00 0.00 0.00 1.13 Industry 0.00 0.00 0.00 19.03

Various 0,00 0,00 0,00 0,00

Load Imp Exp CEEP EEP

96 98

148 142 148 142

400 400 303 303

237 237

0 152 152 0 381 381

54

0 8427 8427

200 200

0.00 1.76 1.76 0.00

Imp/Exp Corrected CO2 emission (M

141 141

MW MW MW MW

Industry

Stab

100 100

100 100

100 100

100 321 321

100

0,00 0,00 0,00 0,00 0,00 -2,98

- - 0,00 0,00 0,00 - - -0,03 -2,93 -2,96 0,92 19,11 66,88 0,00 66,68 - - 71,51 0,00 71,51 - - 0,00 0,00 0,00

0,00 0,00 0.00

0.00 0.00

0 200 0 0 100 0 0 0

Industry

Wave Solar.Tr Transp.househ.Various Total | Imp/Exp Netto

100

Exchange

Payment

Million DKk

Average price

558 36

Total Netto

0,00 0,00 0,00 0,00 -0,01 -0,61 0,00 0,00

0.00 0.00

0.00 0.00

0.00 0.00

-0.01 -0.61

(DKK/MW)

Imp E





The Energy	PLAN model 12.0
echnical regulation no. 3 23458000 ion share 0,00 of CHP 0,00 ioad MW u MW wm NW wm 0,50 xport 0	Fuel Price level: Basic V(1) Capacities Storage Efficient MW-e GWh elsc. Ther Hydro Pump: 0 0.86 Hydro Turbine: 0 0.86 Electrol. Gr.2: 0 0.00 0.00 Electrol. Gr.3: 0 0.00 0.00 Electrol. Gr.3: 0 0.00 0.00 Electrol. Gr.3: 0 0.73 0.73
DKV_2008.bd 100,00 DKK/MWh 1,05 0,02 DKK/MWh pr. MV 106541 DKK/MWh	Ely. MicroCHP: 0 0 0,00 CAES fuel ratio: 0,000 (TWh/year) Coal Oil Ngas Biomas Transport 0,00 0,00 0,00 0,00

micro CHP and CHP-Waste

Run Run Run (Clipboard) (Screen) (Print)

20