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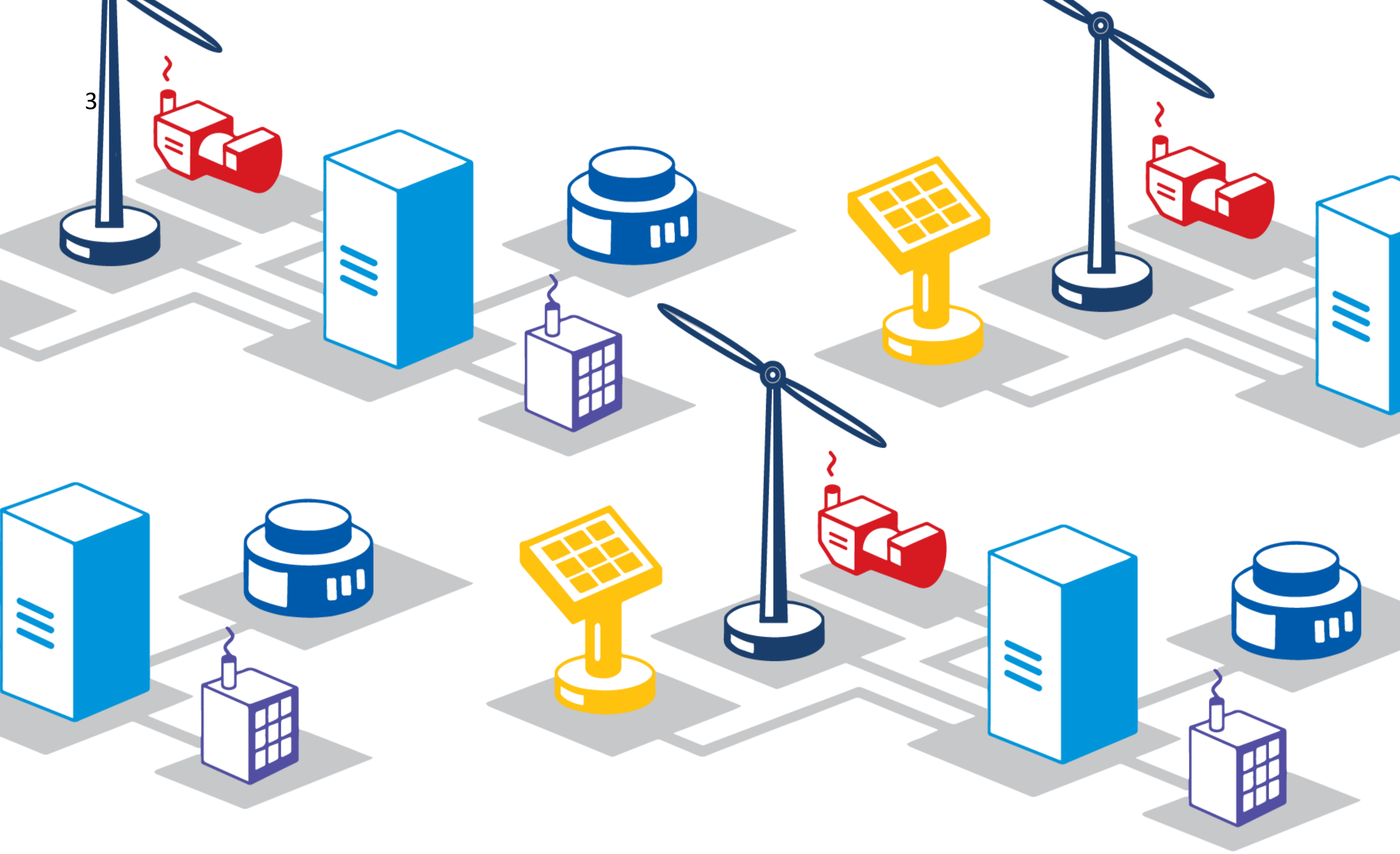

Energy tech company for off grid solutions

Tools for energy and electricity systems

Introduction

Electricity generation from renewable energy sources (RES) is increasing in Europe, much of it driven by ambitious targets for emission reductions set by the European Commission. In the 2050 Low Carbon Economy roadmap, the EU set a goal of reducing emissions to 80% below the 1990 level [1]. The EU also states that all sectors have to contribute to this reduction, but the sector with the highest potential for cutting emissions is the power sector.

Through increasing the share of zero-emitting RES in the electricity mix, the power sector can almost totally eliminate its emissions by 2050. Most of the increased RES in the electricity mix has in the latest years been, and is projected to be, solar and wind technologies. Part of this increase is due to the large cost reductions experienced and also projected.

According to the International Renewable Energy Agency (IRENA), the levelized cost of electricity (LCOE) of solar photovoltaics (PV) has halved between 2010 and 2014 [2]. Furthermore, in November 2016, the winning bid to build the Danish offshore wind farm Kriegers Flak was as low as 49.9 €/MW h [3]. However, solar and wind are variable renewable energy sources (VRES) whose outputs vary temporally on many scales. This is especially the case for wind, which ranges from local gusts of only seconds to large scale patterns evolving over several years. The solar radiation is to some extent more predictable, where the daily and seasonal cycles are well known components. However, on shorter timescales the solar radiation can be difficult to predict due to the rapid change in cloud cover. In an electricity grid that requires a balance between generation and consumption, larger shares of VRES leads to multiple challenges. On a very short timescale, from sub-seconds to minutes, challenges of VRES integration are related to the operation and management of the grid. The main issues include the reduction of inertia of the power system, the increase of curtailment events, the rate of change of frequency as well as the system reactive power capability [4]. Grid support services such as frequency and voltage regulation, fault ride through, spinning reserve and system restoration are currently provided by conventional technologies (i.e. mostly fossil fuelled power plants and hydropower). However, if solar and wind technologies are to replace much of the fossil fuelled capacities, they or new system components like batteries must be able to provide the required grid support services in order to maintain a stable and reliable grid. With existing technology, both wind turbines and PV systems are capable of providing grid support services, but limited to some drive-train topologies for wind turbines and generally only for large utility-scale PV systems [5–7].

On an hourly timescale, both wind turbines and photovoltaic systems can shift from generating at nominal power to not generating anything at all. With a large renewable penetration, this can lead to challenging ramping situations, periods of oversupply as well as periods where the renewable sources are not able to meet the demand. Future power systems with high shares of renewables may require increased system flexibility through e.g. flexible power plants, energy storage, demand response and transmission grid extensions.

On longer timescales, challenges related to renewable integration include identifying pathways to a renewable and emission free energy system, assessing different scenarios and testing the effect of various policies. For example by assessing the impact of a carbon tax, the future evolution of electricity and fuel prices or how much the demand of energy is going to increase due to population growth and increased standard of living. Due to the long investment cycles in the energy sector, such analyses usually cover a time span of several decades.

Technological possibilities for more geographically distributed energy production and better control systems suggest that the development of energy production, storage and distribution systems in the near future may depend more on consumer or prosumer preferences and multi-level governance in addition to planning and optimisation on a national level. Business opportunities arising from periodically low electricity prices can stimulate new technologies and reduce curtailment.

It is suggested that such factors may be relevant to include in scenario modelling.

Tools for energy and electricity systems

From short-term operation to long-term energy system planning, many different models have been developed to assess the numerous challenges related to energy and electricity systems.

User experience during the LOGIC Interreg project

Inspired by the overview of Hans-Kristian Ringkjøb many of the tools have been tested for designing a DHES. The online tool that OGTC has developed is a tool to get a first estimation but to get detailed information about a microgrid we suggest to use HOMER or RETScreen.

HOMER is the global standard for optimizing a microgrid design in all sectors, from village power and island utilities to grid-connected campuses and military bases. Originally developed at the National Renewable Energy Laboratory, and enhanced and distributed by HOMER Energy, HOMER (Hybrid Optimization Model for Multiple Energy Resources) nests three powerful tools in one software product, so that engineering and economics work side by side.

HOMER examines all possible combinations of system types in a single run, and then sorts the systems according to the optimization variable of choice.
HOMER Pro features our new optimization algorithm that significantly simplifies the design process for identifying least-cost options for microgrids or other distributed generation electrical power systems. HOMER Optimizer™ is a proprietary "derivative free" optimization algorithm that was designed specifically to work in HOMER.

RETScreen is a Clean Energy Management Software system for energy efficiency, renewable energy and cogeneration project feasibility analysis as well as ongoing energy performance analysis.

Expert, an advanced premium version of the software, is available in Viewer mode completely free-of-charge. Click here to download RETScreen Expert.

RETScreen empowers professionals and decision-makers to rapidly identify, assess and optimize the technical and financial viability of potential clean energy projects. This decision intelligence software platform also allows managers to easily measure and verify the actual performance of their facilities and helps to find additional energy savings/production opportunities.

Overview of all tools in the open source article of Hans-Kristian Ringkjøb⁎, Peter M. Haugan, Ida Marie Solbrekke

Programming, PE – Partial Equilibrium, A- Accounting, ABS – Agent-based Simulation, MIQCP – Mixed Integer Quadratically Constrained Programming, CGE – Computable General Equilibrium, E – Equilibrium, CMA-ES – Covariance Matrix Adaptation Evolution Strategy, HO – Heuristic Optimisation, ECE – Economic Computable Equilibrium, SDDP – Stochastic Dual Dynamic Programming; Temporal Resolution/Modelling Horizon/Geographical Coverage: UD – user-defined, NL – No limitations.

Models	#	Purpose	Appr.	Methodology	Temporal resolution	Modelling horizon	Geographical coverage
AURORAxmp	1	I & ODS, S, PSAT	BU	S, LP, MIP, PE	UD (Hourly)	UD (50+ years)	Single project → Global
BALMOREL	2	I & ODS	H	PE/LP (MIP)	Hourly/Aggregate	50 years (UD)	Regional → International
Calliope	3	I & ODS	BU	LP (MIP under development)	UD	UD	UD
CASPOC	4	PSAT	BU	S	UD	µs to 1 year	Single-System/Local
COMPETES	5	I & ODS	BU	LP (In.), MIP (Op.)	Hourly	UD	National (Europe)
COMPOSE	6	ODS & S	BU	A (In.), MIP(Op.)	UD (Usually hourly)	UD	Single-Project/System
CYME	7	PSAT	BU	S	UD (Usually ms)	UD	Single-System → Regional
DER-CAM	8	I & ODS	BU	MIP	Hourly (In.) & Minutes (Op.)	Up to 20 years	Single-Project → Regional
DESSTinEE	9	S, I & ODS	BU	S	Hourly	2050	National (Europe)
DIETER*	10	I & ODS	BU	LP	Hourly	1 year	Calibrated to Germany
DIgSILENT/ PowerFactory	11	PSAT	BU	S	UD	UD	Power Systems
EMLab-Generation	12	IDS	H	ABS	Yearly	2050	Two Markets/Countries
EMMA	13	I & ODS	BU	LP	Hourly	Long-term economic equilibrium	National (Europe)
EMPIRE	14	IDS	H	LP (Multi-horizon stochastic)	5 y (In.), UD time-slices per year (Op.)	Typically 40–50 y	National (Europe)
EMPS	15	I & ODS	BU	LP[a]	Weekly[b]	25 years	Regional → Continental
EnergyPlan	16	S, IDS	BU	S	Hourly	1 year	Local → Continental
energyPro	17	I & ODS	BU	AO[c]	Minutes	Max 40 years	Local → Regional
Enertile	18	I & ODS	BU	LP	Hourly	Usually 2050	EUMENA (National)
ENTIGRIS	19	I & ODS	BU	LP	Hourly (Op.), 5 y (In.)	2050	Regional → International
ETM (1)	20	S	BU	PE & LP	Six time slices: three seasons (winter, summer and intermediate), & day/ night	2100	Global (17 regions)
ETM (2)	21	S	H	S	15-min (+ Hourly & Yearly)	2050	Community → International
ETSAP-TIAM	22	I & ODS, S	BU	LP, PE	Yearly (seasons & day-night hours)	2100	Global (15 regions)
EUCAD	23	ODS	BU	MIQCP	Hourly	Yearly	National (Europe)
EUPower-Dispatch	24	ODS	BU	MIP	Hourly	Yearly	National (Europe)
ficus	25	I & ODS	BU	MIP	Typically 15 min	1 year	Local → National
GCAM	26	S	H	PE	5 years	2100	Global (Regional)
GEM-E3	27	S	TD	CGE	5 years	2030 and 2050	Global (38 regions)
GENESYS	28	IDS	BU	CMA-ES & HO	Hourly	2050	EUMENA (National)
GridLAB-D	29	PSAT	BU	ABS	Sub-seconds – Years	3–5 Years	Local → National
HOMER	30	I & ODS	BU	S & O	Minutes	Multi-Year	Local
HYPERSIM	31	PSAT	BU	S	10 µs	UD	Single-System → Regional
iHOGA	32	I & ODS	BU	HO	Hourly	Yearly	Local
IMAKUS	33	I & ODS	BU	LP	Hourly	Several decades	Germany
INVERT/EE-Lab	34	S	BU	S	Y (In), Monthly (Op)	2030/2050/2080	Buildings
IPSA 2	35	PSAT	BU	S	[d]	[e]	Power Systems
IRiE	36	ODS	BU	MIP	15-min	Yearly	26 areas in Northern Europe
LEAP	37	S	H	S & LP	Yearly	Usually 20–50 years	Local → Global
LIBEMOD	38	S	H	ECE	Yearly (El split in summer and winter season; one day split into day and night)	1 → 20 years	National (Europe)
LIMES-EU	39	S, I & ODS	H	LP	5/10 y (6 rep. days per year, 8 time slices per day)	2050	National (Europe)
LOADMATCH*	40	S	BU	S	30 s	6 years (2050–2055)	CONUS (4° × 5° WWS data)
LUSYM	41	ODS	BU	MIP	15 min/Hourly & Daily (UC)/Weekly (Scheduling)	Daily/Weekly (UC) & Yearly (Scheduling)	National
MARKAL	42	S	BU	LP/MIP, PE	Multiple years (UD time-slices within a year)	Long-term (UD)	Local → Regional
MESSAGE	43	S, IDS	H	LP	UD (Multiple years)	Long-term (50–100+ years)	Global (11 Regions)
NEMO	44	I & ODS	BU	CMA-ES & S	Hourly	Typically 1 year	National
NEMS	45	S	H	S, O, PE	Yearly	2050	Regional/National (U.S.)
Oemof (SOLPH)	46	S, I & ODS	All	LP, MILP, PE	Seconds to years	UD	UD
OpenDSS	47	PSAT	BU	S	UD (1 s to 1 h)	UD	Distribution feeders/areas
OSeMOSYS	48	IDS	BU	LP	UD (intra-annual)	UD (10–100 y)	Community → Continental
PLEXOS	49	I & ODS, S, PSAT	BU	[F]	UD up to 1 min (Usually hourly)	UD (1 day to 50 + years)	Single project→ Global
POLES	50	S, I & ODS	H	PE/S	Yearly (Sectoral load shape for two typical days with two-hour resolution)	2050 (2100)	Global (66 regions)

Models	#	Purpose	Appr.	Methodology	Temporal resolution	Modelling horizon	Geographical coverage
PowerGAMA	51	S (IDS)	BU	S, LP	Usually hourly	Usually 1 year	Regional/National

(continued on next page)

Table 2 (continued)

Models	#	Purpose	Appr.	Methodology	Temporal resolution	Modelling horizon	Geographical coverage
PRIMES*	52	S, IDS	H	PE	Yearly	Long-term	National (Europe)
ProdRisk	53	ODS	BU	LP (SDDP)	Usually 5–25 weekly periods	Usually 3–10 years	Local → National
PyPSA	54	I & ODS, PSAT	BU	LP	Hourly	1 year	Local → Continental
RAPSim	55	PSAT	BU	S	Minutes	Multiple days	Local
ReEDS	56	S (& IDS)	BU	LP & PE	[g]	2050	[h]
ReMIND	57	S	H	NLP	[i]	2150	Global (11 regions)
REMix	58	I & ODS	H	LP	Hourly	Typically 1 year	Regional (Germany) → National (Europe)
renpass	59	ODS, S	BU	S (In) & O (Op)	Typically Hourly	1 year	Regional/National (Western Europe)
RETScreen	60	IDS, S	H	S	Monthly/Yearly/Daily	Max 100 years	Single-system → Global
SAM	61	IDS	BU	S	Sub-Hourly	1 year (/Lifetime for e.g. batteries + PV)	Single system
SIMPOW	62	PSAT	BU	S	Milliseconds	Seconds	Single-system → Local
SIREN	63	S	BU	S	Hourly	1 year	Regional/National
SNOW	64	S	H	CGE	Yearly	UD (1–100 years)	[j]
stELMOD	65	ODS	BU	MIP	Hourly	1 year	National (Europe)
SWITCH	66	I & ODS	BU	MIP	Hourly Dispatch/Decadal Investment Period	UD (2050)	Regional/National[k]
Temoa	67	S	BU	LP	Yearly (With UD time-slices)	UD	Regional (UD)
TIMES	68	I & ODS	H/BU	LP/MIP, PE	Multiple years - with UD time-slices within a year	Long-term (UD)	Local - Global
TIMES-Norway	69	S, IDS (& ODS)	BU	LP	Multiple years – 260 time-slices per year	2050	Norway (Sweden optional)
TIMES-Oslo	70	S, IDS (& ODS)	BU	LP	Multiple years – 260 time-slices per year	2050	Oslo (Norway optional)
TRNSYS18	71	PSAT	BU	S & L/NLP	0.01 s to 1 h	Multiple years	Single Project → Local
urbs	72	I & ODS	BU	LP	UD (Hourly)	UD (Yearly)	Local → National
WEM*	73	S	H	S	Yearly[l]	2040	Global (25 Regions)
WeSIM	74	I & ODS	H	LP	Hour or half-hourly	1 h – multi years	National → Continental
WITCH	75	S, IDS	H	NLP, E	5 years	150 years	Global (13 regions (UD))

[a] The model includes stochastic optimisation (Stochastic Dynamic Programming (SDP)), linear programming and simulation. In the strategy evaluation, SDP is used to calculate incremental water values and heuristics is used to treat the interaction between areas. In the simulation part of the model, total system costs are minimised in a linear problem formulation.

[b] In the strategy evaluation the resolution is weekly. In the simulation it can be weekly with a load-duration curve within the week or with hourly resolution.

[c] Analytical optimisation [69].

[d] 30 min (Load flow analysis), Usually Milliseconds (Fault Level & Transient Stability). [e] About 1-year (Load flow), Fault levels (hundreds of milliseconds), Transient (seconds).

[f] Optimisation (Mixed-Integer, Linear and Non-Linear)/Partial Equilibrium (e.g. solving Nash-Cournot with integer problems uses Mixed Integer Quadratic Programming (MIQP)).

[g] Sequential 2-year periods, 17 seasonal/diurnal blocks of non-chronological aggregate hours. [h] U.S. (+ Canada & Mexico) – (134 Supply/demand balancing areas (+ 20 CA/+ 49 ME) & 356 renewable resource regions (+ 47 CA/+ 49 ME).

[i] 5 years until 2060, 10 until 2110, 20 until 2150.

[j] Global version: Flexible, typically 2–10 regions, National version: Norway and rest of the world.

[k] Models typically have 1–50 load zones; models have been created for California, Western U.S., Hawaii, Chile, Nicaragua, China and other regions.