Lecture – 12

Power Flexibility

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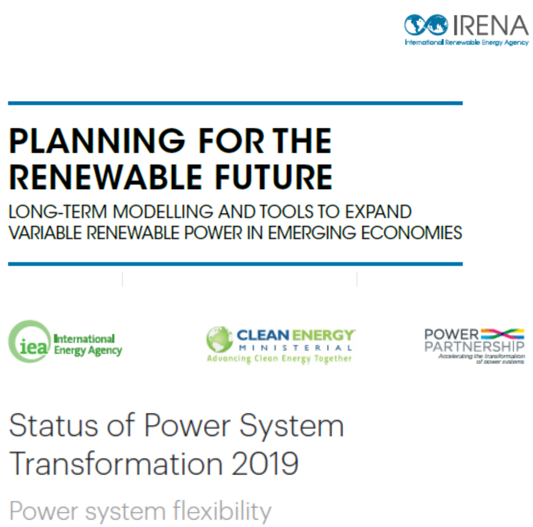
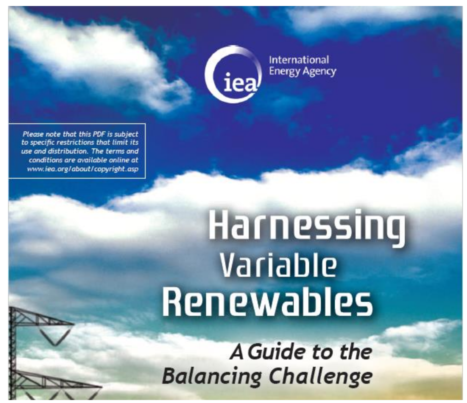
Magister Teknik Sistem Energi

Outline

- Fleksibilitas Sistem
- Pemodelan Sistem Energi dan Fleksibilitas
- Grid-side Flexibility
- Demand-side Flexibility
- Penyimpanan Energi
- *Sector Coupling*

Reference(s)


IRENA
International Renewable Energy Agency
PLANNING FOR THE RENEWABLE FUTURE
LONG-TERM MODELLING AND TOOLS TO EXPAND VARIABLE RENEWABLE POWER IN EMERGING ECONOMIES
International Energy Agency
CLEAN ENERGY MINISTERIAL
Advancing Clean Energy Together
POWER PARTNERSHIP
Status of Power System Transformation 2019
Power system flexibility


International Energy Agency
Harnessing Variable Renewables
A Guide to the Balancing Challenge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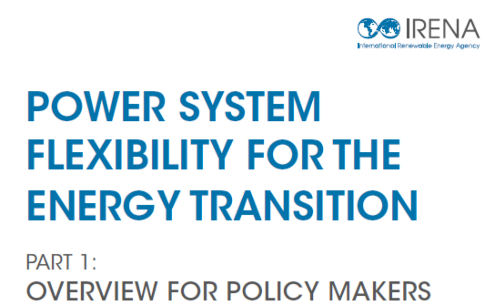
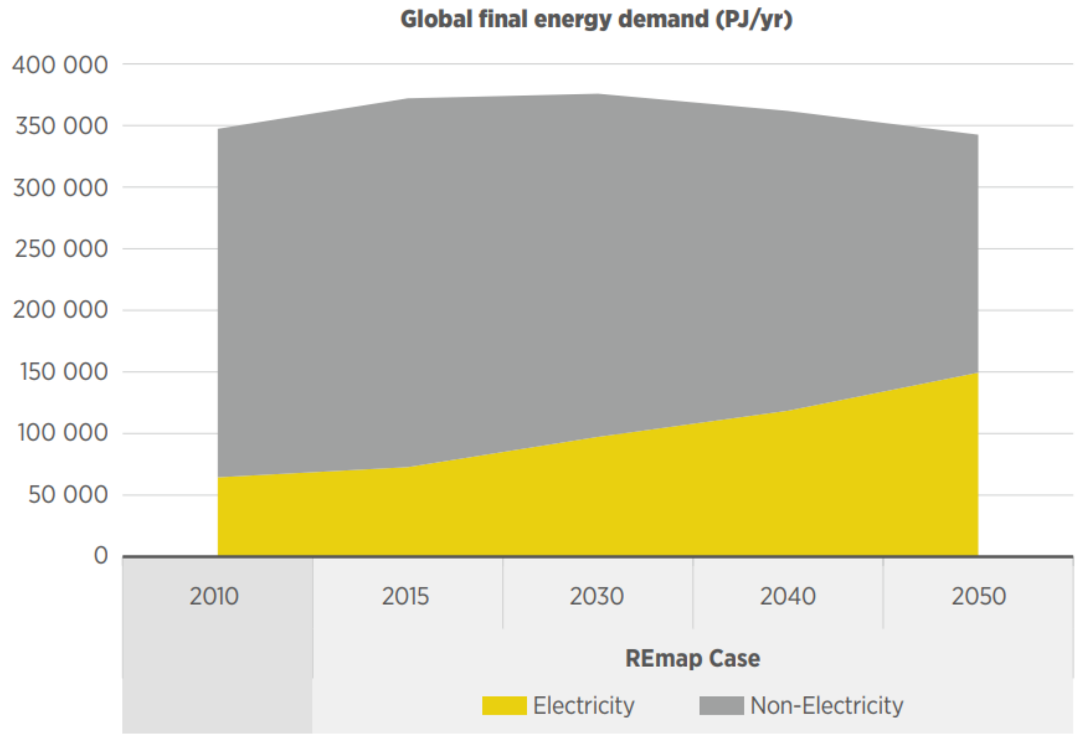
ELSEVIER
Long-term energy system planning considering short-term operational constraints
Ankita Singh Gaur, Partha Das, Anjali Jain, Rohit Bhakar, Jyotirmay Mathur


Power Transmission & Distribution Systems
Flexibility needs in the future power system
Discussion paper
Emil Hillberg (RISE)
Antony Zegers (AIT), Barbara Herndler (AIT), Steven Wong (NRCan), Jean Pompee (RTE), Jean-Yves Bourmaud (RTE), Sebastian Lehnhoff (OFFIS), Gianluigi Migliavacca (RSE), Kjetil Uhlen (NTNU), Irina Oleinikova (NTNU), Hjalmar Pihl (RISE), Markus Norström (RISE), Mattias Persson (RISE), Joni Rossi (RISE) & Giovanni Beccuti (ETHZ)
ISGAN Annex 6 Power T&D Systems
March 2019


IRENA
POWER SYSTEM FLEXIBILITY FOR THE ENERGY TRANSITION
PART 1:
OVERVIEW FOR POLICY MAKERS

Energy Transition

- Keeping the global temperature rise below 2 degrees Celsius requires energy transition from fossil fuels to renewable energy and large-scale electrification of end-use sectors.



(IRENA, 2018)

Energy Transition

- A fully decarbonized electricity sector is the essential foundation of a net zero energy system.
- Electricity is at the heart of modern economies, and its share of final energy consumption is projected to rise from 20% today to 40% by 2050 in the Net Zero Emissions by 2050 Scenario as electricity demand increases rapidly to decarbonize end-use sectors.
- The share of renewable energy in the power sector would need to more than triple compared to current levels.

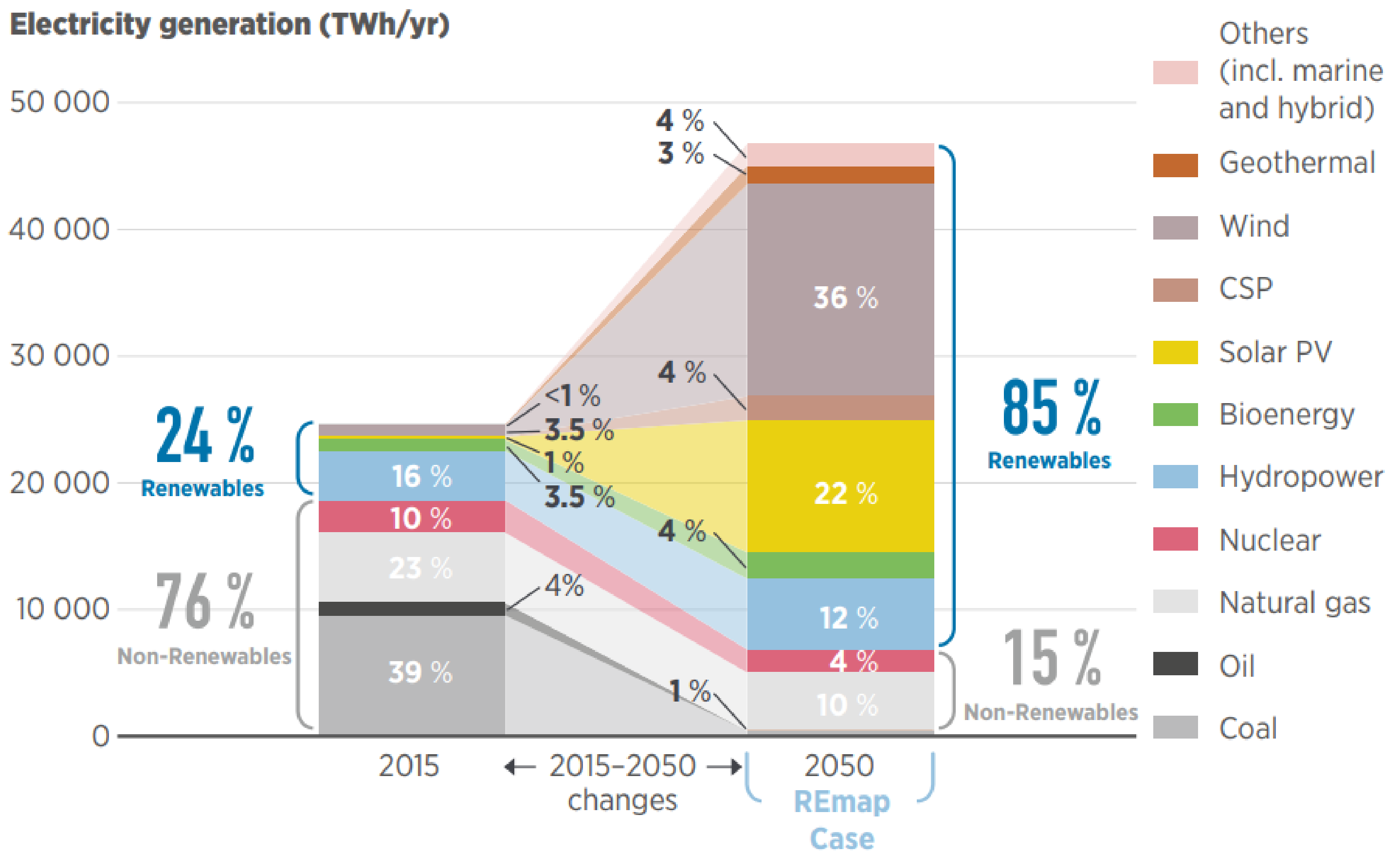
(IRENA, 2018)
Electricity - Energy System - IEA

Energy Transition

- Variable Renewable Energy (VRE) refers to renewable energy sources whose output depends on environmental conditions that change over time.
- One of the key characteristic of VRE is non-dispatchable: Cannot be turned on or off at will to meet demand.
- VRE sources are wind, solar photovoltaics (PV), run-of-river hydropower, ocean energy and concentrated solar power (CSP) without thermal storage.
- Variable renewable energy (VRE) sources such as solar and wind will account for 60 % of total electricity produced.
- Many countries will need to gradually transform their power systems to cater for more VRE.

(IRENA, 2018)
Electricity - Energy System - IEA

A 2-degree Celsius scenario for electricity generation, REmap Case, 2015–2050



(IRENA, 2018)

Fleksibilitas Sistem

Evolusi Sistem Energi

Flexibility is needed

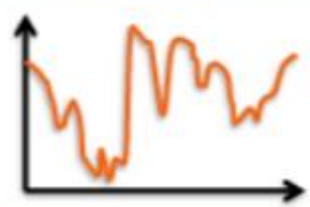
- Fluctuating production
- Forecast errors


Old-fashioned infrastructure

- Networks are designed for centralized production


New possibilities

- Smarter and more efficient ways to manage energy

Conventional → production
non conventional → prod + consumed E

Fleksibilitas Sistem

"Sejauh mana **sistem** tenaga dapat **memodifikasi produksi atau konsumsi listrik** dalam **menanggapi variabilitas**, yang diharapkan atau sebaliknya. Dengan kata lain, hal tersebut mengekspresikan kemampuan sistem tenaga untuk **mempertahankan pasokan** yang dapat **diandalkan** dalam menghadapi ketidakseimbangan yang cepat dan besar, apa pun penyebabnya" (IEA, 2011)

Fleksibilitas tidak memadai

↓

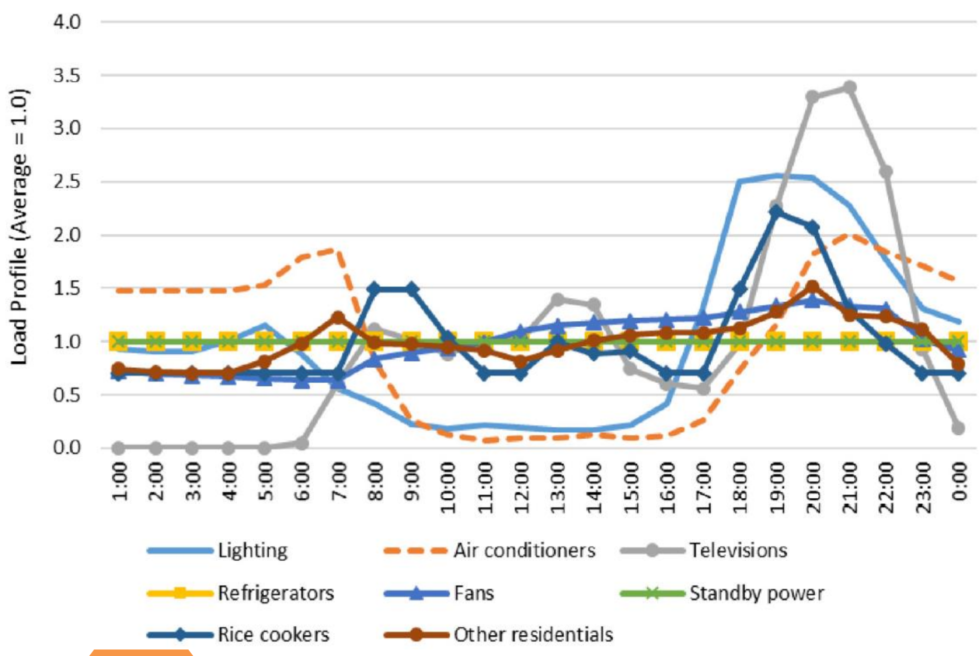
Load shading dan/atau VRE *curtailment*

↓

Biaya meningkat karena kebutuhan kapasitas untuk memenuhi beban puncak

(IRENA, 2019)

Variabilitas Permintaan



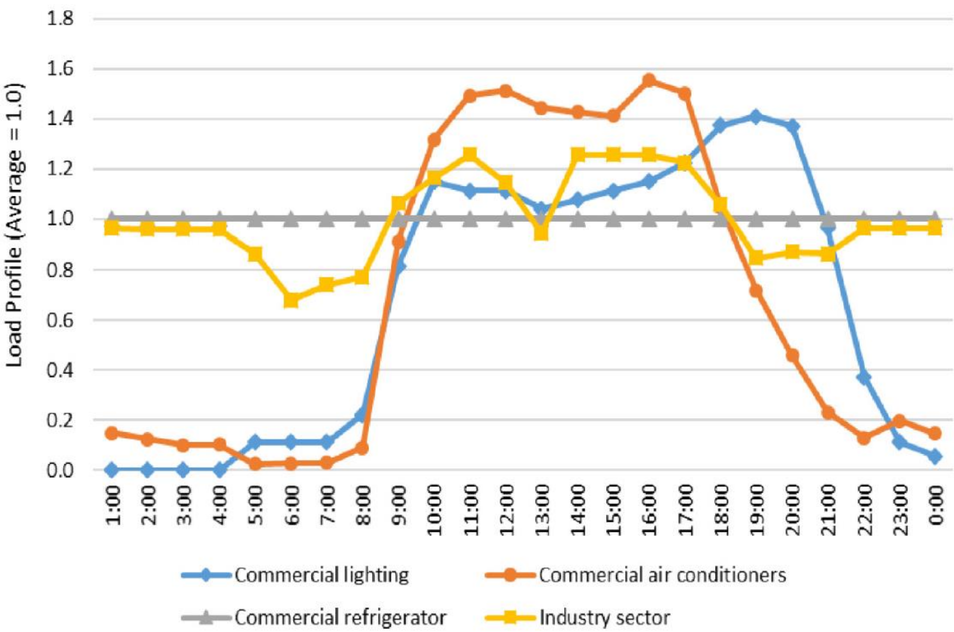
Profil Beban Listrik Indonesia pada Sektor Rumah Tangga

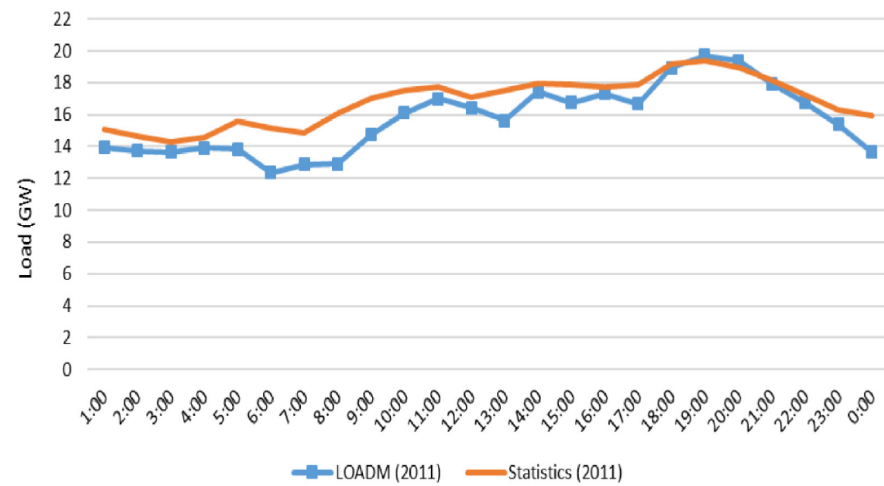
Sistem pasokan konvensional (IRENA, 2018b) :

- Variabilitas terjadi pada sisi permintaan
- Ketidakpastian dalam parameter sosio-ekonomi
- Kesalahan dalam memprediksikan kebutuhan energi

Michael A. McNeil, Nihan Karali, Virginie Letschert. Forecasting Indonesia's electricity load through 2030 and peak demand reductions from appliance and lighting efficiency. Energy for Sustainable Development 49(7):65-77.

Variabilitas Permintaan





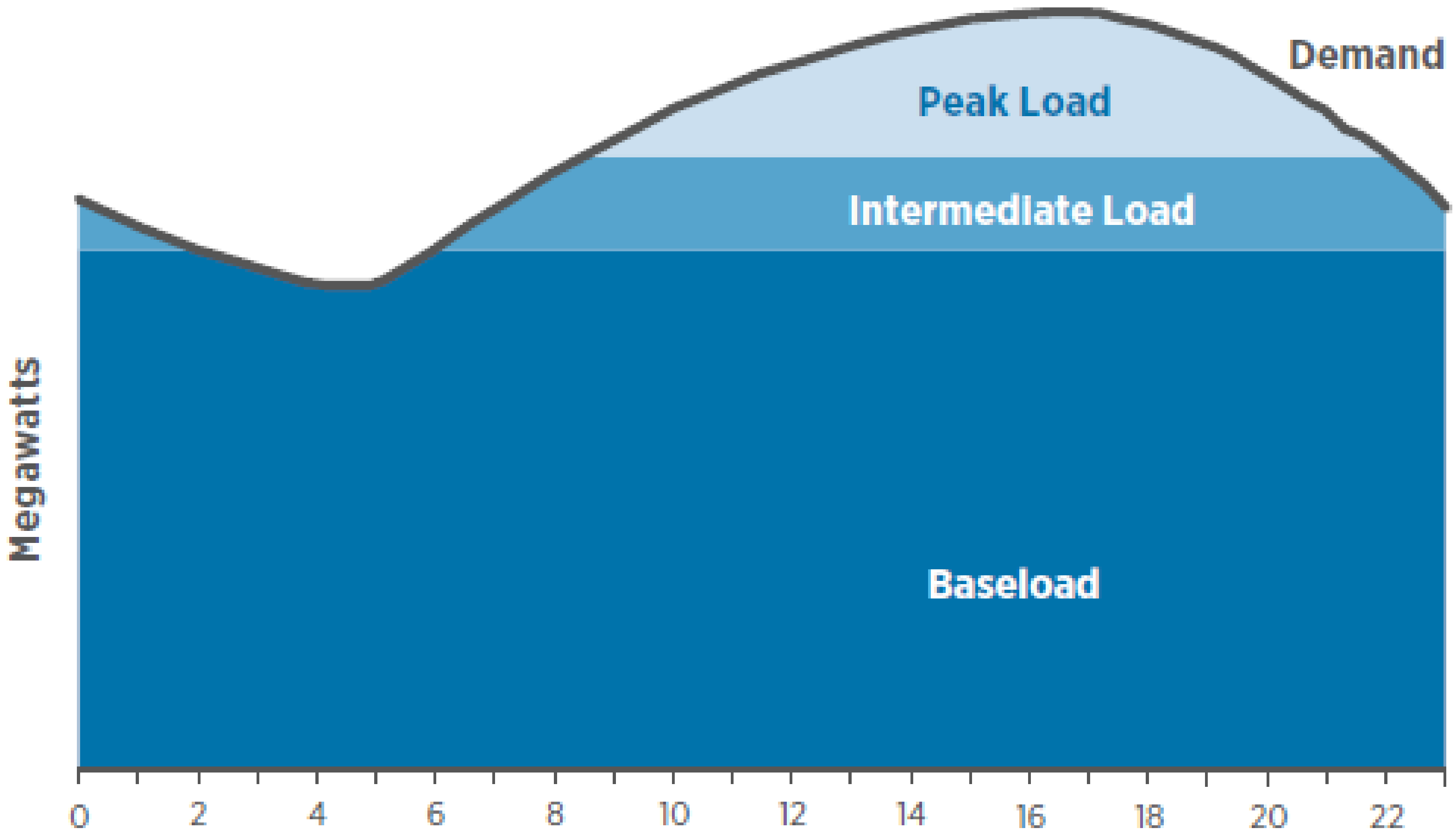
Profil Beban Listrik Indonesia pada Sektor Komersial dan Industri

Kurva Beban Harian Sistem Jamali

Comparison of typical daily load curve of Java-Bali system in 2011, modeled with LOAD curve Model (LOADM) vs. actual statistics (Batih & Sorapipatana, 2016).

Michael A. McNeil, Nihan Karali, Virginie Letschert. Forecasting Indonesia's electricity load through 2030 and peak demand reductions from appliance and lighting efficiency. Energy for Sustainable Development 49(7):65-77.

Sistem Pasokan Listrik Saat Ini



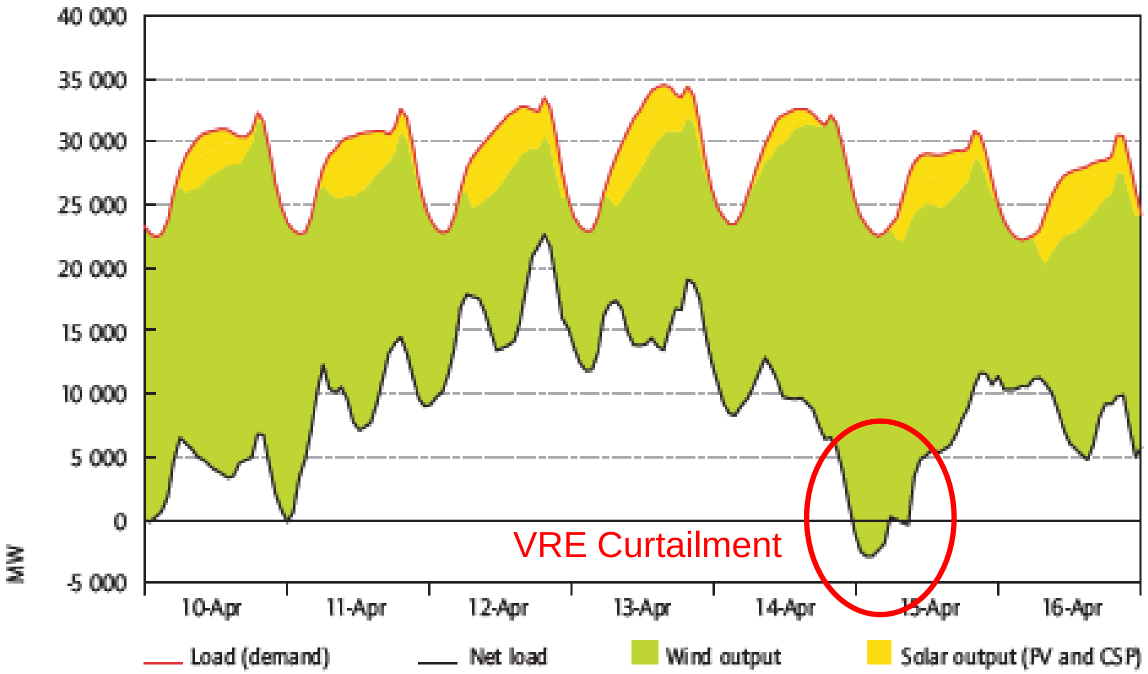
Load on Grid

- Load is the amount of electricity on the grid at any given time, as it makes its journey from the power source to all the homes, businesses and industries within a utility's territory.
- Baseload is the minimum load on the grid over any given period, peak demand is the maximum load.
- Baseload units are able to generate **large amounts** of energy at relatively **low operational costs**. Typical baseload units include coal, biomass and nuclear power plants, mostly using steam turbines to generate electricity (and, in combined heat and power (CHP) plants, also heat).

Load on Grid

- Peaking generators usually have opposite techno-economic characteristics. They are designed for **flexible operation** with **rapid start-up** and **fast ramping capabilities** and low minimum operational level.
- Peaking units are usually gas turbines (open-cycle gas turbines) and internal combustion generators (internal combustion engines).
- Intermediate units/generators are usually modern combined-cycle gas turbines (which combine gas and steam turbines) and reservoir hydropower units. They can be used to provide either base or peak load.

Sistem Kelistrikan dengan VRE Tinggi

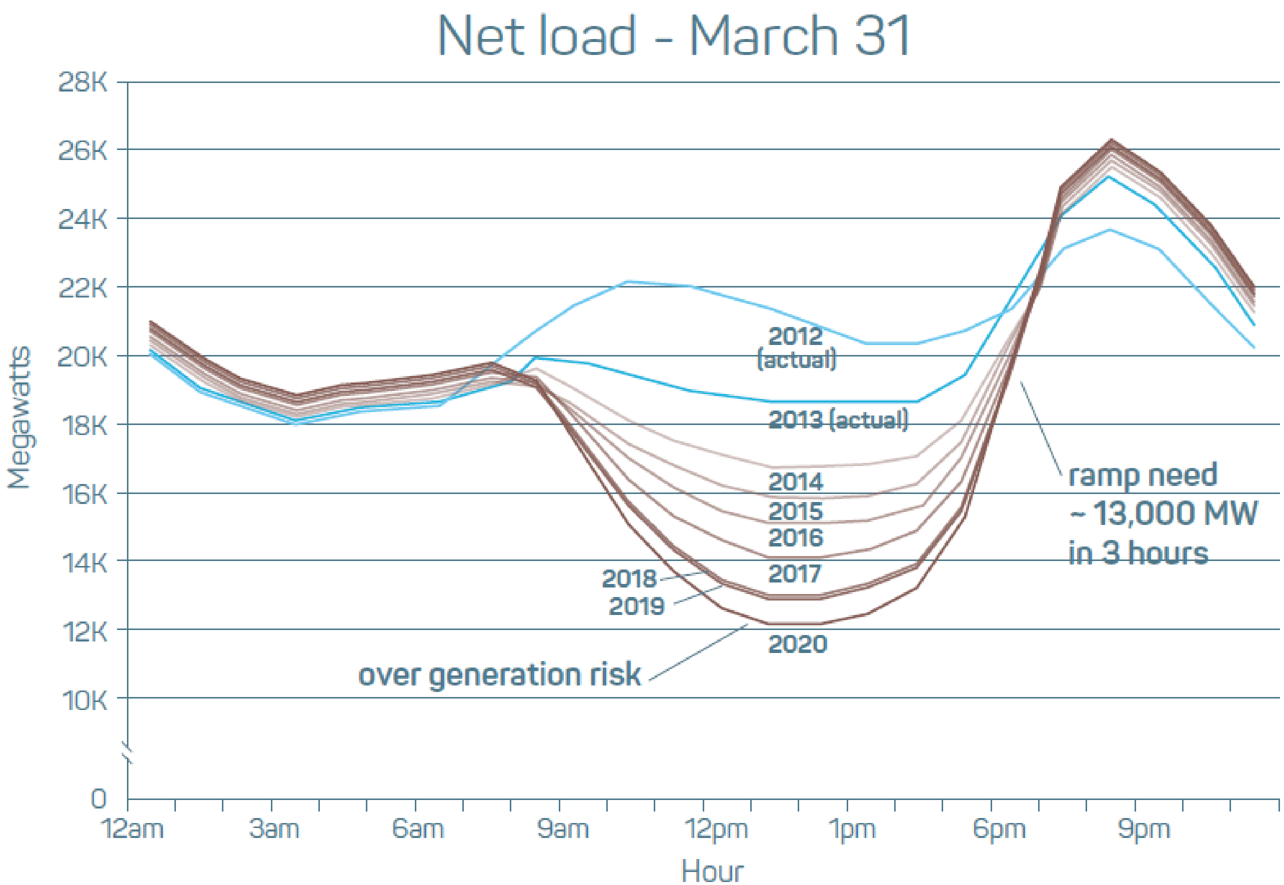


Net load adalah kebutuhan listrik dikurangi dengan produksi listrik yang berasal dari VRE.

Net load ini nantinya akan menjadi informasi penting untuk dihubungkan ke perencanaan jangka panjang sistem kelistrikan.

VRE curtailment: the reduction of renewable energy delivered due to oversupply or lack of system flexibility.

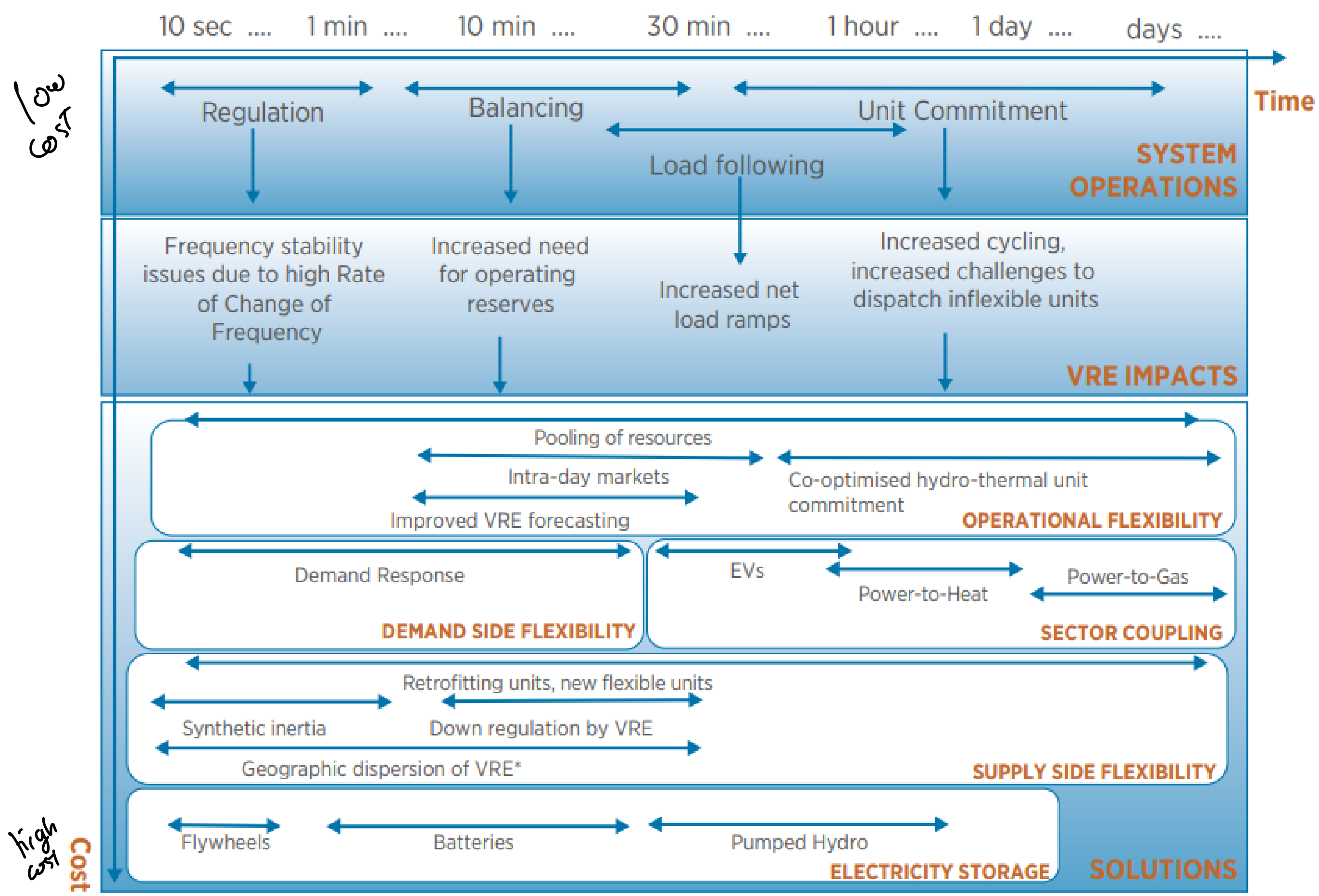
Duck Curve



Adapted from NREL (2015)

Sources of Flexibility

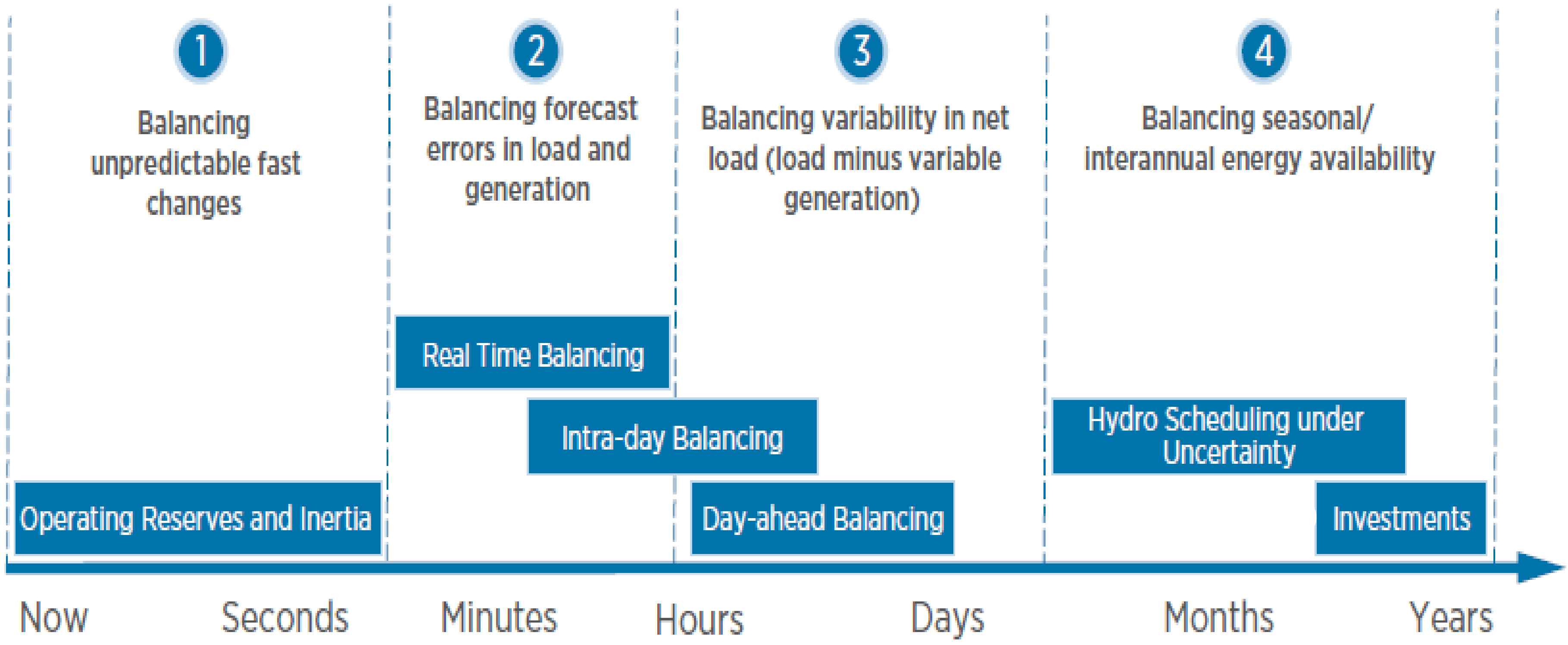
Figure 8: Impacts of VRE at various time scales and relevant flexibility solutions



World Bank (2015) as cited in IRENA (2018)

Operational Flexibility

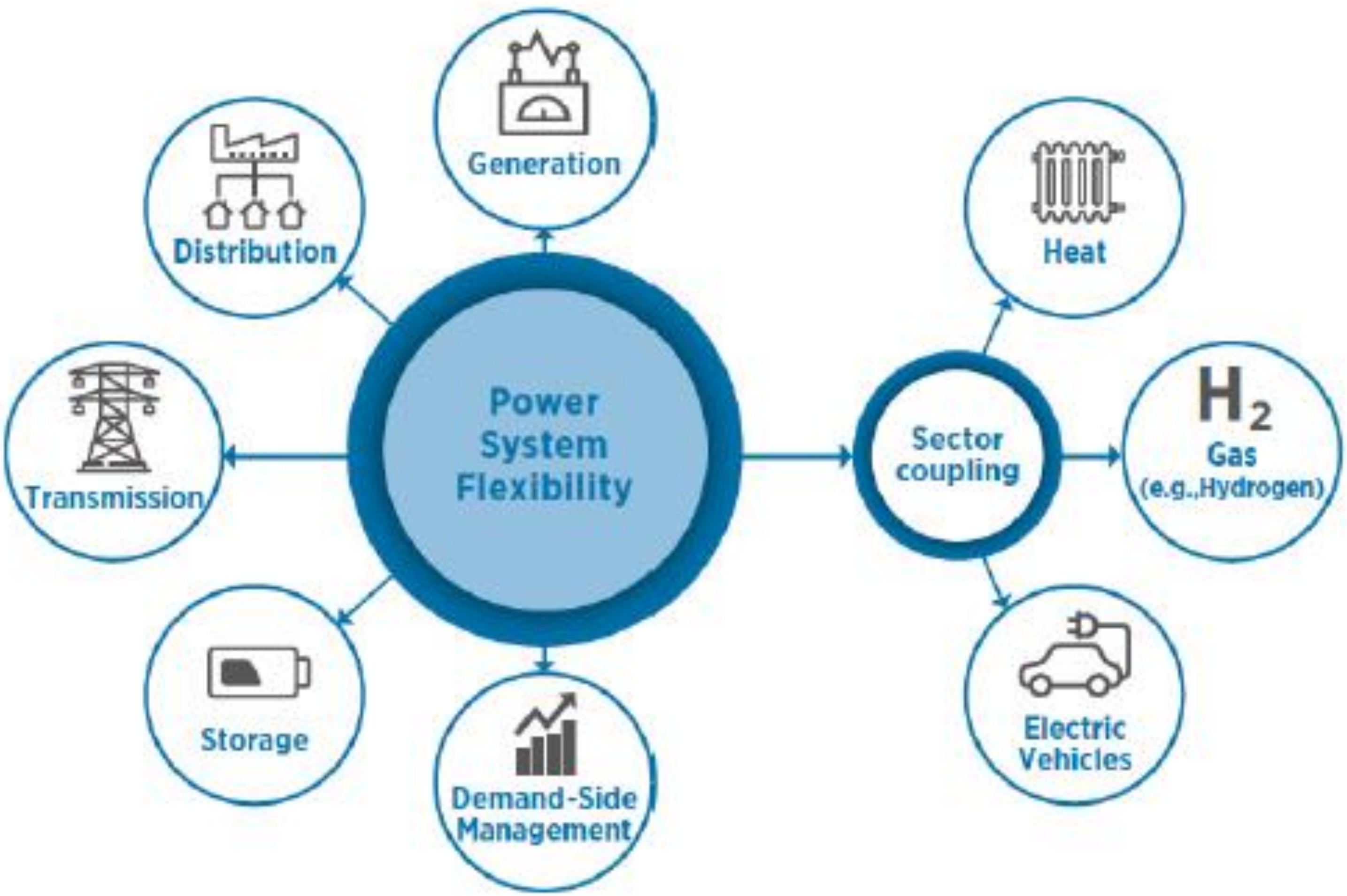
Different time scales in which flexibility has to be analyzed.



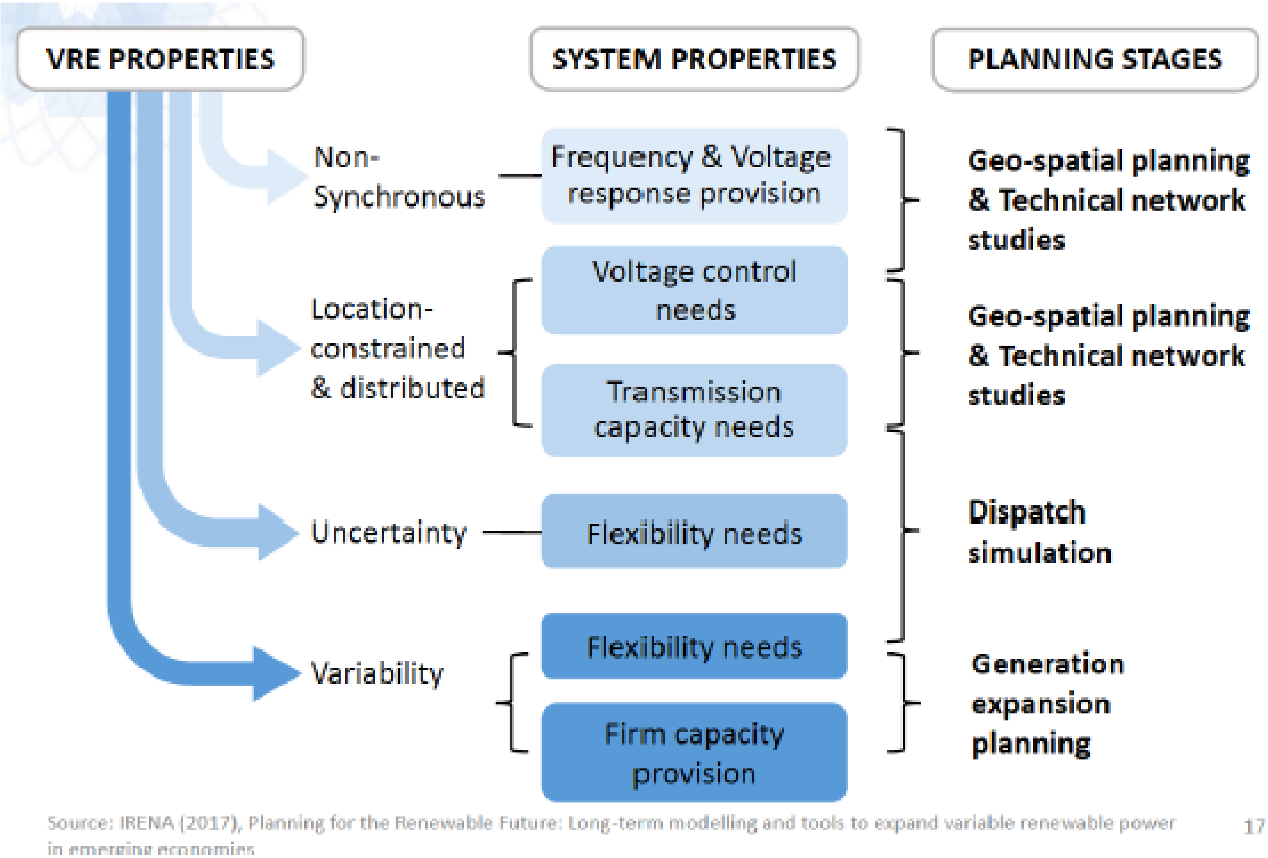
Operational Flexibility

- Operational flexibility refers to how the assets in the power system are operated.
- In **the long to medium term** the system has to balance the seasonal and inter-annual energy variability, which traditionally is achieved with hydro scheduling under uncertainty in systems with significant shares of hydropower.
- In **the medium to short term** the commitment, and the economic dispatch, of generation units should be planned before real-time generation. In this time scale the design of day-ahead and intra-day markets will be relevant to enable the full flexibility potential of the system.
- In the **short to very short term**, ancillary services markets are required to procure grid services, including to compensate sudden imbalances between supply and demand. Here regulators need to define operating reserves in a way that flexible resources are incentivized to participate. For example in UK, fast frequency response (FFR) that can be supplied by batteries and VRE if the proper power electronics are in place.

Fleksibilitas Sistem



Fleksibilitas Sistem pada VRE tinggi



Source: IRENA

Key properties of variable renewable energy

1. Due to its weather-dependent nature, VRE is limited in dispatchability (i.e., the ability to control its output) and has **variable** seasonal and diurnal (i.e., within-day) patterns of production.
2. VRE generation can be forecasted, but some **uncertainty** in forecasts remains.
3. VRE is **location constrained**, because its primary energy source cannot be transported, and VRE generators normally are built where the resources they need are good. These places may be far from centres of demand.

Key properties of variable renewable energy

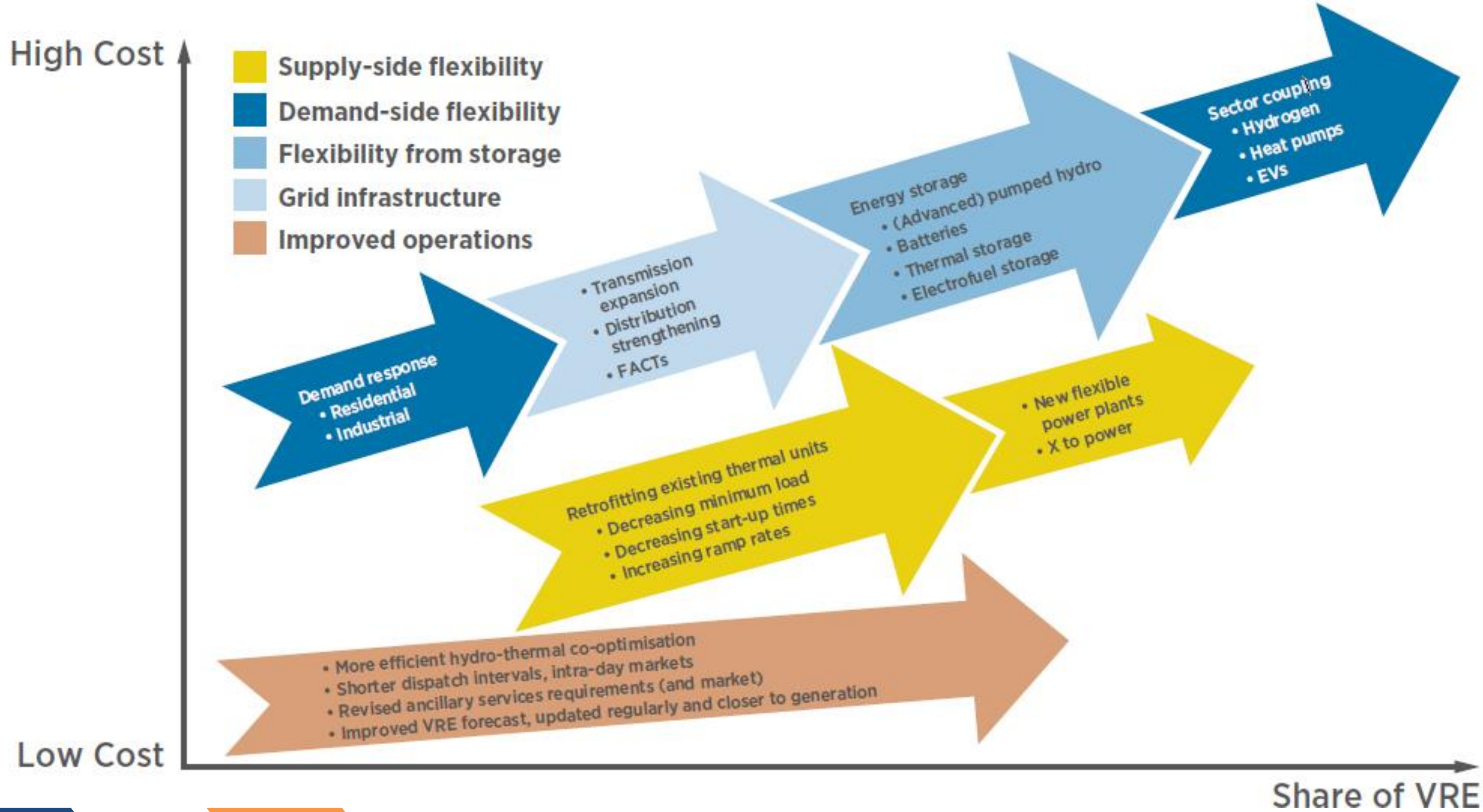
4. VRE resources are considered **non-synchronous power** sources (i.e., sources that have a power electronic interface with the grid, rather than a rotating mass that is directly connected). Under certain circumstances, they may pose challenges to the maintenance of system stability, which traditionally relies on the “inertia” provided by synchronous generators.
5. VRE generators are not necessarily connected to the transmission level of grid infrastructure and thus often feature as **distributed** generation.

Fleksibilitas Sistem – Fleksibilitas Teknis

1. ***Supply-side flexibility*** diperoleh dengan mengurangi ketidakpastian dalam pasokan VRE dan meningkatkan fleksibilitas dari pembangkit konvensional.
2. ***Grid-side flexibility*** diperoleh dari *ancillary service* dan pembangunan jaringan transmisi dan distribusi listrik yang terinterkoneksi dan memiliki cakupan wilayah yang besar
3. ***Demand-side flexibility*** diperoleh dengan sistem energi yang terdistribusi, elektrifikasi dari sektor pengguna seperti transportasi, komersial, dan industry, *demand side management* (DSM)
4. ***System-wide-side flexibility*** diperoleh dengan pemanfaatan penyimpanan energi dan *sector coupling*.

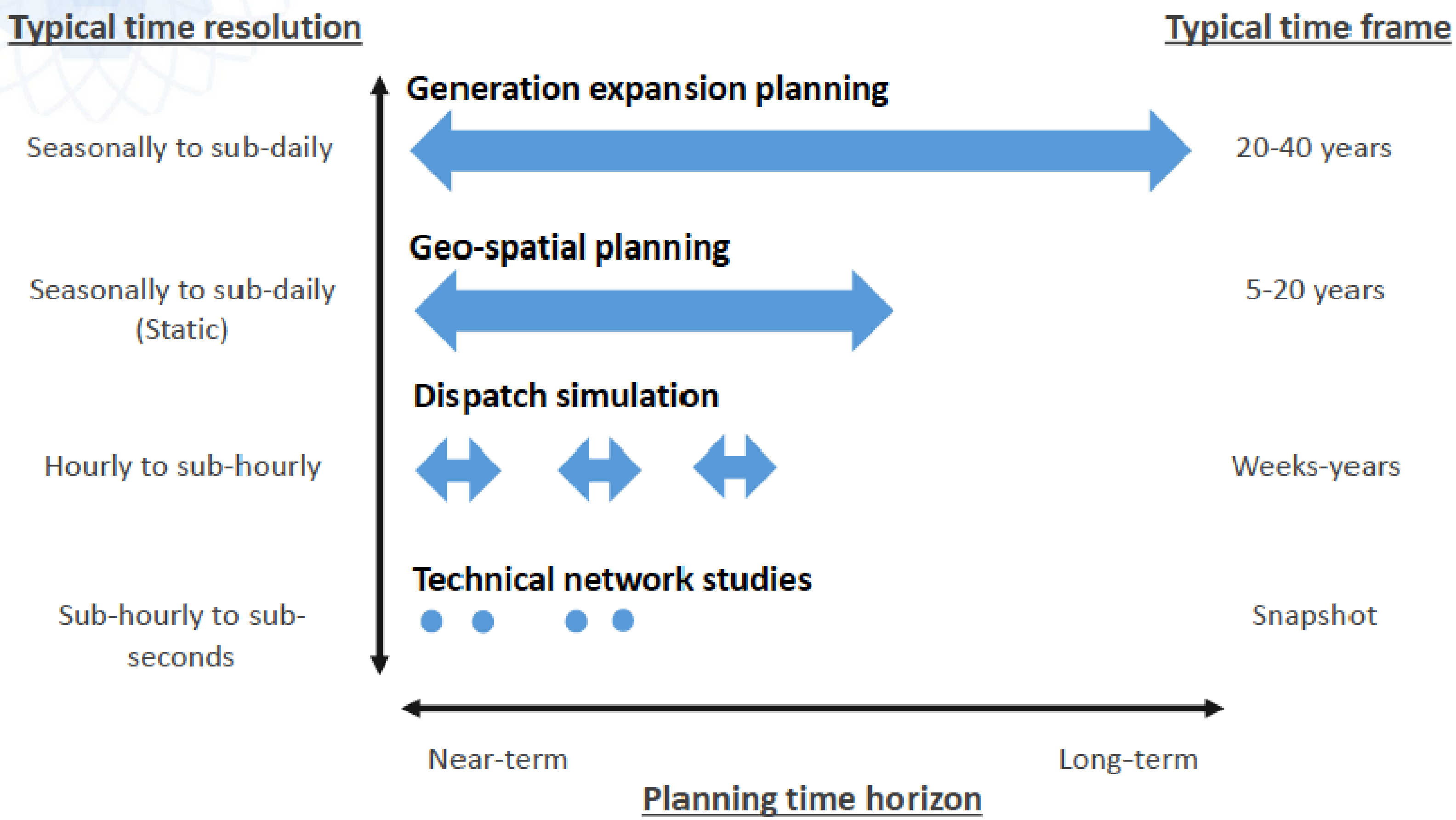
(IRENA, 2019c, Lund et al., 2015, Chen et al., 2020, Moura and de Almeida, 2010)

Pemetaan Fleksibilitas Sistem berdasarkan Biaya dan Penetrasi VRE



Pemodelan Sistem Energi dan Fleksibilitas

Perencanaan Sistem Kelistrikan



Perencanaan Sistem Kelistrikan

- The planning time horizon, which refers to how far in the future the specific planning analysis is relevant;

- The timeframe, which refers to the overall period of time that is subject to techno-economic analysis; and

- The time resolution, which refers to the granularity, or level of detail, of analysis within the timeframe.

Perencanaan Sistem Kelistrikan

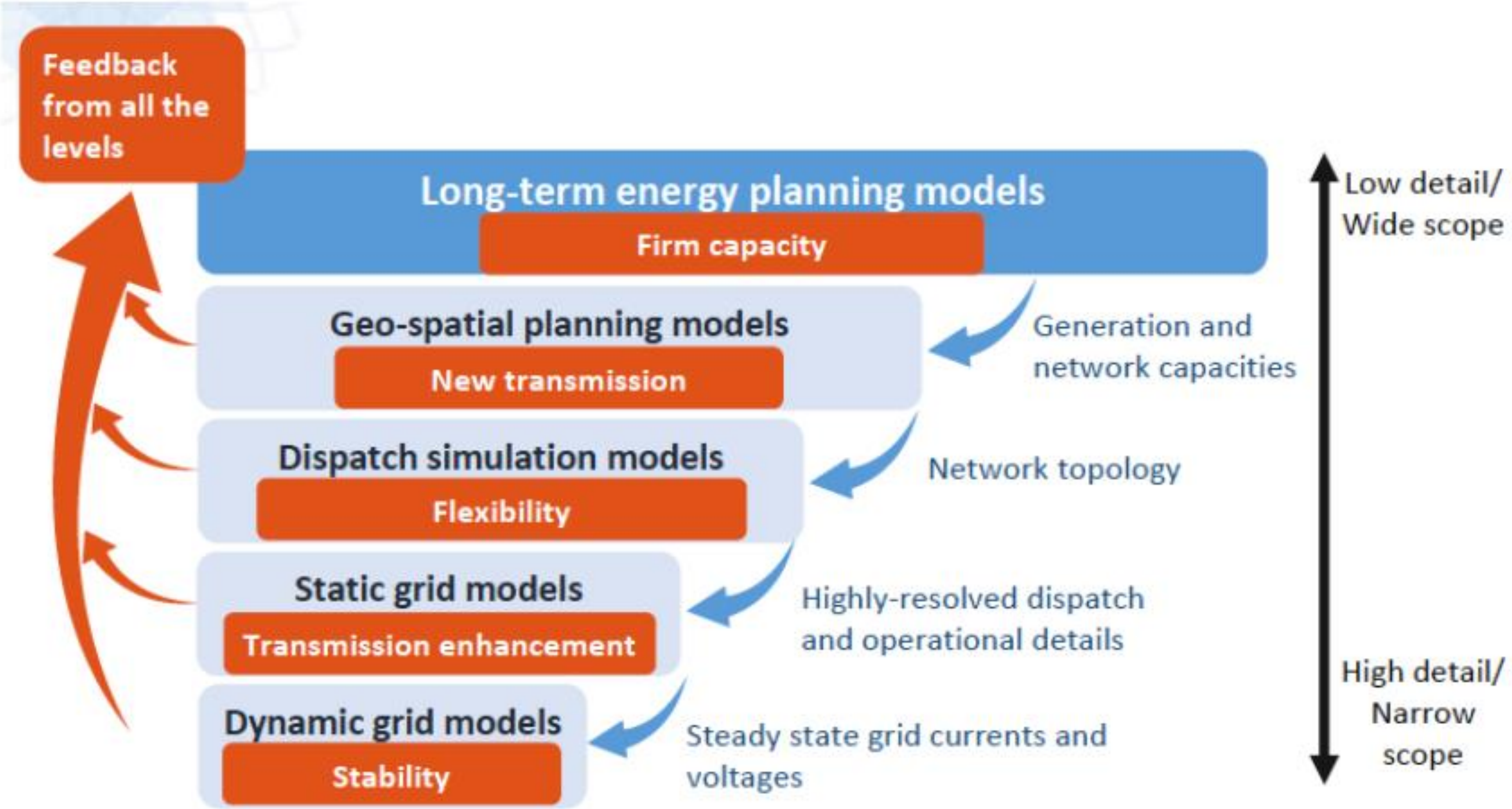
1. Generation expansion planning – typically with a **long planning horizon, 20-40 years** or more. Such plans represent a **broad political commitment** to integrate renewable energy and are often linked with long-term targets. Balancing costs, environmental impact, and grid reliability using models like capacity expansion models (e.g., PLEXOS, TIMES).

2. Geo-spatial planning – primarily **addresses the site location of VRE projects** and **the economics of long-term transmission** expansion needs over 5-20 years or more. Geographic Information System (GIS) software is commonly used to overlay data and visualize optimal placements.

Perencanaan Sistem Kelistrikan

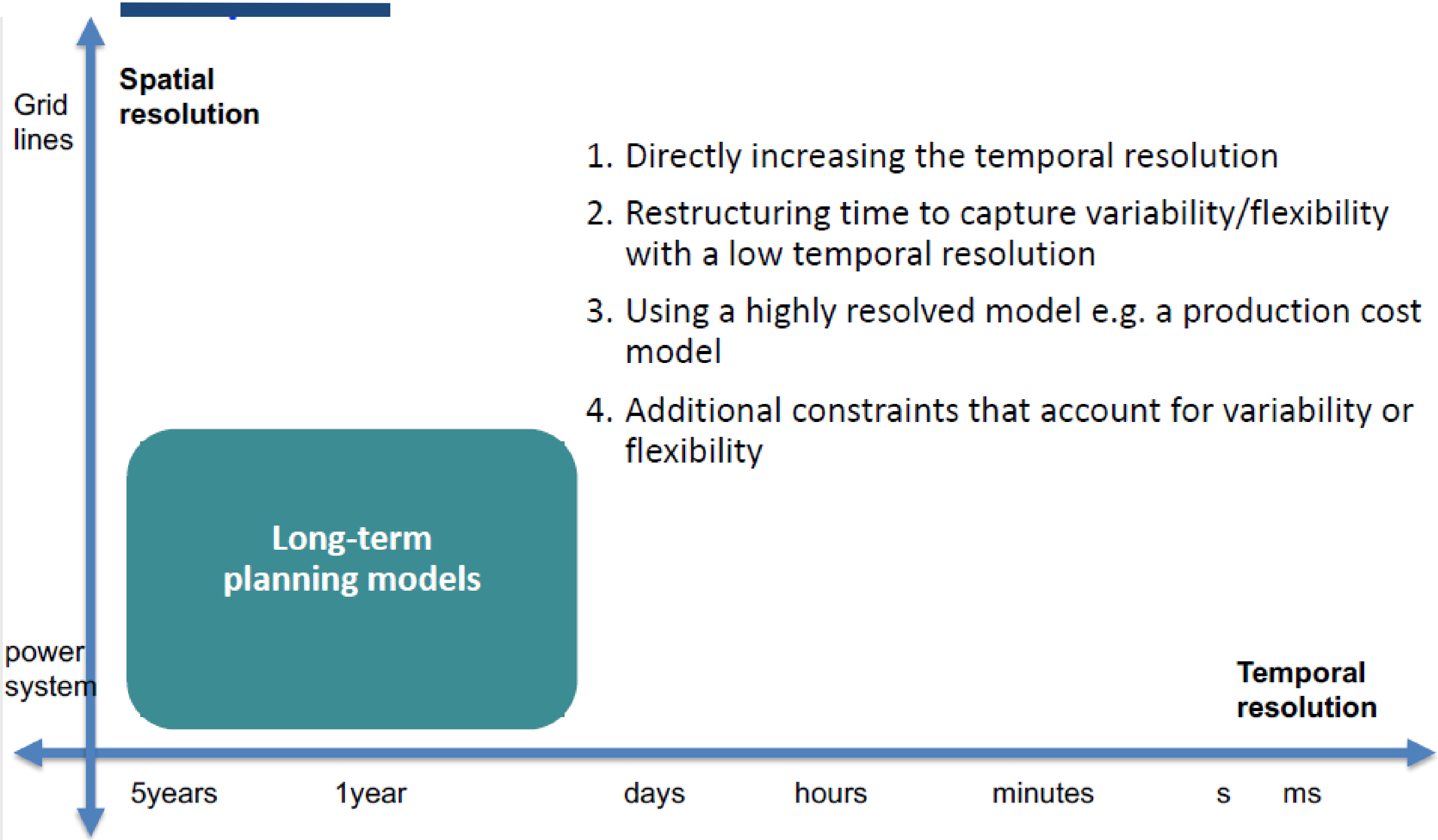
3. **Dispatch simulation** – within a planning timeframe of weeks to a year (or a few years at most) during which the generation capacity mix in an energy system remains constant. It is applied either to a current system or to a system at a future point in time. Tools used are simulation software like PLEXOS, PSSE, or DigSILENT.
4. **Technical network studies** – used for **detailed static or dynamic analysis of a system at a point in time**, and typically applied to the current and near-term (e.g., 5 years) planning horizon, or longer-term for less detailed analysis. It primarily **addresses network security issues so as to identify security bottlenecks in the grid**, such as voltage control and stability. Commonly used software includes PSSE, ETAP, and DIgSILENT.

Fleksibilitas pada Perencanaan Sistem Kelistrikan



Pendekatan dalam Pemodelan

1. Directly increasing the temporal resolution
2. Restructuring time to capture variability/flexibility with a low temporal resolution
3. Using a highly resolved model e.g. a production cost model
4. Additional constraints that account for variability or flexibility



Pendekatan dalam Pemodelan

1. Directly increasing the temporal and spatial resolution
2. Restructuring time to capture variability/flexibility with a low temporal resolution
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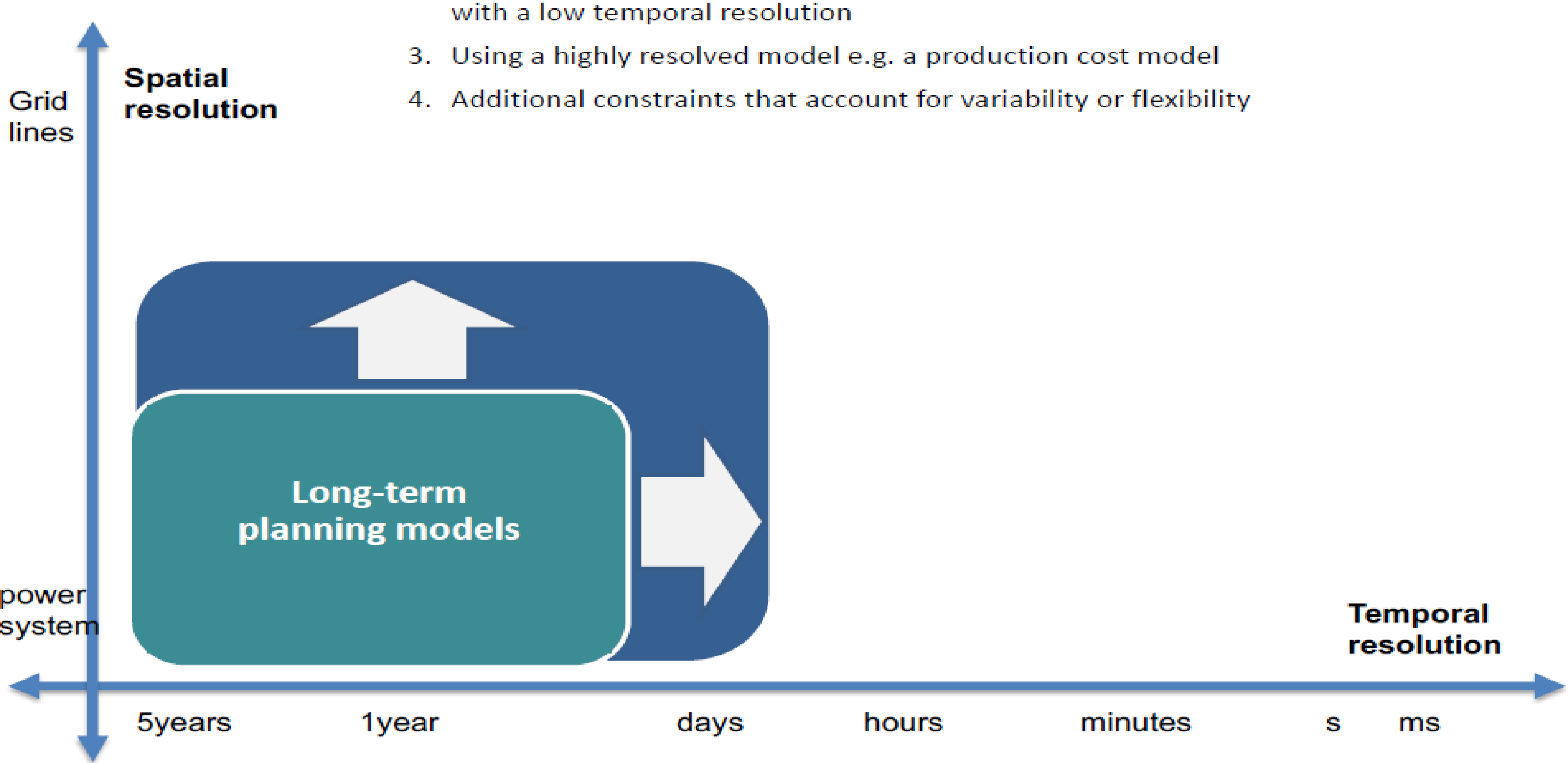

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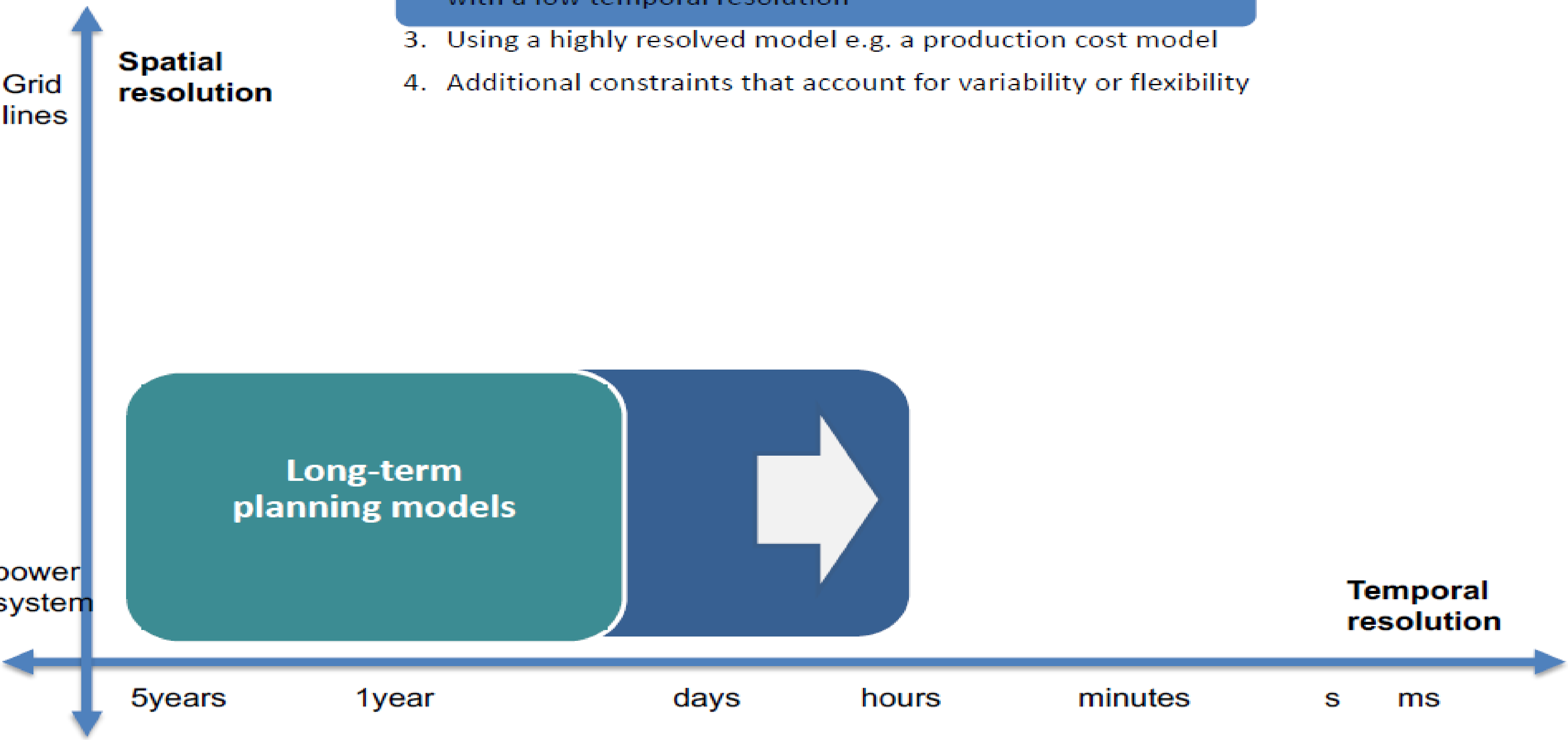
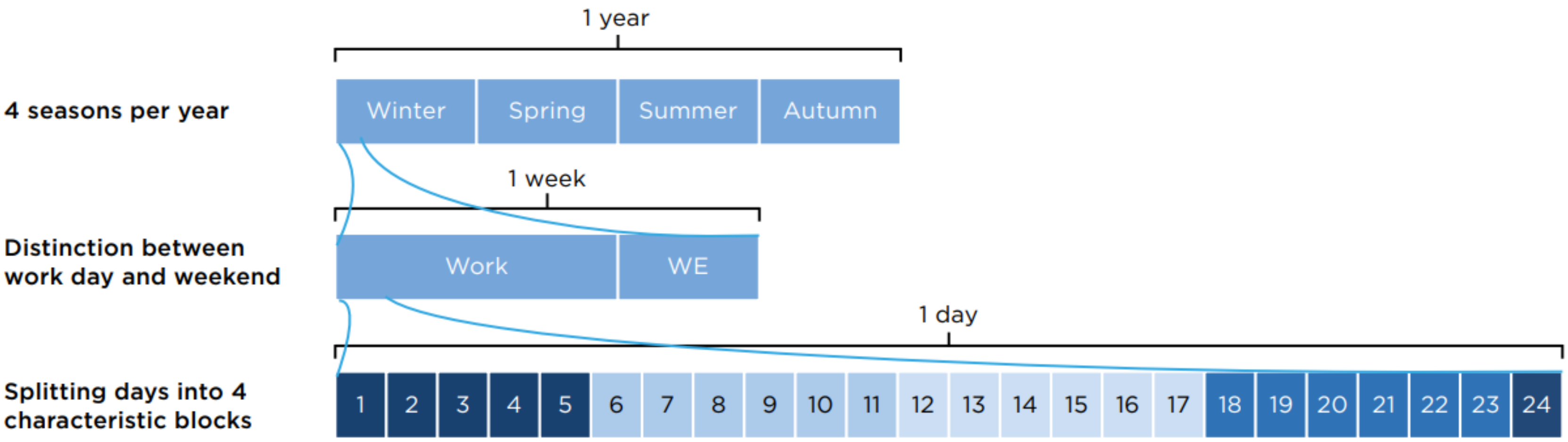


Increasing the Temporal Resolution

In order to represent the variability of demand, the 8 760 hours that make up a year are broken down into time blocks (referred to here as "**time slices**") that capture **seasonal, weekly and daily variations**. A rather small number of representative time slices – typically in the range of 12 to 64 – is used in long-term generation expansion models. To illustrate: seasonal demand variation can be represented by the **four seasons**; weekly demand variation can be represented by two contrasting types of day (**weekdays versus weekends**); and daily variation can be represented by **four** six-hour blocks – totaling 32 time slices



Increasing the Temporal Resolution

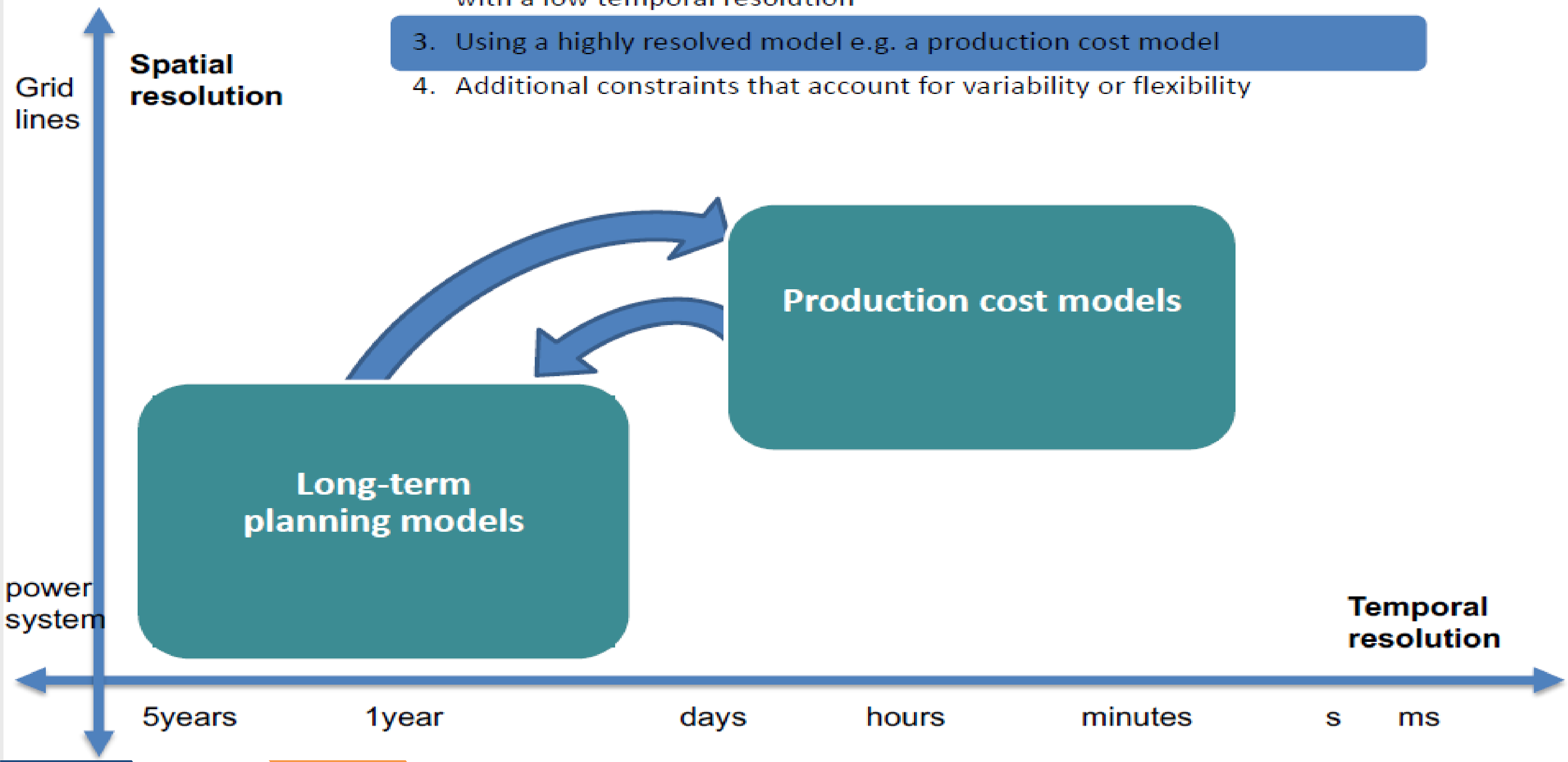
- When VRE is only a negligible part of the power system, such time slices are defined primarily according to the variability of demand.
- As VRE increasingly penetrates the system, however, models need to capture the variability of its supply as well. <u>Insufficient capture of the variability of supply could lead to a sub-optimal or even an inadequate capacity mix</u>, as the costs linked with periods of VRE over- or underproduction are insufficiently represented, and the need for flexibility in the system may be underestimated.

Increasing the Spatial Resolution

- The entire geographical area of these models is often divided into multiple sub-regions, allowing the spatial distribution of load, VRE resources and non VRE resources to be reflected. These sub-regions are represented in generation expansion models as **nodes**, which are associated with the aggregated demand of a given sub-region.
- Models with **multiregional nodes** can provide a first-order approximation of the quantity and cost of the expansion of transmission that would be needed to accommodate increasing levels of VRE.

Pendekatan dalam Pemodelan

1. Directly increasing the temporal and spatial resolution
2. Restructuring time to capture variability/flexibility with a low temporal resolution
3. Using a highly resolved model e.g. a production cost model
4. Additional constraints that account for variability or flexibility



Production Cost Model

- **Production cost models** simulate decisions on economic unit commitment and dispatch at hourly time resolutions or less, typically over a timeframe of one year.
- Production cost models have been used to validate, and in some cases to correct, results from long-term **generation expansion models** to complement their inherent limitations in time resolution (and the level of operational detail linked with it). Such an approach – often referred to as a "**coupling**" approach.

Production Cost Model

- Most “coupling” attempts are unidirectional (i.e**., from long-term generation expansion models to production models**) and are aimed primarily at validating improved features of long-term generation expansion models (e.g., through imitating some of the operational constraints, with higher time resolution).

Production Cost Model

- Ireland (**Deane et al., 2015**): In this study, soft-linking methodology is applied to the Irish **TIMES** model (a generation expansion model with 12 time slices in a year), coupling it with a **PLEXOS** model (a dispatch model for the power sector applied with half-hourly temporal resolution). <u>The power sector results – capacity mix and electricity sector demand – are taken from the Irish TIMES model for 2020 and used as inputs to the PLEXOS model</u>. This system is simulated in PLEXOS to calculate the optimal generation mix, which is then compared to the generation mix from the Irish TIMES.

Note: The Integrated MARKAL-EFOM System (TIMES)

Pendekatan dalam Pemodelan

1. Directly increasing the temporal and spatial resolution
2. Restructuring time to capture variability/flexibility with a low temporal resolution
3. Using a highly resolved model e.g. a production cost model
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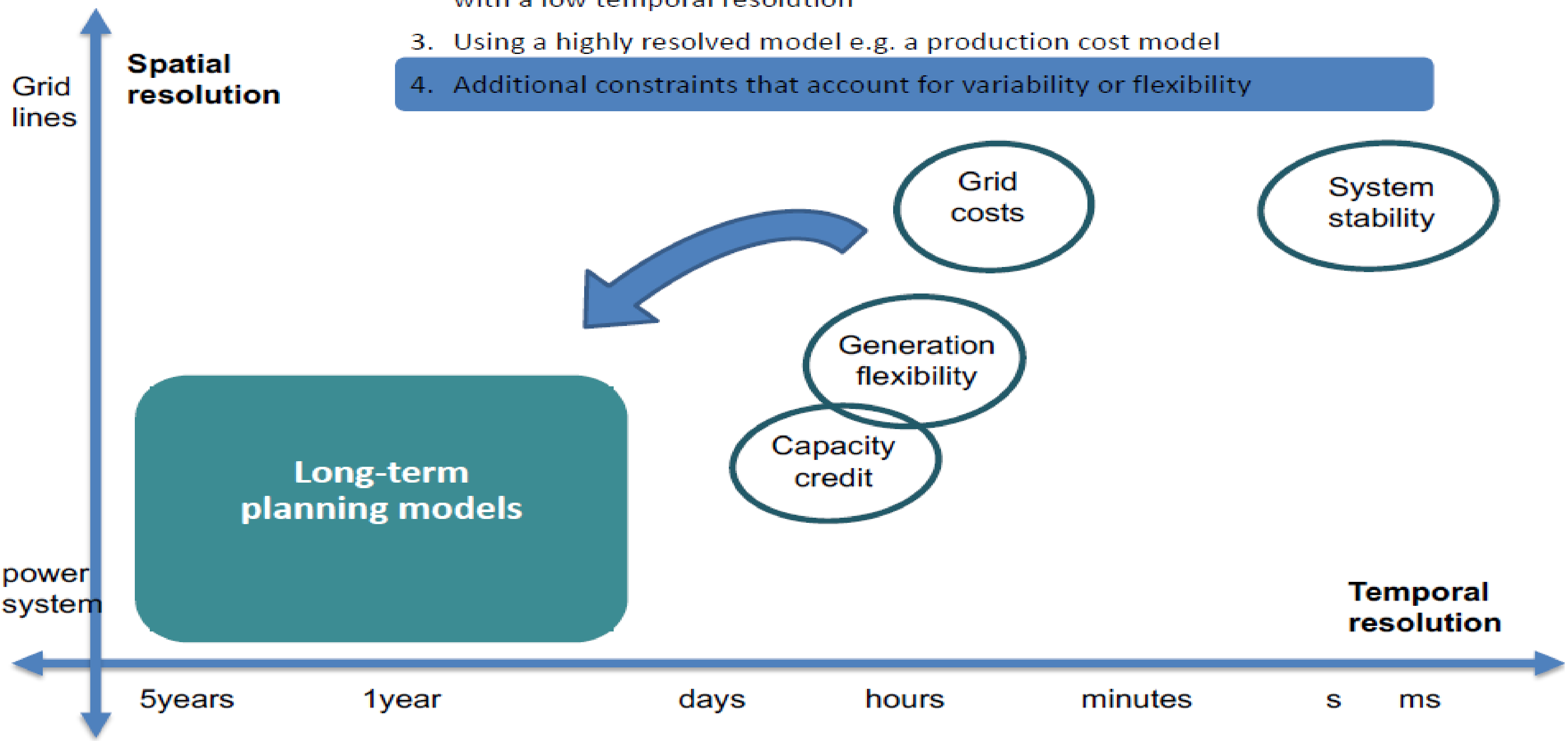


Fleksibilitas Sistem

Supply-side Flexibility

Pembangkit yang fleksibel:

- mampu *ramp-up* dan *ramp-down* secara cepat
- memiliki minimum *load* yang rendah
- memiliki waktu *start-up* dan *shut-down* yang cepat.

Perubahan pembangkit dari *base load* menjadi fleksibel dapat dilakukan dengan cara melakukan retrofit dari pembangkit tersebut.

Menurut Chen et al. (2020) dan Koltsaklis and Georgiadis (2015) perubahan peran dari *baseload* menjadi pembangkit yang fleksibel memilliki potensi tertinggi untuk meningkatkan fleksibilitas sistem dengan biaya teknologi dan tantangan non teknologi yang tidak terlalu tinggi.

Parameter Operasional

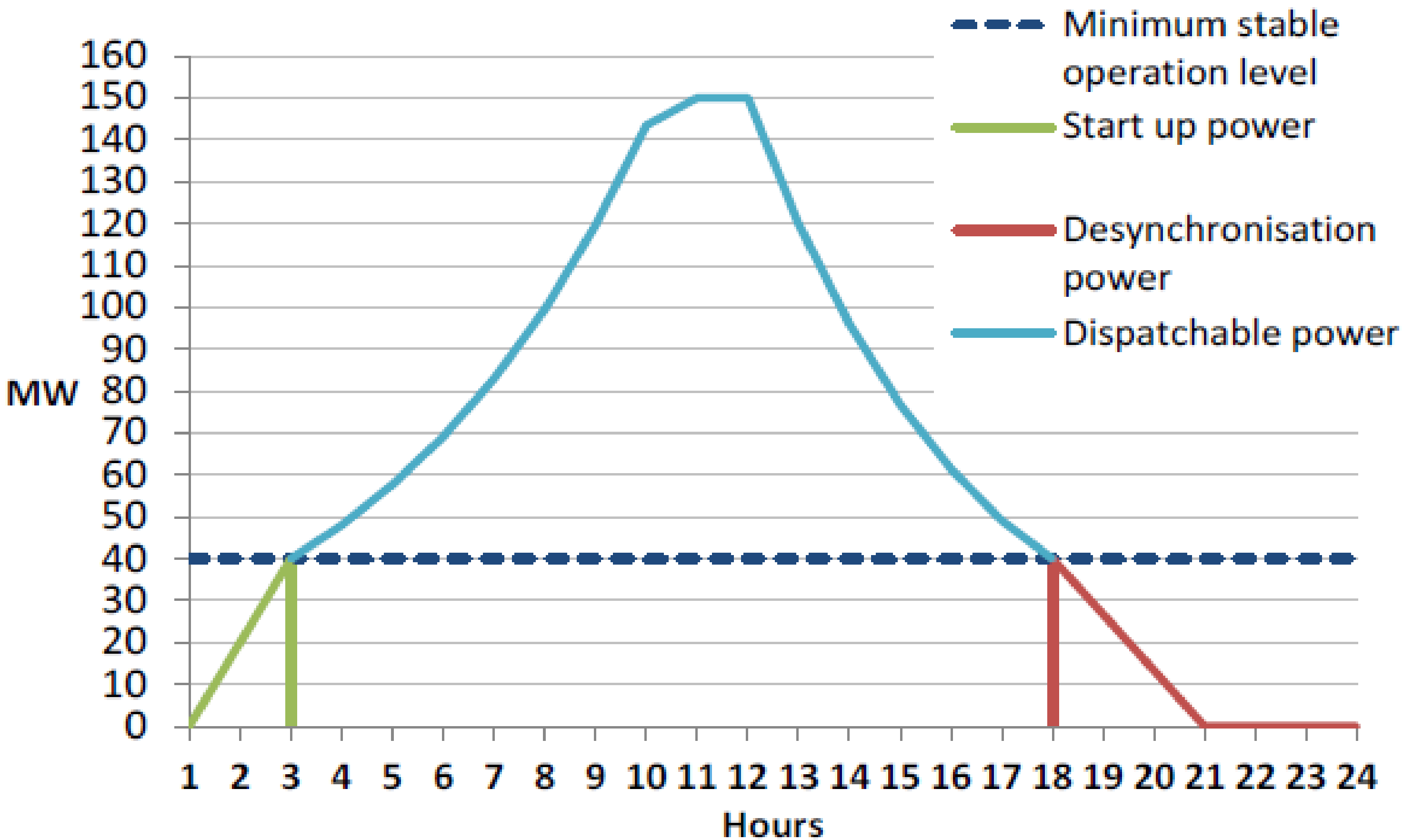
Peninjauan parameter operasional dapat dilakukan dengan meninjau *unit commitment*.

Unit commitment → penentuan strategi operasional yang optimum untuk memenuhi kebutuhan listrik pada biaya terendah.

Teknologi	*Min. Load*	*Min. Time (h)*		*No Load Cost*	*Start Up Cost (USD/GW)*	*Part Load EFF (-)*	*Ramp Rate (% online cap)*
		Offline	*Online*				
Diesel	10%	0.5	0.5			38%	1.0
Sb Coal	40%	8.5	6.0	5259.5	103,711	30%	0.3
Sc Coal	40%	11.0	11.0		-	34%	0.3
USC Coal	40%	4.0	4.0		Ada	47%	0.3
OCGT	10%	3.5	3.5	139.5	281	15%	1.0
Gas Engine	10%	0.5	0.5			35%	1.0
CCGT	40%	2.0	2.0	3488.6	5,938	53%	0.2
Comb.+GT	30%	2.0	2.0	3488.6	5,938	71%	0.2
LG+ICE	30%	2.0	2.0	3488.6	5,938	37%	0.2
AD+GT	30%	2.0	2.0	3488.6	5,938	14%	0.2
Gasif+GT	30%	2.0	2.0	3488.6	5,938	16%	0.2
BECC	30%	2.0	2.0	3488.6	5,938	23%	0.2
EFF = efficiency							

(Sumber: (Green et al., 2014, GHD, 2018, Kumar et al., 2012b, PGE, 2018, Simoglou et al., 2010, Henderson, 2014, Op et al., 2017, Kumar et al., 2012a, IEA, 2011b, Nalbandian and Sugden, 2016, Wakabayashi, 2018, Mohanpurkar et al., 2017, Pratamaa and Dowell, 2019)

Operasional Pembangkit



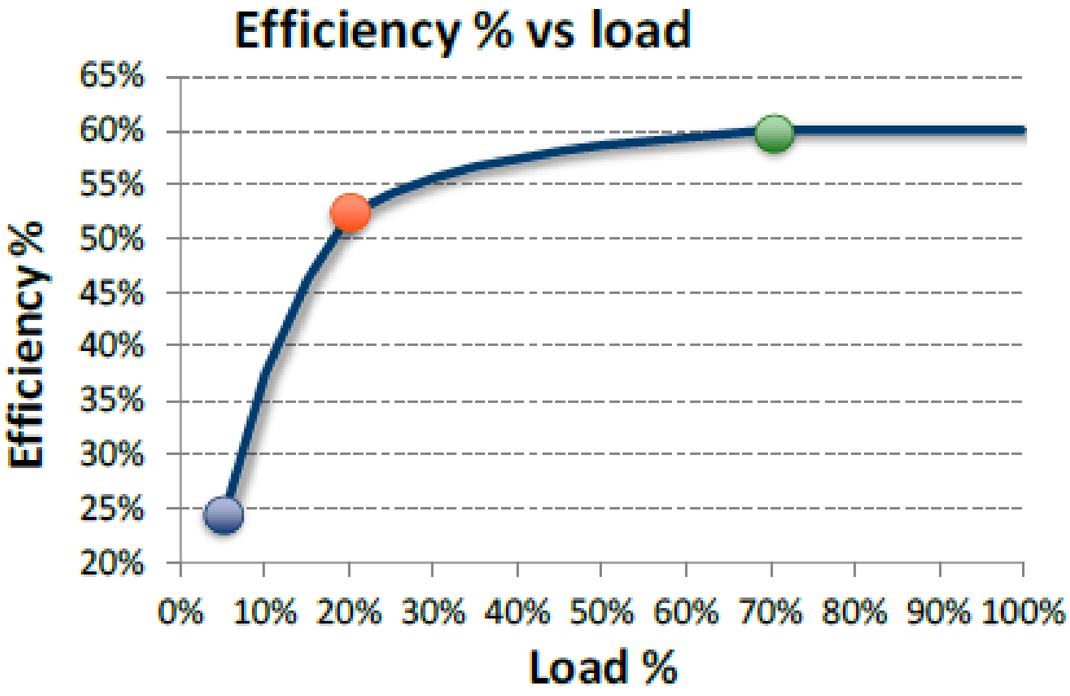
Parameter Operasional Pembangkit

1. **Start-up time** that represent the synchronization of the generator to the grid frequency which are imposed in order to avoid thermal stress through extreme temperature and pressure differences within the components of a plant (in particular for classical base load power plants with attached steam cycles) and they are also affected by the non-operational time after shut-down
2. **Ramping constraints** describing the ability of the power plants to adjust production levels within a certain time interval, i.e. the speed of load level changes, in order also to reduce thermal stress during the dispatching phase1, or due to environmental regulations and electricity system requirements.
3. **Minimum load level** at which a power plant can be effectively operated in order to achieve a stable generation
4. **Shut-down times** which represent the desynchronization of the generator from the grid frequency and are also restricted by thermal stress in unit’s components
5. **Minimum online and offline** times to sustain production and also avoid thermal stress.

Operational cost

- Biaya bahan bakar *start-up*, listrik tambahan, bahan kimia, proses yang berkaitan untuk menyesuaikan dan mengontrol tekanan dan suhu steam
- Depresiasi komponen yang sudah menurun kualitasnya
- *Partial load efficiency* saat ramping
- Ramping: *Fuel cost* dan *maintenance and capital cost for power plant changing their output*

Part Load Efficiency



a) the start-up load (blue dot)
b) the minimum stable operation load (red dot)
c) a load level above which no more efficiency losses are assumed to occur (green dot)
d) the shut-down load level (in Figure 5 it also corresponds to the blue dot for simplicity)

Parameter Operasional

Table 1 • Key technical and economic parameters of benchmark power station

Technical/economic parameters	Hard coal (old) ~1981-1985	Hard coal (new) state-of-the-art	CCGT (old) ~1976-1980	CCGT (new) state-of-the-art
Plant capacity in [MW]	400	800	350	400
Minimum load in [MW]	200	200	210	160
Maximum efficiency in [%]	38%	46%	48%	59%
Part-load efficiency in [%]	31%	40%	37%	48%
Emission factor in [t CO2/MWh(th)]	0.339	0.339	0.202	0.202
Start-up cost in [EUR/start-up]	30 000	40 000	9 000	7 000
Fixed operation and maintenance costs in [EUR/kWa]	28	28	23	23
Ramping gradient [% of installed capacity/min]	1.5%	3.0%	2.0%	4.0%
Duration of start-up process in [h]	3	3	2	2
Minimum down time [h]	3	3	3	2

Source: IEA analysis.

Parameter Operasional

Table 1: Comparison of technical characteristics between coal-fired and gas-fired power generation technologies

Property	Open cycle gas turbines (OCGT)	Combined cycle gas turbines (CCGT)	Hard coal-fired power plant	Lignite-fired power plant
Most commonly used power plants				
Minimum load (% P_{Nom})	40–50 %	40–50 %	25–40 %[a]	50–60 %
Average ramp rate (% P_{Nom} per min)	8–12 %	2–4 %	1.5–4.0 %	1–2 %
Hot start-up time (min) or (h)	5–11 min[b]	60–90 min	2.5–3 h	4–6 h
Cold start-up time (min) or (h)	5–11 min[c]	3–4 h	5–10 h	8–10 h
State-of-the-art power plants				
Minimum load (% P_{Nom})	20–50 %	30–40 % (20 % with SC[d])	25[e]–40 %[f]	35[g]–50 %
Average ramp rate (% P_{Nom} per min)	10–15 %	4–8 %	3–6 %	2–6[h] %
Hot start-up time (min) or (h)	5–10 min[i]	30–40 min	80 min–2.5 h	1.25[j]–4h
Cold start-up time (min) or (h)	5–10 min[i]	2–3 h	3–6 h	5[k]–8 h

[a] Source: (Heinzel, Meiser, Stamatelopoulos, & Buck, 2012)

[b] Large heavy-duty gas turbines such as the Siemens SGT5-4000F typically have longer start-up times. A fast start takes about 11 minutes and a normal start about 30 minutes.

[c] The amount of fuel that can be burned at the maximum continuous rating of the appliance ultiplid by the net calorific value of the fuel and expressed as megawatts thermal. The thermal input is specified by the manufacturr of a plant.

[d] SC (sequential combustion): Some state-of-the-art CCGT power plants are equipped with sequential combustion, which enables a very low load operation without exceding emission limits.

[e] See (then, 2016)

[f] Minimum load: 25–30 % in "recirculation mode" and 35–40 % in "once-through mode".

[g] See Boxberg "unit R", with a minimum load of 35 %

[h] See the "Belchatów II Uni 1" power plant in Poland or the Boxberg power plant in Germany, both with a ramp rate of up to 6 % Pnom.

[i] Large heavy-duty gas turbines such as the Siemens gas turbine SGT5-8000H typically have lonter start-up times. A fast start takes about 11 minutes and a normal start about 30 minutes.

[j] See the Boxcberg power plant "unit R" with start-up time (hot) of 75–85 minutes.

[k] See the Boxberg power plant "unit R" with start-up time (cold) of 290–330 minutes.

Sc

Source: Agora Energiewende, 2017

Parameter Operasional

Box 13: Flexibility parameters of dispatchable plants

The key parameters that define the flexibility of power plants, as detailed in various publications, are summarised below. Seven sources are used, denoted as: A (Schröder et al., 2013), B (IEA, 2014), C (Welsch et al., 2014a), D (Poncelet et al., 2016a), E (Vuorinen, 2016), F (Bruynooghe et al., 2010), G (Hout et al., 2014) and H (Ulam-Orgil et al., 2012). The maximum ramp rate is expressed as a percentage of net capacity per minute; start-up time is expressed in hours; minimum load is expressed as a percentage of net capacity; minimum up time and down time is expressed in hours; and part load efficiency (efficiency loss at minimum load) is expressed in percentage (%) or percentage points (% pt). The design characteristics of plants – rather than the fuel they use per se – lead to very different flexibility profiles (IEA, 2014).

While Tables 8 to 13 present useful sources of information, further innovation may help increase the flexibility of power plants. Using current parameters for assessing future energy systems may overestimate the challenge of integrating VRE.

Nuclear: Nuclear power plants also are typically run in baseload mode. Their flexibility is often regulated on safety grounds, but nuclear is operated with some flexibility in counties where its share in the system is high (see Table 10).

Table 9: Flexibility parameters for nuclear power plants found in the literature

	Maximal ramp rate	Start-up time (cold/hot)	Minimum load	Minimum up/ down time	Part load efficiency	Source
Nuclear	5		50	24/48		D
Nuclear	0.25-10	24-50 /<0.3	40-50	6-48 / 4-48	5%	A
Nuclear	0-5	N/A / 2-48	40-100			B
Nuclear	1-5					E
Nuclear	5					F
Nuclear	20*		50	8 / 4		G

* % of capacity in one hour

53 These technologies can be made to operate flexibly, with a range of new-build and retrofit options available (see, for example, the discussion of coal flexibility in Cochran et al. (2013)).

Coal: Coal power plants traditionally have been run as baseload generators, and so are generally inflexible. However, they are increasingly being designed for more flexible operation (see Table 9).

Table 10: Flexibility parameters for coal power plants found in the literature

	Maximal ramp rate	Start-up time (cold/hot)	Minimum load	Minimum up/ down time	Part load efficiency	Source
Coal	0.6-8	NA / 2-7	20-60			B
Coal (2020)	17.9*		64.3			C
Coal (Mongolia)	10-20					H
Standard coal (subcritical)	0.58-8	7.3-10 / 3	25-50	3-15 / 2-15	4%	A
Subcritical pulverised coal plants	3		40	6 / 4	2% pt	D
(Ultra-) supercritical pulverised coal plants	4		50	6 / 4	2% pt	D
Advanced coal (supercritical)	0.66-8	4-12 / 1-5	20-50	4-6 / 4	2% pt	A
Lignite	0.6-6	NA / 2-8	40-60			B
Lignite (new)	0.58-4	6-12.8 / 4	40-50	4 / 4		A
Lignite (old)	0.58-8	10-12.8 / 6	40-60	4-6 / 4-8	10%	A
Lignite and Pulverised coal (PC) (before 2010)	40**		40	8 / 4		G
Lignite and PC (2010)	50**		35	8 / 4		G
Lignite and PC (after 2010)	50**		30	8 / 4		G
Steam turbine plants	1-5	1-10				E
Integrated gasification combine cycle (IGCC) (before 2010)	30**		45	8 / 4		G
IGCC (before 2010)	40**		40	8 / 4		G
IGCC (after 2010)	40**		35	8 / 4		G
IGCC	4		50	4 / 1	8% pt	D
IGCC (2050)	12*		47.7			C

* % of capacity in five minutes; ** % of capacity in one hour

Parameter Operasional

Oil and gas: OCGT plants are typically flexible, and a subset of them, used as peaking plants, is highly flexible. CCGT plants are typically less flexible (see Table 11).

Table 11: Flexibility parameters for oil and gas power plants found in the literature

	Maximal ramp rate	Start-up time (cold/hot)	Minimum load	Minimum up/ down time	Part load efficiency	Source
OCGT	0.83-30	<1 / <0.17	10-50	0-6 / 0-6	20%	A
Gas OCGT	7-30	NA / 0.1-1	0-30			B
OCGT (2020)	10*		55			C
OCGT (2050)	16.9*		17			C
OCGT	17.5		10	1 / 1	21% pt	D
OCGT	100**		10	1 / 1		G
Aeroderivative gas turbine	20	5-10				E
Industrial gas turbine	20	10-20				E
Combustion engine bank CC	10-100	NA / 0.1-0.16	0			B
CCGT	0.83-12	2-5 / 0.5-2	30-50	1-6 / 1-6	5-9%	A
CCGT	5-10	0.5-1				E
CCGT	7	3 / NA	40			F
CCGT (2020)	16.9*		42.2			C
CCGT - new (2020)***	12*		52.9			C
CCGT	7		50	4 / 1	8% pt	D
Gas CCGT	0.8-15	NA / 3	15-50			B
NGCC (before 2010)	50**		40	1 / 3		G
NGCC (2010)	60**		30	1 / 3		G
NGCC (after 2010)	80**		30	1 / 3		G
Oil	1-20	1 / NA	10-50	1-6 / 1-6	-	A
Steam (oil / gas)	0.6-7	NA / 1-4	10-50			B
Distillate oil	10.1*		10.1			C
Gas engines	10-85	3-10 min				E
Diesel engines	40	1-5 min	30-50			E
Heavy oil			20-35			H
Diesel oil						H

* % of capacity in five minutes; ** % of capacity in one hour; *** According to the authors of Source C, the higher minimum load figures from this source for newer CCGT represent an observed trend in the Irish market, and may not necessarily be representative

Parameter Operasional

cek unit
di IEA

Hydropower plants: Hydropower with a reservoir is highly flexible, with a low minimum load and a quick start up time (see Table 12).

Table 12: Flexibility parameters for hydropower plants found in the literature

	Maximal ramp rate	Start-up time (cold/hot)	Minimum load	Minimum up/ down time	Part load efficiency	Source
Hydro reservoir	15-25	NA / <0.1	5-6			B
Hydro run-of-river	5	NA / 0.16	50			B
Hydropower	12.8*		13.7			C
Pumped storage	17.1*		3.4			C

* % of capacity in five minutes

Combined heat and power (CHP): In most countries current CHP operational practice prioritises covering heat demand, making its electricity generation very inflexible (see Table 13). However, in Denmark, where electric boilers are installed, CHP plants are operated flexibly, even allowing even for negative generation (i.e., consumption of electricity) (IEA, 2014).

Table 13: Flexibility parameters for combined heat and power plants found in the literature

	Maximal ramp rate	Start-up time (cold/hot)	Minimum load	Minimum up/ down time	Part load efficiency	Source
CHP - coal	2-4	NA / 5-9	50-80			B
CHP - CCGT	2-8	NA / 2-3	40-80			B
CHP - steam turbine (oil / gas)	2	NA / 4	100			B
CHP	90*		10	1 / 1		G

* % of capacity in one hour

Other: See Table 14.

Table 14: Flexibility parameters for other types of power plants found in the literature

	Maximal ramp rate	Start-up time (cold/hot)	Minimum load	Minimum up/ down time	Part load efficiency	Source
Peat (2020)	34.6*		69.2			C
Bioenergy	8	NA / 3	50			B
Biogas (2020)	0*		22.7			C
Waste (2020)	0*		23.8			C
Biomass (2050)	0*		34.2			C
Geothermal	5-6	NA / 1-2	10-20			B
Wind onshore (2020, 2050)	0*		0			C
Solar (2050)	0*		0			C
Solar CSP	4-8	NA / 1-4	20-30			B

* % of capacity in five minutes

Grid-side Flexibility

Stabilitas Sistem

- Jaringan sistem kelistrikan terkoneksi dengan jaringan T&D dengan membawa listrik AC pada frekuensi dan voltase tertentu
- Arus listrik, diukur dalam Amp, adalah laju aliran muatan listrik melalui kawat konduksi. Tegangan, diukur dalam Volt, adalah gaya yang menggerakkan muatan ini melalui konduktor.
- Pada sistem T&D AC listrik berfluktuasi pada voltase negatif dan positif setiap detiknya sehingga arus mengalir maju dan mundur. Perubahan voltase per detik disebut sebagai frekuensi
- Besaran frekuensi tergantung dengan standar yang disepakati biasanya terdapat 2 standar 50 atau 60 Hz

INA

daya aktif → KW
reaktif → KVAR → analogi bir
voltage Ampere reactive

K vs P	f	V
>	↓	↓
<	↑	↑

V tinggi → bisa putus jaringan — generator

Stabilitas Sistem

→ menghindari kerusakan alat

- Kebutuhan >pasokan → frekuensi dari grid akan turun. Artinya semakin banyak listrik yang harus dipasok untuk memperbaiki frekuensi. Pasokan > kebutuhan → frekuensi meningkat
- Setiap grid beroperasi pada voltase tertentu. Voltase tinggi pada jaringan transmisi dan voltase rendah pada jaringan distribusi. Voltase dapat dinaikturunkan menggunakan transformer. Pengaliran listrik pada voltase tinggi menghindari terjadinya *losses* pada transmisi (hilang menjadi panas).
- Kebutuhan > pasokan → voltase akan turun → undervoltage/brownout. Pasokan > kebutuhan → voltase meningkat

Stabilitas Sistem

- Penjagaan frekuensi dan voltase tugas dari sistem operator. Di UK variasi frekuensi +/- 1%, variasi voltase +/- 5 sampai 10%.
- Sistem operator menyediakan jasa tambahan atau cadangan untuk menjaga keseimbangan pasokan dan permintaan pada rentang *timeslice* yang singkat hingga sub-sekon.

Grid Ancillary Service

Grid ancillary services refer to the range of support functions provided to the power grid to ensure the **reliable** and **efficient operation** of the electricity supply system. These services maintain **grid stability, security, and power quality**, particularly in the face of fluctuations in supply and demand.

Grid Ancillary Service

- Very short duration (ms to 5 min)
  - Energy storage
  - DSM: load shifting in decentralized system
- Short duration (5 mins to 1 h)
  - Spinning, non-spinning and contingency reserves
  - Black start
- Intermediate duration (1 h to 3 d)
  - Load following with energy storage
  - Load leveling with energy storage
  - Transmission curtailment prevention and loss reduction
  - Unit commitment
- Long duration (several months)
  - Seasonal shifting (Large PHES and gas storage)

Grid Ancillary Service

Table 4
Grid ancillary services categorized based on service duration [136,137].

Duration	Services	Examples of technologies
Very short: 1 ms–5 min	Power quality, regulation	Flywheels, DSM
Short: 5 min–1 h	Spinning reserve, contingency reserve, black start	Flow batteries, PHES, DSM
Intermediate: 1 h–3 d	Load following, load leveling/peak shaving/valley filling, transmission curtailment prevention, transmission loss reduction, unit commitment	CAES, PHES, DSM
Long: months	Seasonal shifting	CAES, PHES

Technologies for Grid Ancillary

PHES = Pumped Hydro ES

CAES = Compressed Air ES

FES = Flywheel ES

ES = Energy Storage

DSM = Demand Side Management

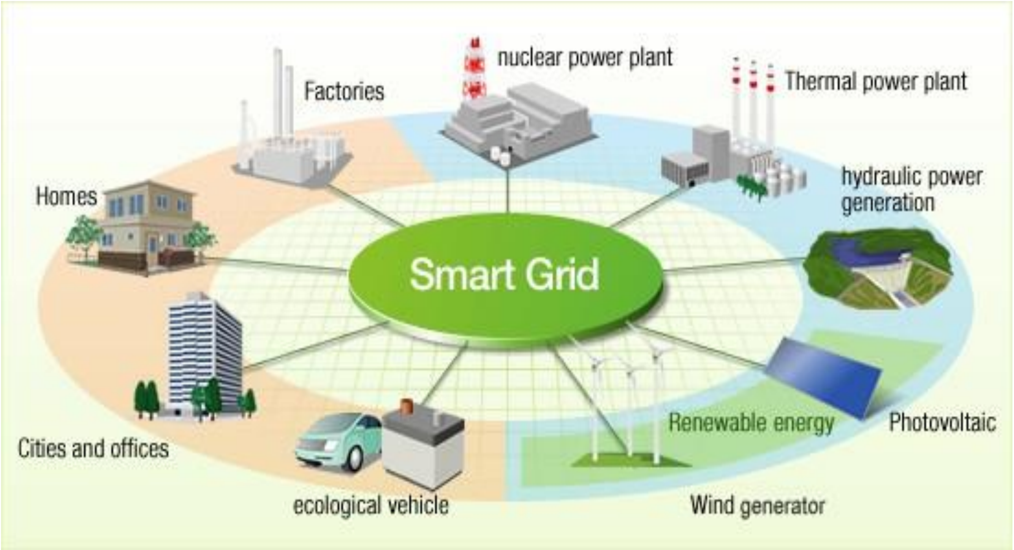
Smart Grid

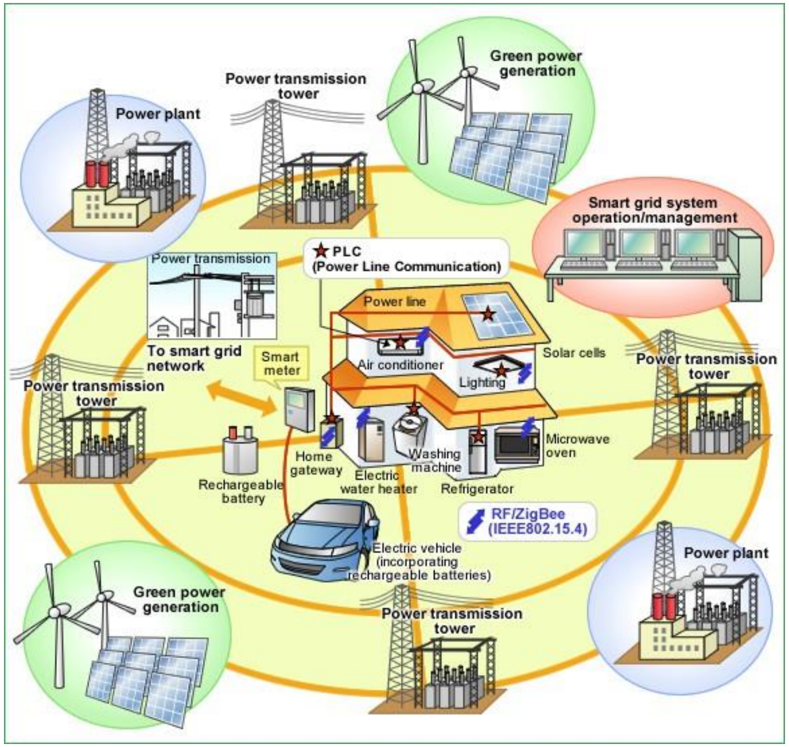
- Smart grids are electricity network that use **digital technologies, sensors and software** to better match the supply and demand of electricity in real time while **minimizing costs and maintaining the stability and reliability** of the grid.
- Clean energy transitions entail large increases in electricity demand and the widespread **rollout of variable renewables** like wind and solar, placing greater demands on power grids. Smart grid technologies can help to manage this **transition** while **reducing the need for costly new grid infrastructure**, and can also help to make grids **more resilient and reliable**.

https://www.iea.org/energy-system/electricity/smart-grids

Smart grid power system

Characteristics	Conventional grid	Smart grid
Communication	Uni-directional	Bi-directional
Monitoring control	Manual	Autonomous and intelligent
Inclusion of smart sensors and meters	Limited	Throughout
Consumer participation	Passive	Active
Power generation	Centralized	Distributed
Recovery	Manual	Self-healing



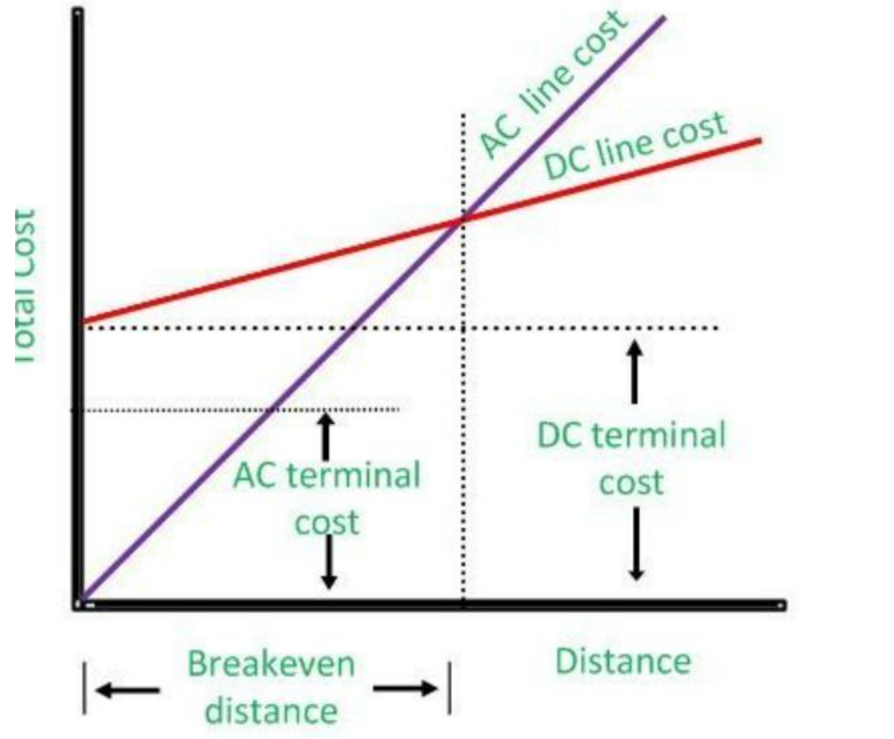


Super Grid

- *"A super grid is an ultra-large-scale power system coordinating the energy dispatch of multiple nations or regions across the continent to achieve global optimal targets* (Yuan, 2017)".
- Uses high-voltage direct current (HVDC) in the transmission
- High voltage direct current (HVDC) power systems use D.C. for transmission of bulk power over long distances. For long-distance power transmission, HVDC lines are less expensive, and losses are less as compared to AC transmission.
- Connecting mismatched location
- Main challenge: installation, technical standard, interaction with AC, and operational principles.

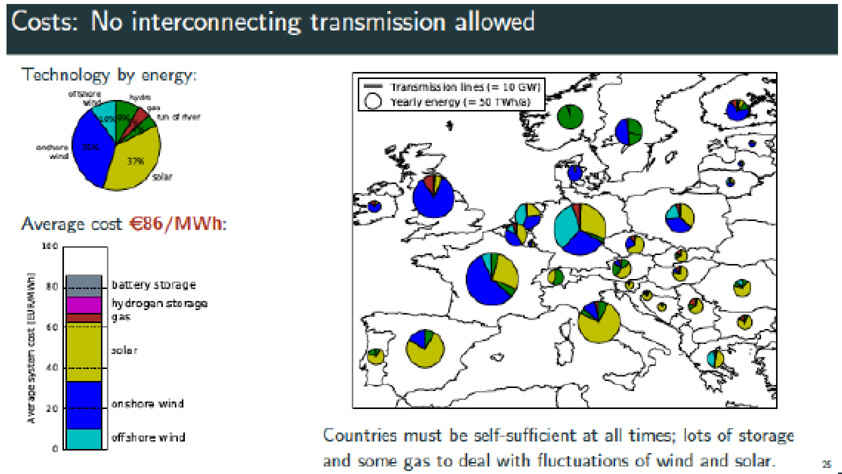
AC vs DC Transmission Lines

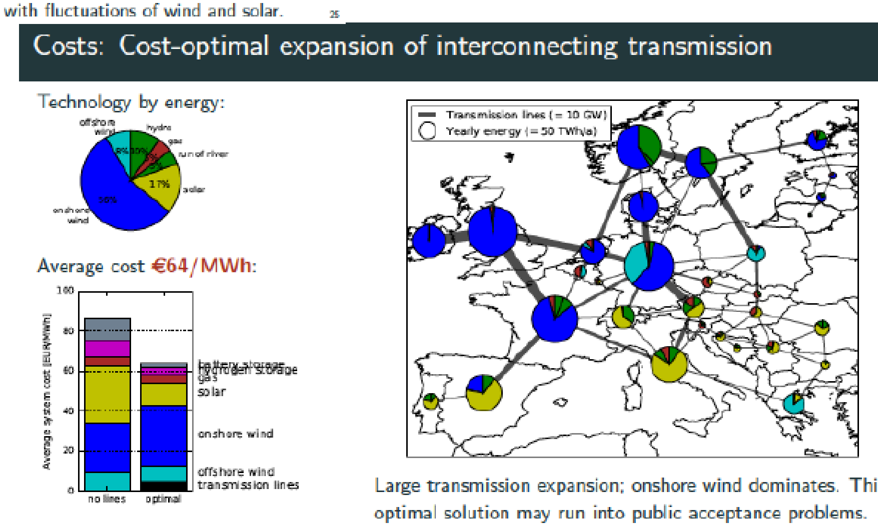
The point where two curves meet is called the **breakeven distance**. Above the breakeven distance, the HVDC system becomes cheaper. Breakeven distance changes from **500 to 900** km in overhead transmission lines.



Comparision of the costs of AC and DC transmission

Super Grid


Costs: No interconnecting transmission allowed
Technology by energy:
offshore wind
hydro
gas
run of river
onshore wind
37%
solar
Average cost €86/MWh:
Average system cost [EUR/MWh]
battery storage
hydrogen storage
gas
solar
onshore wind
offshore wind
Transmission lines (= 10 GW)
Yearly energy (= 50 TWh/a)
Countries must be self-sufficient at all times; lots of storage and some gas to deal with fluctuations of wind and solar.
25


Costs: Cost-optimal expansion of interconnecting transmission
Technology by energy:
offshore wind
hydro
gas
run of river
17%
solar
onshore wind
Average cost €64/MWh:
Average system cost [EUR/MWh]
battery storage
hydrogen storage
gas
solar
onshore wind
offshore wind
transmission lines
no lines
optimal
Transmission lines (= 10 GW)
Yearly energy (= 50 TWh/a)
Large transmission expansion; onshore wind dominates. This optimal solution may run into public acceptance problems.

SuperGrid vs. SmartGrid

Technology components	SuperGrid	SmartGrid
Knowledge	Builds on existing power-rationality relationships in energy supply and transmission	Builds on new power-rationality relationships in distributed generation and end-use.
Organization	Centralized top-down initiative and implementation manageable within existing regulatory frameworks	Decentralized bottom-up implementation required engaging individuals and small-scale companies. New solutions, markets and institutions required.
Technique	Large-scale expansion of T&D cable infrastructure, potential innovations in materials.	A variety of technical changes in distributed generation, grids, end-use, as well as in markets and tariff systems
Product	Priority objectives (Verbong and Geels, 2010): (1) reliability. (2) environment. (3) cost efficiency.	Priority objectives (Verbong and Geels, 2010): (1) local control and reduced external dependence. (2) reliability. (3) environment.

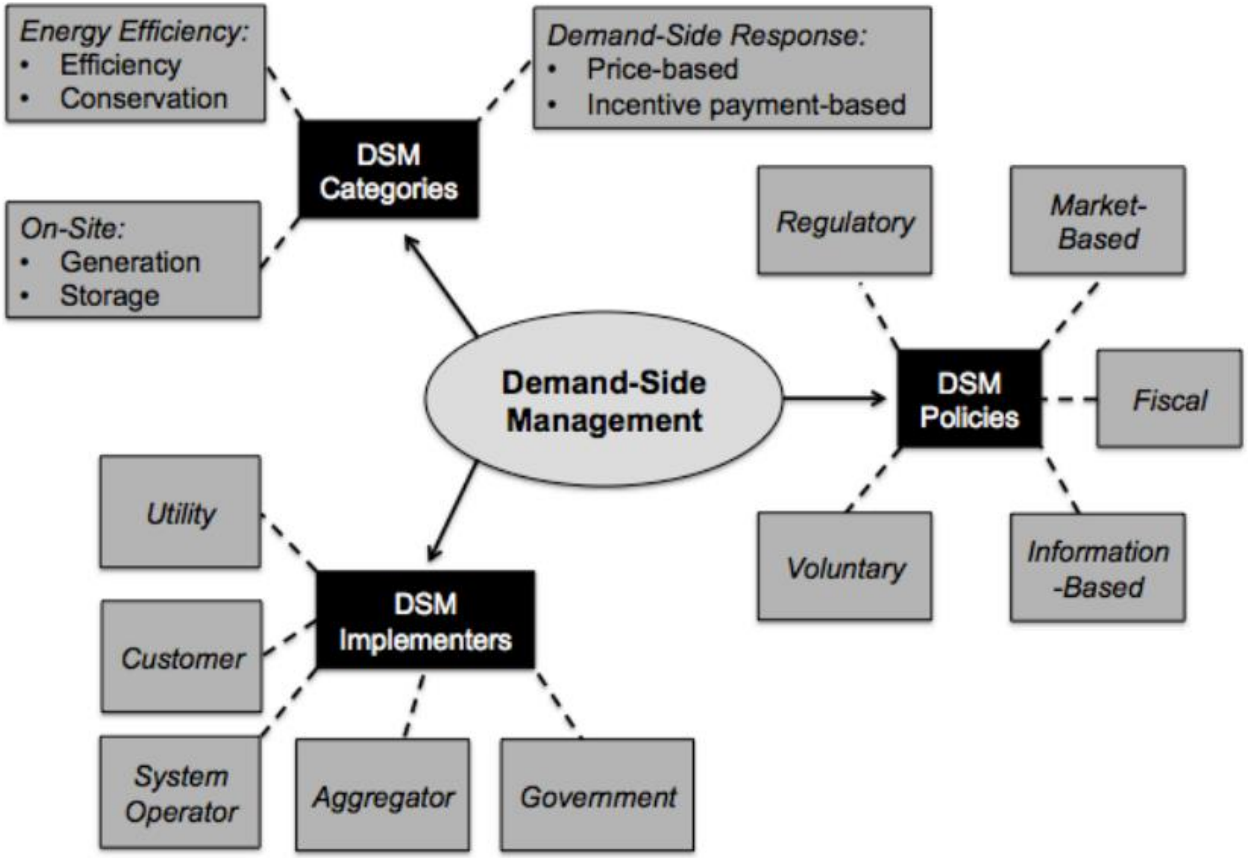
Blarke and Jenkins, 2013

Demand-side Flexibility

Demand Side Management

- *“Demand-side management (DSM) refers to technologies, actions and programmes on the demand-side of energy meters that seek to manage or decrease energy consumption, in order to reduce total energy system expenditures or contribute to the achievement of policy objectives such as emissions reduction or balancing supply and demand.” (Warren, 2014a)*
- *“Demand-side management (DSM) refers to* ***technologies, actions and programmes*** *on the* ***demand-side*** *of energy meters, as* ***implemented*** *by governments, utilities, third parties or consumers, to* ***manage or decrease energy consumption*** *through energy efficiency, energy conservation, demand response or on-site generation and storage, in order to reduce total energy system expenditures or to contribute to the* ***achievement of policy objectives****, such as emissions reduction, balancing supply and demand or reducing consumer energy bills.”* (Warren, 2015)

Demand Side Management



Warren (2015)

Demand Side Management

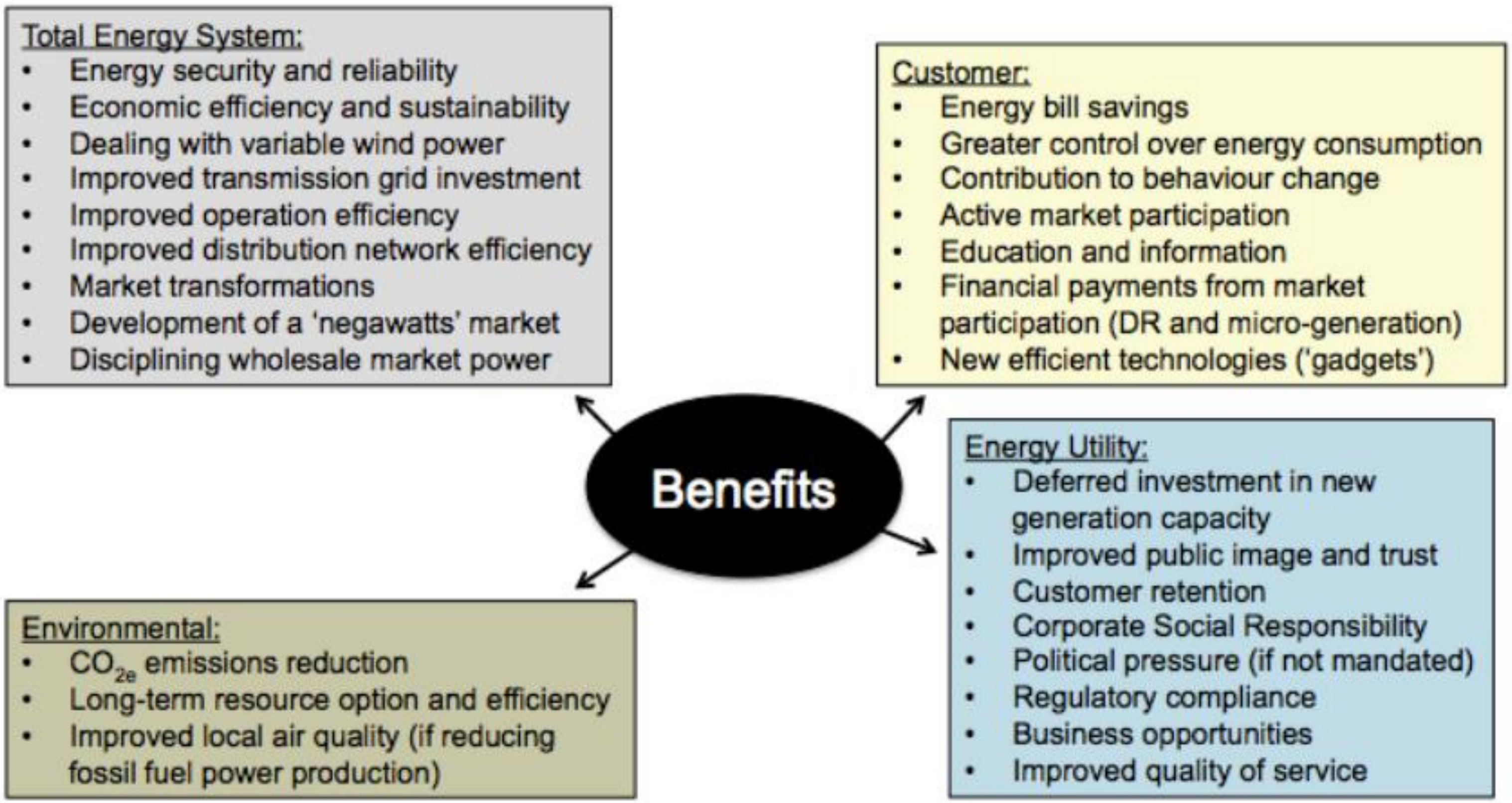
- DSM includes energy efficiency, energy conservation, price-based demand response, incentive payment-based demand response, on-site generation and on-site storage.
- DSM implementers can be national or local governments, consumers, third parties or utilities. This can also be extended to include system operators, which operate and own the transmission and distribution networks in liberalized markets, and aggregators.
- DSM policies can be categorized into regulatory, market-based, fiscal, information-based or voluntary policies

Warren (2015)

Demand Side Management

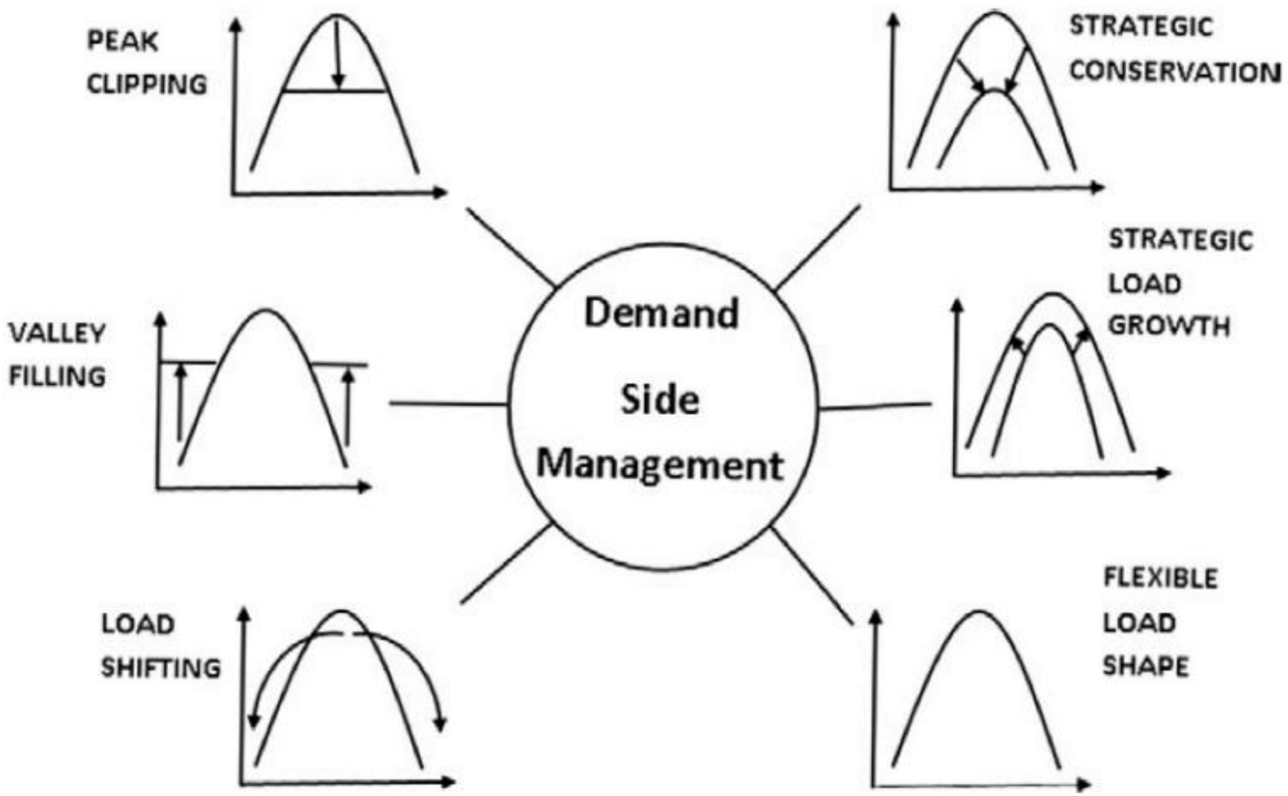
- ***Demand response*** mengacu program manajemen sisi permintaan dengan pola permintaan dan besarannya bergeser untuk menyesuaikan dengan pasokan listrik (IRENA, 2018b, Lund et al., 2015).
- Respons permintaan adalah metode yang efektif yang memberikan peluang bagi <u>konsumen untuk memainkan peran</u> dalam pengoperasian jaringan listrik.
- DSM dapat dikategorikan sebagai mengurangi (***peak shaving***) atau meningkatkan (***valley filling***) atau mengatur ulang (***load shifting***) permintaan energi.
- *Load shifting* dinilai paling menguntungkan dibandingkan DSM lainnya karena tidak mengganggu jalannya proses ataupun kualitas dari energi final.

Keuntungan dari DSM



Warren (2015)

The Six Main Types of Load Shapes in Demand-side Management



Gellings and Chamberlin (1993) cited in Warren (2015)

Demand Side Management

- Barriers for DSM:
  - The lack of information communication technology (ICT) infrastructures dan technology financing
  - The need for real-time energy and price information
  - Benefits for involved *stakeholders* and their participations

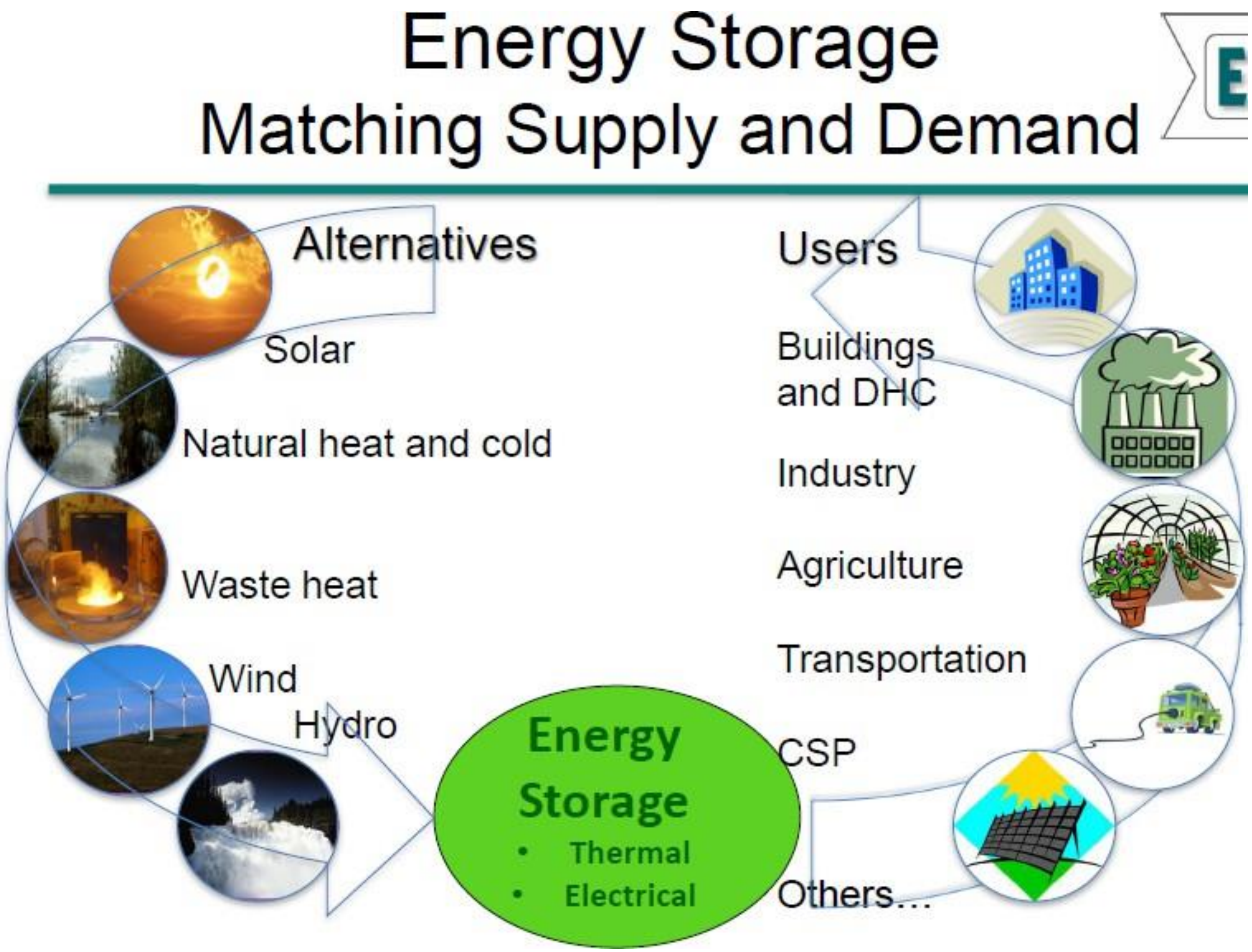
Penyimpanan Energi

What is energy storage

An energy storage system can take up energy and deliver it at a later point in time. The storage process itself consists of three stages: The charging, the storage and the discharging. After the discharging step the storage can be charged again.

Source: Hauer

Why we need energy storage?



Typical energy storage applications

- **Arbitrage**: storing energy during off-peak (low-priced) periods, and selling it during peak (high-priced) periods on the same market.
- **Frequency regulation**: the operator of the power system continuously has to keep the balance between supply and demand, in order to regulate the frequency of the system (nominally 50 or 60 Hz). Suitable technologies for such application are batteries with fast response, and flywheels.
- **Demand shifting and peak shaving**: similar to arbitrage, energy storage can be used to 'shift' or delay the demand for energy, typically by several hours. Such shifting can be directly used to reduce ("shave") peak demand, which can reduce the total generation capacity required.
- **E-mobility**: electric vehicles play an important part in future power system visions, as presenting a possible zero-emission transport solution, particularly when integrated with renewable energy sources. These vehicles can also serve as distributed energy storage units, used to balance fluctuations of the power system.
- **Integration of variable renewables**, typically wind and solar: the use of energy storage is viewed as one potential means to support the integration of variable renewable energy sources into the system, by bridging both rapid and longer-term output changes.
- **Seasonal storage**: storage of energy for longer time periods (e.g. months) to compensate for seasonal variability on the supply or demand side of the power system. The reservoirs of conventional hydro stations are often used in this way.

Source: WEC

Table 1. Transportation Application Descriptions

Application Sector	Application Description
Mobility – battery storage	Electric vehicles (light-duty, medium-duty, and heavy-duty)
	Battery electric vehicle
	Plug-in hybrid electric vehicle
	Hybrid electric vehicle
Mobility – hydrogen storage	Hydrogen storage on FCEVs (light-duty, medium-duty, and heavy-duty)
SLI – starting, lighting, and ignition	Batteries in cars, trucks, boats, and other internal combustion motorized vehicles

Table 2. Stationary Application Descriptions

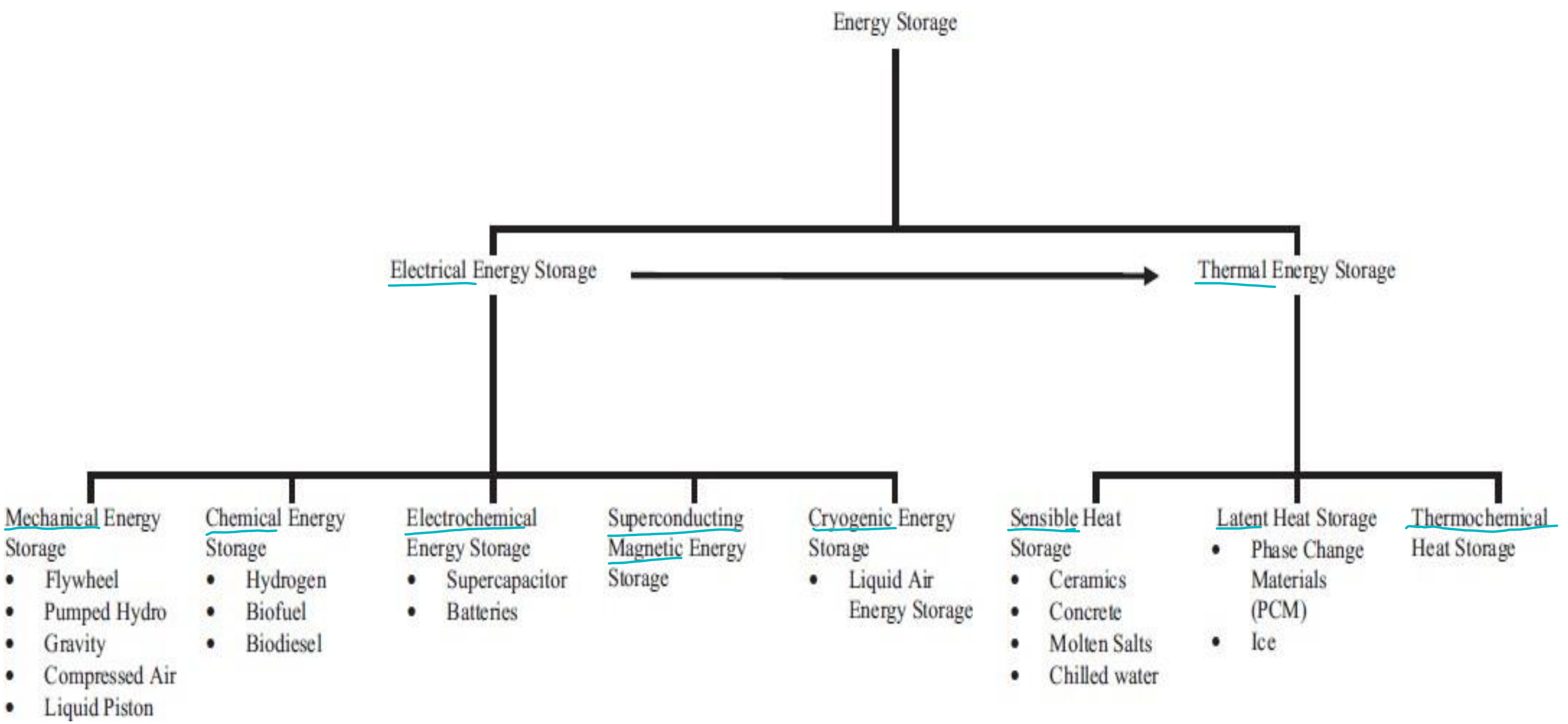
Sector Category	Application	Application Description
Grid-related – utility	Ancillary services	Provision or absorption of short bursts of power to maintain supply and demand and thus the frequency of the grid; frequency regulation and reserves
	Peaking capacity	Provision of capacity to meet system maximum demand
	Energy shifting	Uptake is driven by increasing system flexibility needs. Energy storage is charged during low prices and surplus supply and discharged to meet demand. Batteries can be charged from surplus renewable energy or from assets that, along with battery, become dispatchable
	Transmission-level	Use of an energy storage system as an alternative to traditional network reinforcement, such as to meet an incremental increase in transmission capacity instead of an expensive transmission line upgrade
	Distribution-level	Use of an energy storage system as an alternative to traditional network reinforcement such as to meet an incremental increase in distribution capacity instead of an expensive distribution line upgrade

Sector Category	Application	Application Description
Grid-related – residential		
Grid-related – C&I	C&I energy storage	Energy storage that is used to increase the rate of self-consumption of a PV system from a commercial or industrial customer
Grid-related – utility/residential and C&I	EV charging infrastructure	
LDES	Long-duration energy storage	
Industrial, including military use	Uninterruptible power source (UPS) + data centers	Use of batteries for uninterruptible power and data centers
	Telecom backup power	Telecommunications towers require UPS and backup power and are a significant demand in the stationary sector
	Air conditioning/ refrigeration	
	Hydrogen refueling stations	Refueling stations for FCEVs
	Motive (forklifts)	Commercial and industrial use of battery systems on forklifts for motive power

C&I: Commercial & Industrial

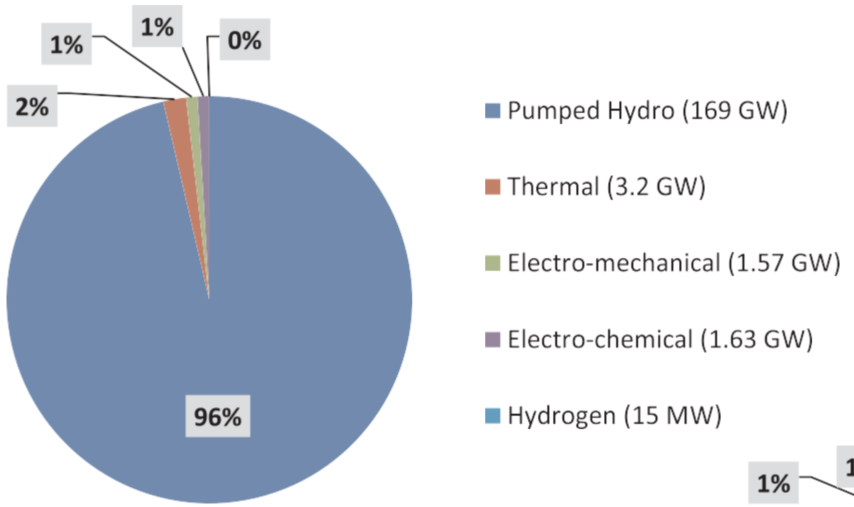
Source: NREL, 2020

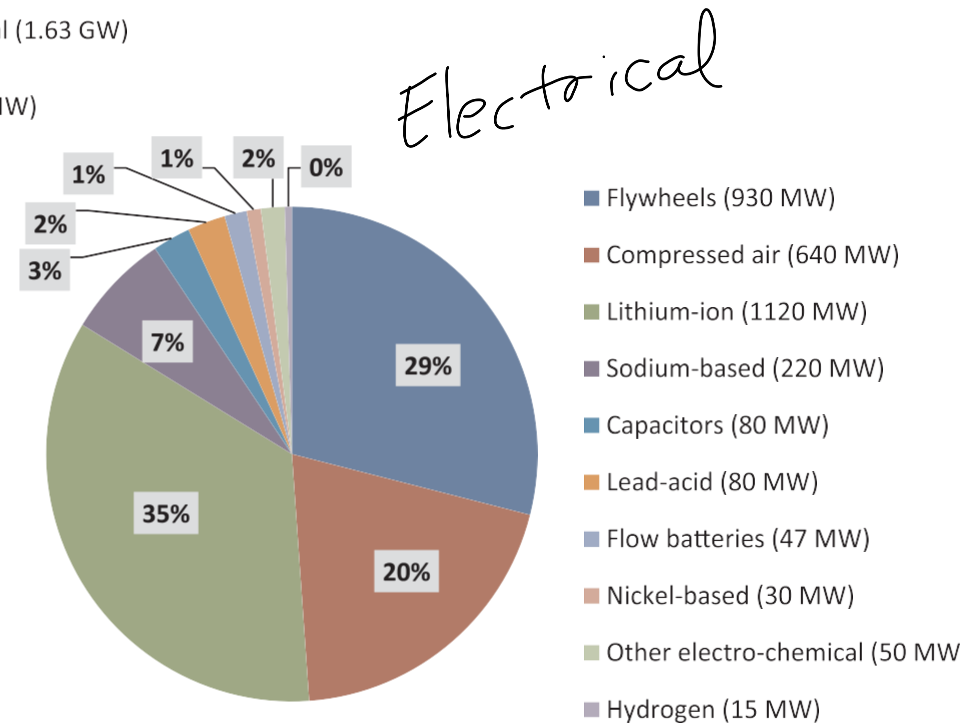
Energy storage technologies classification



Source: Aneke and Wang, 2016

Global energy storage power capacity by technology (2017)

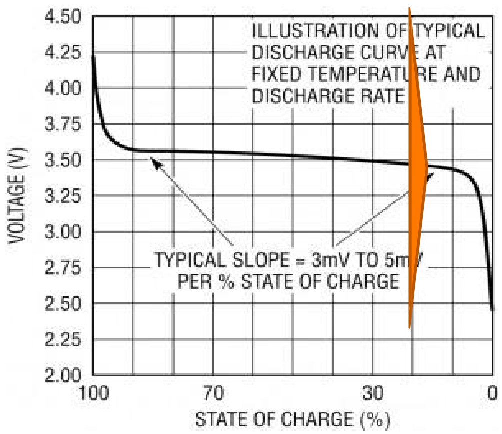




Source: Argyrou, 2018

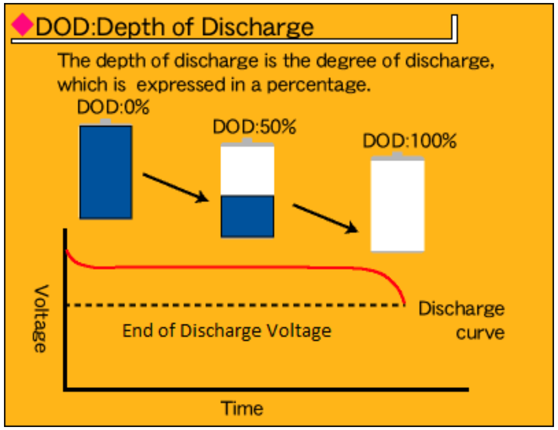
State of charge (SOC) & Death of discharge (DoD)

- State of charge (SOC) is the value which defines the available capacity of the battery.



100 % of SOC means a new full charged battery

Depth of discharge (DoD) is the removed specific energy from a battery expressed as a percentage of the capacity.



A discharge to at least **50-80 %** DOD is referred to as a deep discharge.

Common way use % but also possible to use Ah

Source: Aalto

Table 4
Characteristics of EES technologies.

EES Technology		Power rating (MW)	Storage capacity		Response time	Self-discharge rate (%/day)	Suitable storage duration	Efficiency (%)	Lifetime	
			Energy rating (MWh)	Discharge time					(years)	(cycles @80% DOD)
PHS	Conventional (Upgrading)	100–5000+	1000+	1–24+ h	~3 min	0.005–0.02	h-month	65–85	30–60	N/A
	Underground shaft & piston	200–1000	8.5–200	0.3–4 h	< 1 min	Very small	h-month	75–80	30	N/A
CAES	D-CAES	5–300+	1000+	1–24+ h	~ 10 min	0.003–0.03	h-month	40–60	20–40	N/A
	A-CAES	0.1–10 small	1–10 small	1–12 h small	min	0.5–1	h-month	75–95	20–30	N/A
		100+ large	100+ large	1–24+ h large						
	I-CAES	0.1–10	1–10	1–12 h	< 1 min	Very small	h-month	75–95	20–30	N/A
	UW-CAES	1–1000+	1–1000+	1–24+ h	< 1 min	Very small	h-month	75–95	20–30	N/A
Flywheel		0.1–10	0.01–5	s-min	ms-s	55–100	s-min	75–95	15–20	20,000–100,000
LAES		10–100+	10–1000+	1–12+ h	5–10 min	Very small	h-month	40–85	20–40	N/A
PTES		0.5–10+	0.5–60+	1–6+ h	< 1 min	1	h-month	70–80	25	N/A
Conv. Batteries	Lead-acid	0.001–50	0.1–100	s-h	ms	0.033–0.3	min-day	70–90	5–15	400–1500
	Ni-Cd	0.01–40	$10^{-5}-1.5$	s-h	ms	0.067–0.6	min-day	60–73	10–20	1000–1500
	Ni-MH	0.01–1	$10^{-5}-0.5$	h	ms	0.4–1.2	min-day	70–75	5–10	800–1200
	Li-ion	0.1–50	$10^{-5}-100$	min-h	ms	0.1–0.3	min-day	85–95	5–15	2000–5000+
HT Batteries	NaS	0.05–50	6–600	s-h	ms	0.05–20	s-h	70–90	10–15	4000–4500
	$Na\text{-}NiCl_2$	0.001–1	0.12–5	min-h	ms	15	s-h	85–90	15	4000–4500
Flow Batteries	VRB	0.005–7	0.01–10	s-10 h	ms	0.2	h-month	60–85	5–15	10,000–13,000
	ZBB	0.025–2	0.05–4	s-10 h	ms	0.24	h-month	60–75	5–10	5000–10,000
	PSB	1–15	0.01–10+	s-10 h	ms	Very small	h-month	57–85	10–15	2000–2500
Supercapacitors		0.001–10	$10^{-6}-10^{-2}$	ms-h	ms	20–40	s-h	85–95	10–20	> 100,000
SMES		0.01–10	$10^{-4}-0.1$	ms-min	ms	10–15	min-h	80–90	15–20	> 100,000
PtG+ Storage +GtP	Hydrogen	0.1–1000+	100–1000+	1–24+ h	s-min	Very small	h-month	30–50	20–30	N/A
	Methane	0.1–1000+	100–1000+	1–24+ h	min	Very small	h-month	25–35	30	N/A

Storage Type	Power	Duration of Discharge	Efficiency (%)	Lifetime	Total Capital Cost (USD/kW)
CAES (100-300 MW, Underground)	15-400 MW	2-24 hrs	54 (Eff_{NG}=1)* 76(Eff_{NG}=0.54)* 88(Eff_{NG}=0.39)*	35 years	600-750
Pumped Hydro	250 MW >1 GW	12 hrs	87	30 years	2700-3300 Upgrade:300**
Li Ion	5 MW	15 min to several hrs	90 (DC)	15 years	4000-5000
Lead Acid	3-20 MW	10 sec to several hrs	75-80 (DC) 70-75 (AC)	4- 8 years	1740-2580
NaS	35 MW	8 hrs	80–85 (DC)	15 years	1850-2150***
VRB Flow Cell	4 MW	4-8 hrs	75–80 (DC) 63–68 (AC)	10 years	7000-8200
ZnBr Flow Cell	40-100 kW, 2 MW	2-4 hrs	75–80 (DC) 60–70 (AC)	20 years	5100-5600
High Power Flywheel	750- 1650 kW	15 sec to 15 min	93	20 years	3695-4313
ZEBRA	<10 MW	Up to 8 hrs	80-85 (DC)	Over 1500 cycles shown	1500-2000***
Fe/Cr Flow Battery	<10 MW	2-4 hrs	50-65	20 years	200-2500***
Zn/Air	20 kW- 10 MW	3-4 hrs	40-60	a few hundred cycles	3000-5000***
SMES	1-3 MW	1-3 sec	90	>30,000 cycles	380-490
SMES****	100 MW- 200 MW	100 sec (MWh) 0.5-1h (100MWh) 5-10 hr (GWh)	90	>30,000 cycles	700-2000
Ultra capacitors	10 MW	Up to 30 sec	90	>500,000 cycles	1500-2500

**For CAES, the following round-trip efficiency is usually used:*

$$\eta = \frac{1.0 \ kWh}{(4220/3600) * Eff_{NG} + 0.67}$$

where Eff_{NG} is 1.00 for natural gas, 0.54 for NGCC, 0.385 for simple GT. When Eff_{NG} =1.00, and the round-trip efficiency is equivalent to the conventional energy efficiency.

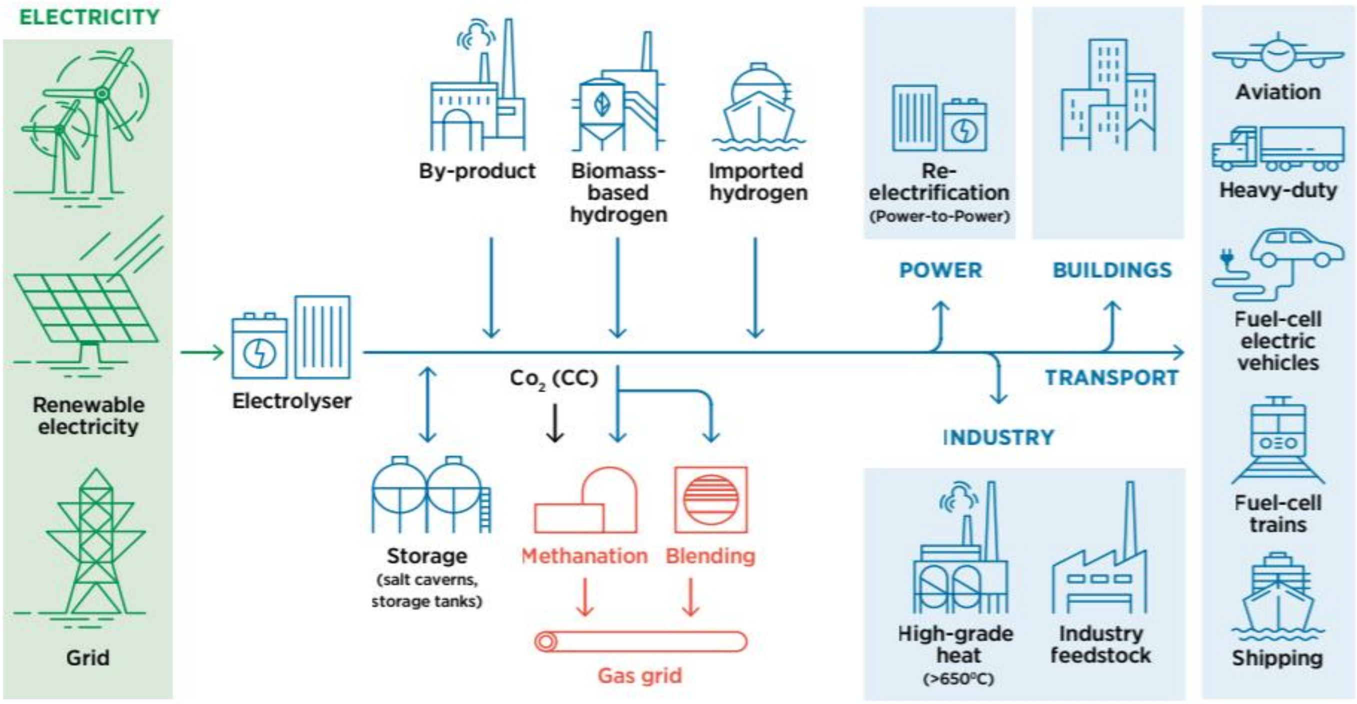
*** Based on an interview for manufacturers*

**** Projected*

*****Estimated by RASMES (Research Association of SMES, Japan)*

Sector Coupling

Sector Coupling



Integrasi dengan pemanasan dan pendinginan (E2T) → boiler elektrik dan CCHP (Combined Cooling, Heat and Power).

Gas/hydrogen → elektrolisis dan fuel cell

Transportasi → HEV, BEV, dan FCEV

Sector Coupling

- Sector coupling is about **connecting the energy sector with the industry, transport, and building sectors and then optimizing them together**.
- Sector coupling comes in with two strategies.
    1. **Electrification:** To reduce CO_2 emissions, part of the final energy consumption can be electrified, i.e., covered by electricity, which in the long term is to come from renewable energies. In the case of electromobility, cars, scooters, and other vehicles run on electricity instead of gasoline and diesel. In buildings, traditional heating systems are replaced by electric heat pumps.

Sector Coupling

- Sector coupling comes in with two strategies.
    2. **Power-to-X**: Climate-neutral, synthetic, or biogenic fuels such as hydrogen, methane, gasoline, or kerosene can also reduce CO_2 emissions. In the so-called power-to-X process, **synthetic fuels are produced from (surplus) electricity from renewable sources**. These fuels can be used through the existing gas and heat infrastructure.

https://www.ewi.uni-koeln.de/en/topics/sector-coupling/#:~:text=Sector%20coupling%20is%20about%20connecting,be%20reduced%20with%20renewable%20energies.

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Thank you