University of South-Eastern Norway

Conceptual Modeling to Explore Problem and Solution Space, Illustrated by Examples from Future Energy Systems

ICONS 2021

Gerrit Muller
Professor Systems Engineering
University of South-Eastern Norway
Senior Research Fellow at TNO-ESI, the Netherlands

IARIA

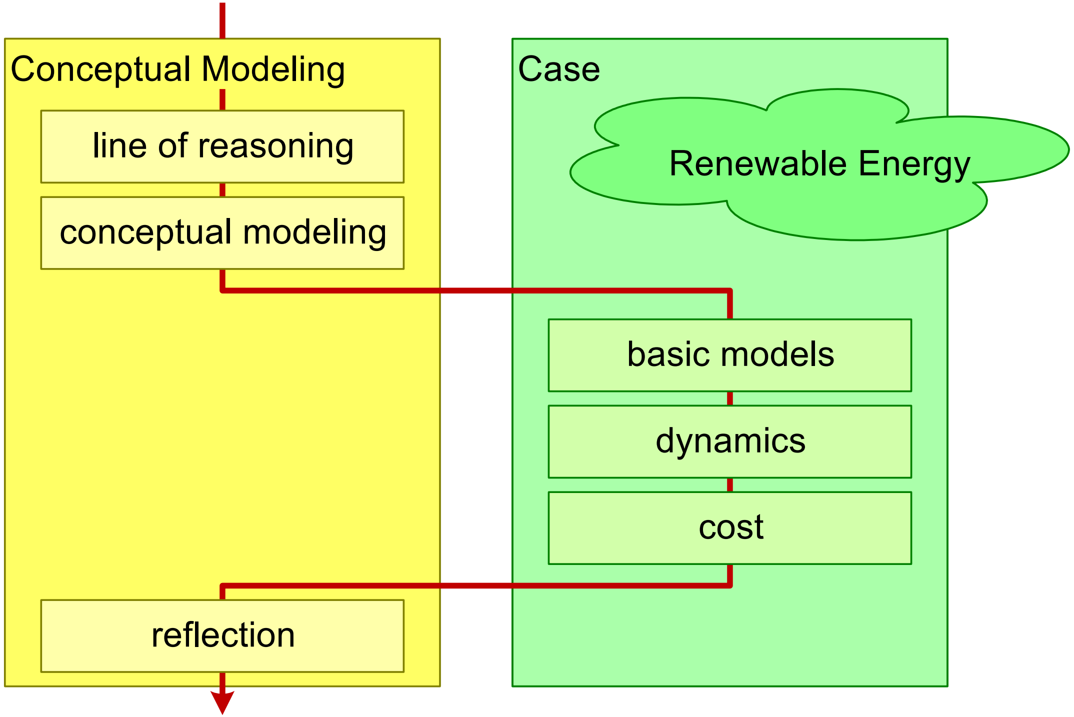
Speaker Biography

- **Gerrit Muller**
- worked 20 years in the industry as systems architect
- Since 1999, he worked in research and education in close cooperation with industry.
- In 2008, he became professor systems engineering at USN.
- Since 2020, he is INCOSE Fellow an Excellent Educator at USN.

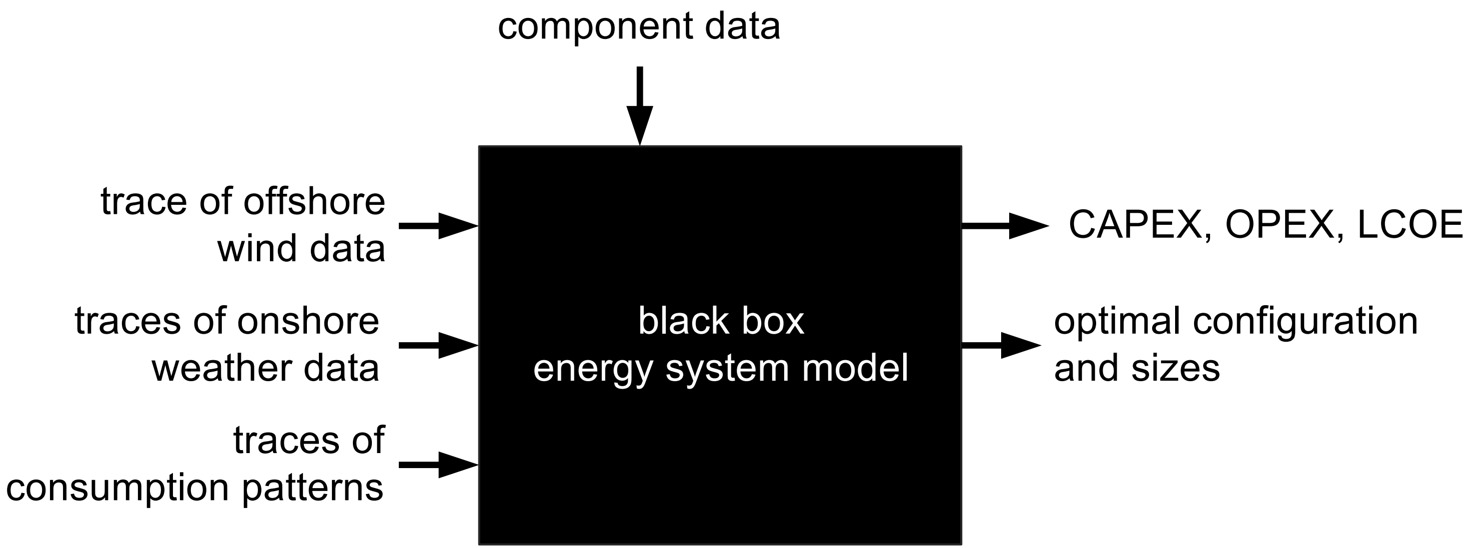
Specific interests

- Systems Architecting, Conceptual modeling
- Education in Systems Engineering
- Research in Systems Engineering
- Connecting Education, Research, and Practice
- Sustainability

Figure of Content



As-Is: System Model Calculates Optimum



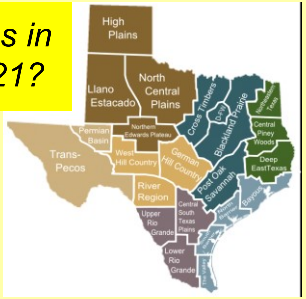
Problem: No Understanding, No Reasoning

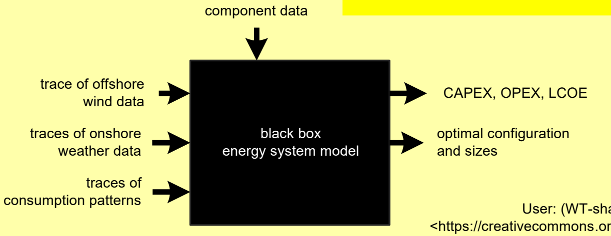
Designers explore and find an **optimum**,

however, they **lack understanding**.

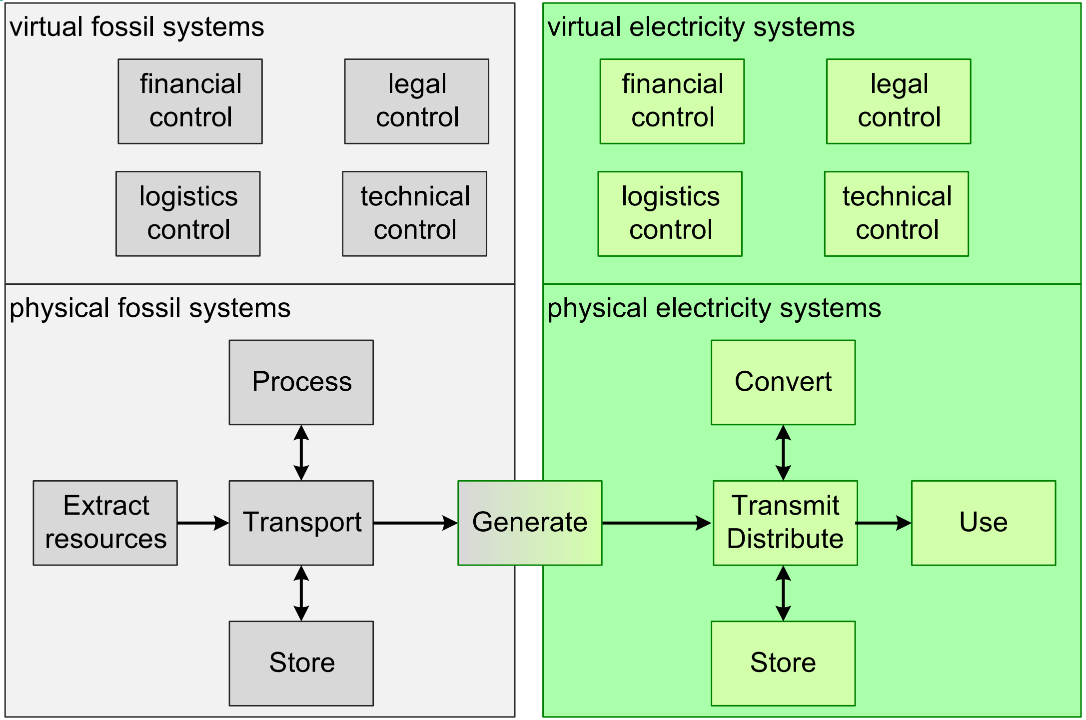
- How **sensitive** is the model for parameter or data **changes**?
- How do we reason about **use cases**?
- How do we reason about **options** and **risks**?
- What happens when we make **wrong assumptions**?

Remember Texas in the winter of 2021?

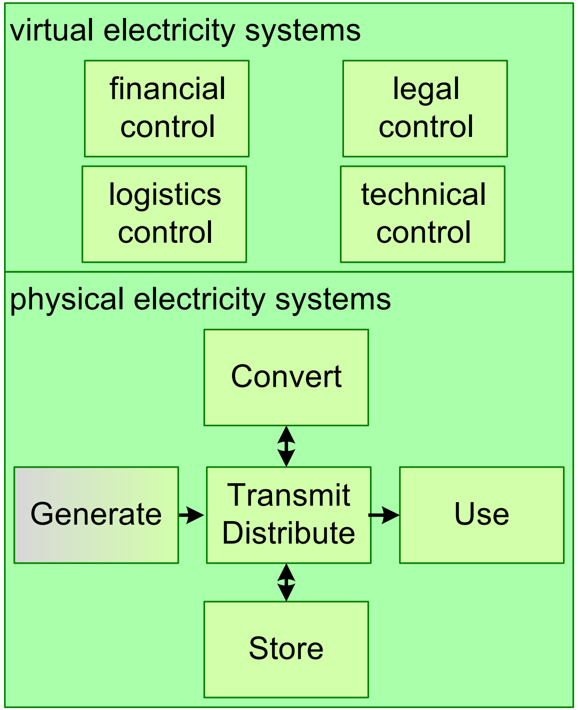




A Model of the As-Is Energy System



Main Questions about the Renewable Energy System



What is an **appropriate configuration** and **sizing** of

generation, **transmission**, **distribution**, **storage**, and **demand control**

to obtain a **sustainable**, **robust**, **reliable**, and **affordable**

energy system?

What **legal**, **financial**, **logistics**, and **technical**

control strategies and measures

do we need to **operate** these **resources effectively**?

What Architecting Means do we need?

What **methods**, **techniques**, **formalisms**, **models**, and **tools**

will help us to **create** and **explore problem** and **solution space**

to **understand**, **communicate**, **reason**, and **facilitate decision making**,

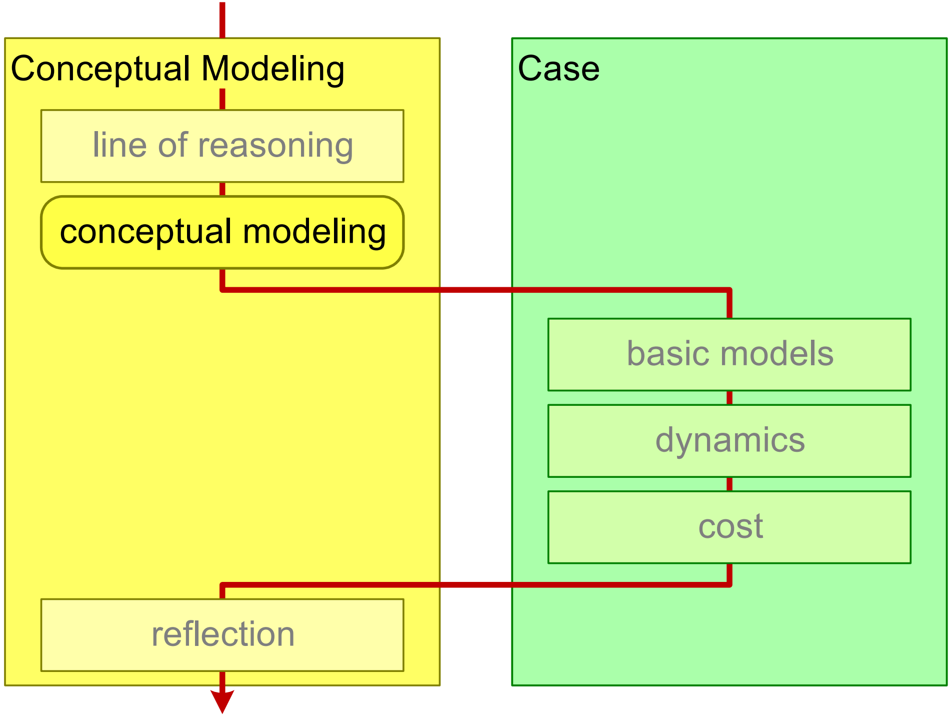
with **many diverse stakeholders** and

a large set of **complicated technology options**,

ranging from **idea** stage to fully **mature**,

in a **complex natural environment**?

Conceptual Modeling



First Principle Models

First principle model: a model based on **theoretical** principles.

A first principle model **explains** the desired property from first principles from the **laws of physics**.

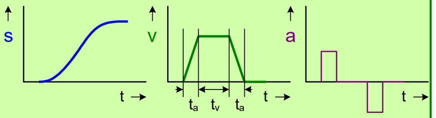
A first principle model **requires values** for **incoming parameters** to calculate results.

first principle model $t_{top\ floor}$ elevator

$v = \frac{dS}{dt}$ $\quad a = \frac{dv}{dt}$ $\quad j = \frac{da}{dt}$

Position in case of uniform acceleration :

$S_t = S_0 + v_0 t + \frac{1}{2} a_0 t^2$



$t_{top\ floor} = t_a + t_v + t_a$

$t_a = v_{max} / a_{max}$

$S(t_a) = \frac{1}{2} * a_{max} * t_a^2$

$S_{linear} = S_{top\ floor} - 2 * S(t_a)$

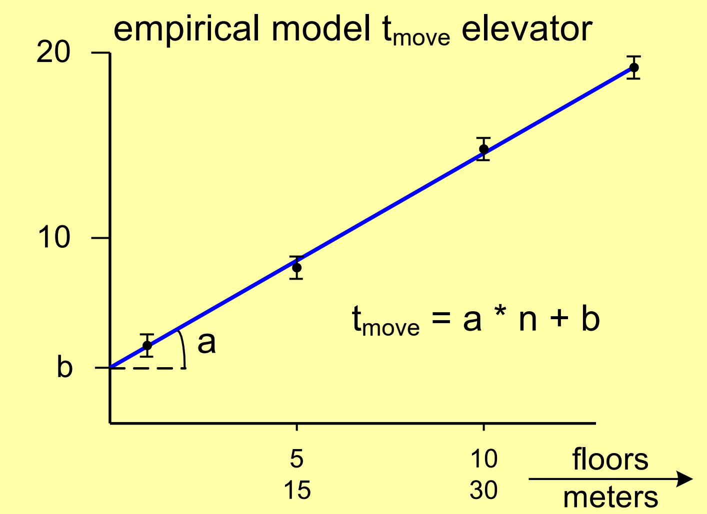
$t_v = S_{linear} / v_{max}$

Empirical Models

Empirical model: a model based on **observations** and **measurements**.

An empirical model ***describes*** the observations.

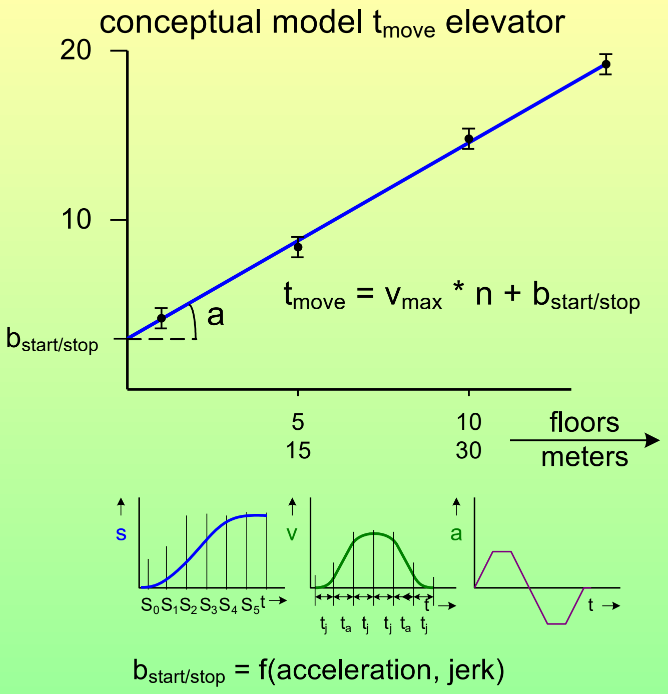
An empirical model provides **no understanding**.



Conceptual Models

Conceptual model: a model **explaining observations** and **measurements** using a selection of **first principles**.

A conceptual model is a **hybrid** of empirical and first principle models; **simple** enough to **understand** and to **reason, realistic** enough to make **sense**.



Mental Models

Mental Models are models in our **human brains**. These models depend entirely on the **individual** and his/her background

Mental models help us to ***think***.

Individuals may have a verbal or visual orientation, they may think in concrete or abstract ways, etc.

mental models of an elevator

Simulations

Simulation: an executable model based on **first principle** and **empirical models**.

Designers run simulations to ***explore***, ***analyze***, and ***gain insights***.

A simulation provides **understanding**, when **the users transform** the outcomes into **insights**.

simulation of an elevator

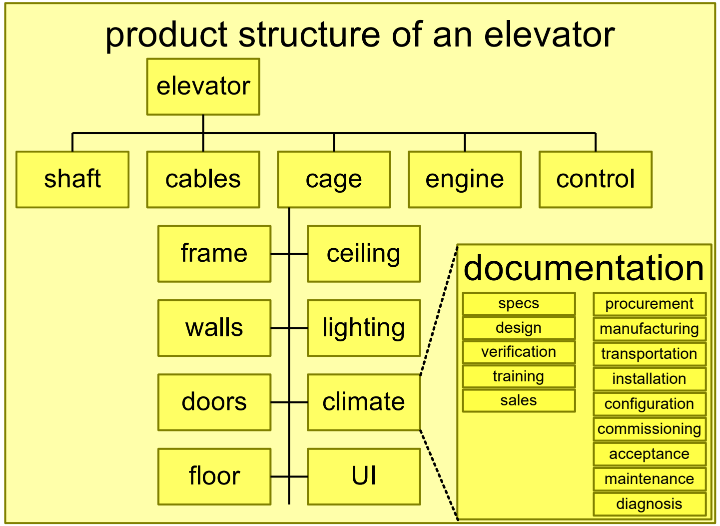
dt	0.2	s	
vmax	2.5	m/s	
amax	1	m/s2	

t (s)	s (m)	v (m/s)	a (m/s2)
0	0	0	1
0.2	0.02	0.2	1
0.4	0.08	0.4	1
0.6	0.18	0.6	1
0.8	0.32	0.8	1
1	0.50	1	1
1.2	0.72	1.2	1
1.4	0.98	1.4	1
1.6	1.28	1.6	1
1.8	1.62	1.8	1
2	2.00	2	1
2.2	2.42	2.2	1
2.4	2.88	2.4	1
2.6	3.38	2.6	0
2.8	3.90	2.6	0
3	4.42	2.6	0
3.2	4.94	2.6	0
3.4	5.46	2.6	0

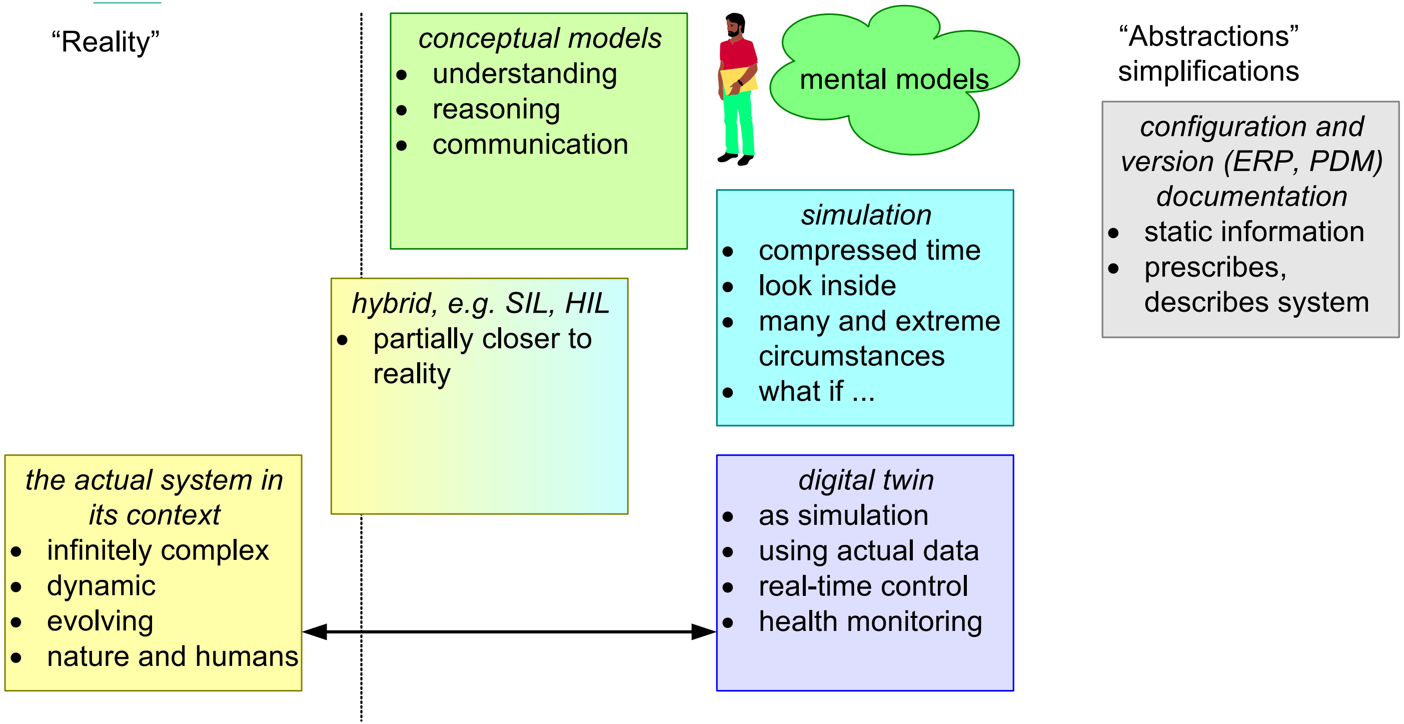
Product Structure and Documentation

The **Product Structure** prescribes the **parts hierarchy**. Each part in the hierarchy has associated **documentation** and **information** for the entire **life cycle.**

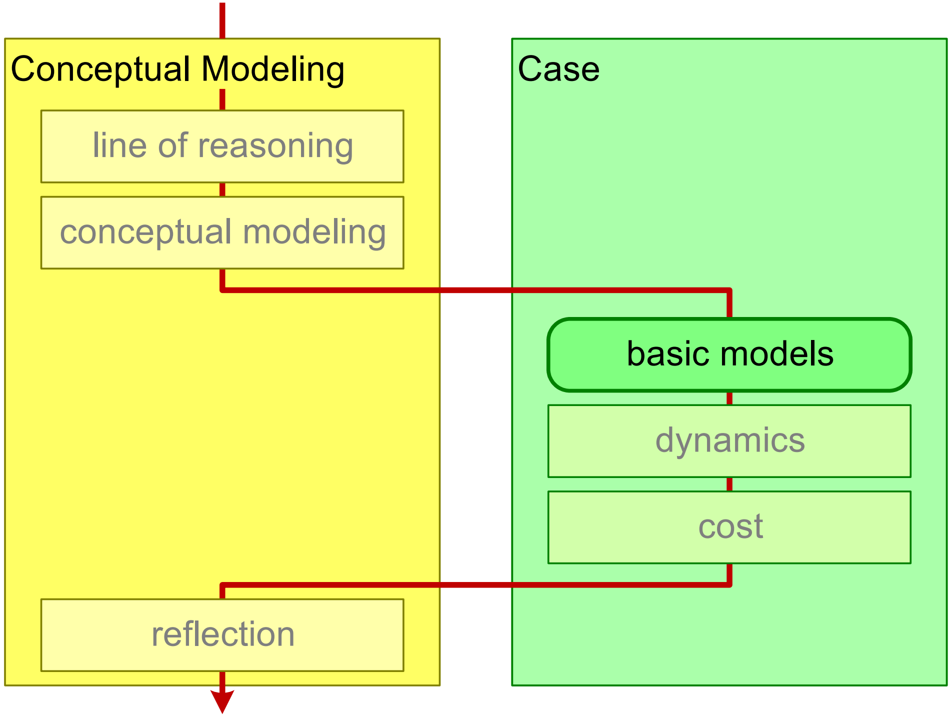
The Product Structure and associated documentation help the organization to ***manage*** all processes from creation to decommissioning and recycling, via **ERP**, **PDM**, **PLM** etc. systems.



Map of Various Model Types



Case



Conceptual Modeling
line of reasoning
conceptual modeling
reflection
Case
basic models
dynamics
cost

Starting Point: Irish Energy Data

NI: Northern Ireland
IE: Ireland

DateTime	GMT Offset	NI Generation	NI Demand	NI Wind Availability	NI Wind Generation	NI Solar Availability	NI Solar Generation	IE Generation	IE Demand	IE Wind Availability	IE Wind Generation	SNSP
01-01-2020 00:00	0	805.808	736.418	268.222	267.818	0	0	2708.45	3035.95	331.08	324.1	21.3%
01-01-2020 00:15	0	808.93	727.636	271.798	272.509	0	0	2757.59	3001.06	332.35	324.88	19.8%
01-01-2020 00:30	0	799.635	715.448	264.655	264.816	0	0	2765.93	2956.65	326.64	318.97	19.2%
01-01-2020 00:45	0	781.243	704.161	256.279	255.498	0	0	2741.16	2912.98	319	311.37	18.7%
01-01-2020 01:00	0	828.025	714.902	256.845	257.602	0	0					
01-01-2020 01:15	0	852.065	708.819	265.536	265.553	0	0					
01-01-2020 01:30	0	802.759	693.102	269.476	269.548	0	0					
01-01-2020 01:45	0	813.181	680.919	289.076	287.469	0	0					
01-01-2020 02:00	0	829.529	669.815	307.113	305.538	0	0					
01-01-2020 02:15	0	838.336	655.935	325.403	324.447	0	0					
01-01-2020 02:30	0	845.129	640.637	336.459	334.505	0	0					
01-01-2020 02:45	0	852.376	624.397	342.903	339.328	0	0					
01-01-2020 03:00	0	880.49	615.8	366.08	362.413	0	0					
01-01-2020 03:15	0	840.47	605.929	364.687	299.381	0	0					

https://www.eirgridgroup.com/how-the-grid-works/renewables/

Simulation Using Hydrogen Storage

wind trace data		
year	day	produc-tion
2018	1	44214
2018	2	39969
2018	3	51687
2018	4	19293
2018	5	15842
2018	6	26849
2018	7	14014
2018	8	43098
2018	9	50887

use

- daily use

21370

surplus
22844
18599
30317
-2077
-5528
5479
-7356
21729
29517

convert

* η_{H2}

50%

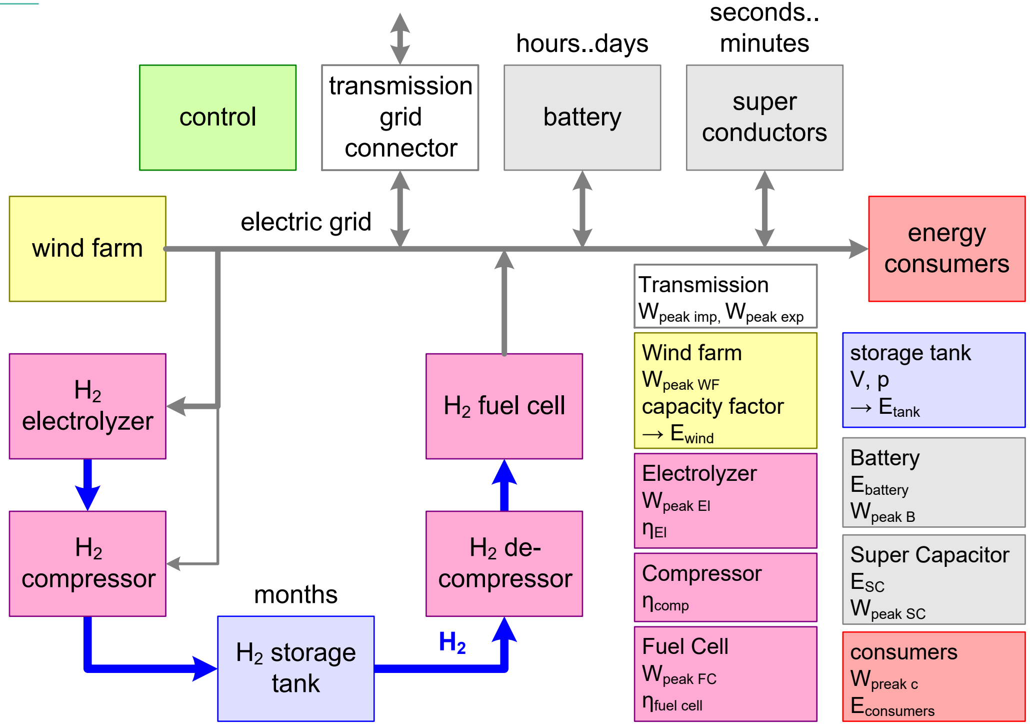
store/retrieve	
delta	storage
11422	700000
9300	709300
15159	724458
-2077	722382
-5528	716854
2740	719593
-7356	712237
10864	723101
14759	737860

aggregated production		
	2017	2018
jan	1179179	842549
feb	849591	1221703
mar	881203	1134683
apr	653040	863695
may	571785	503499
jun	322225	544853
jul	351038	522236
aug	618113	746528
sep	832528	710308
oct	968051	946287
nov	1270278	710351
dec	1041645	1100137
unscaled	9538677	9846828

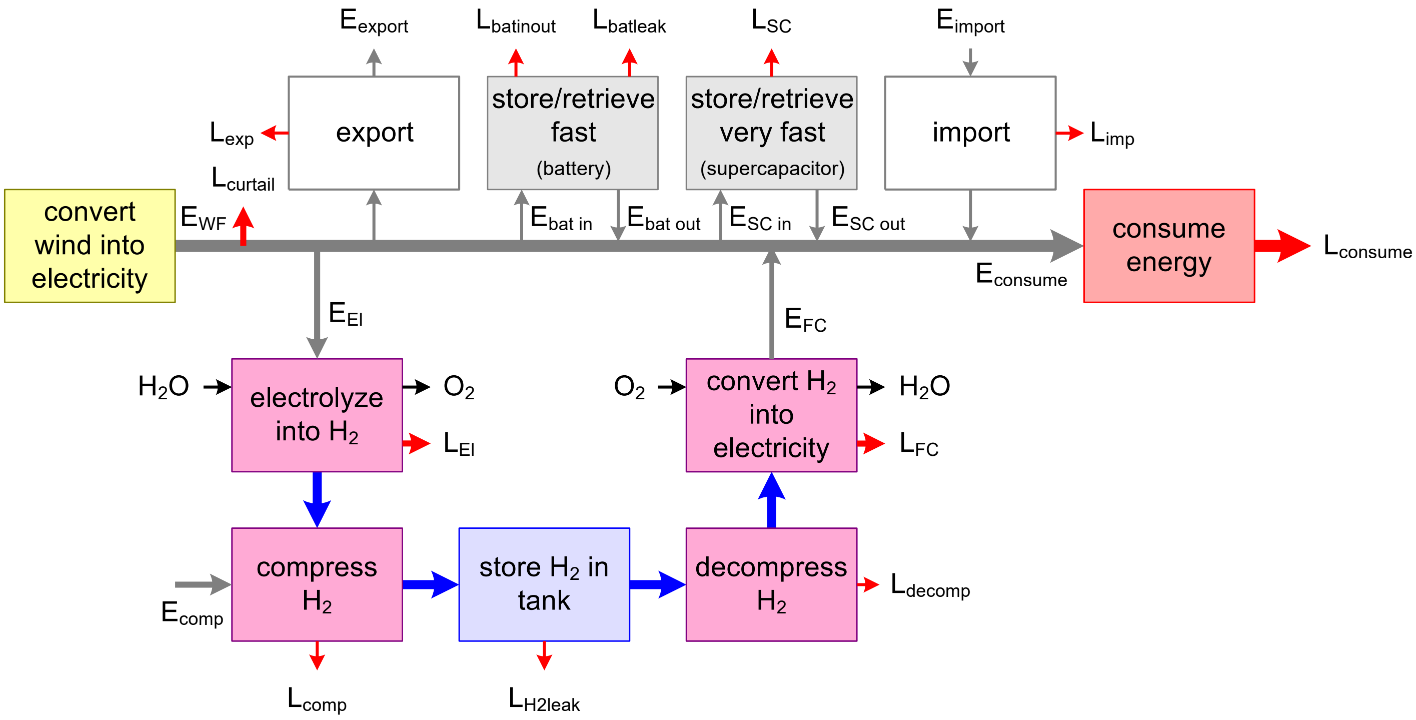
aggregated surplus			
surplus +		surplus -	
2017	2018	2017	2018
583321	337872	-66607	-157789
316200	669854	-64965	-46508
368354	536118	-149616	-63901
209203	310924	-197259	-88325
100599	114026	-191280	-272992
78620	122038	-397491	-218281
49842	125676	-361270	-265906
159892	242967	-204244	-158904
319105	262903	-127673	-193691
425785	389846	-120199	-106025
659014	232856	-29831	-163602
466746	530776	-87566	-93105
3736680	3875856	-1998003	-1829028

aggregated store/retrieve			
store		retrieve	
2017	2018	2017	2018
291660	168936	-66607	-157789
158100	334927	-64965	-46508
184177	268059	-149616	-63901
104601	155462	-197259	-88325
50300	57013	-191280	-272992
39310	61019	-397491	-218281
24921	62838	-361270	-265906
79946	121483	-204244	-158904
159553	131452	-127673	-193691
212892	194923	-120199	-106025
329507	116428	-29831	-163602
233373	265388	-87566	-93105
1868340	1937928	-1998003	-1829028

Block Diagram



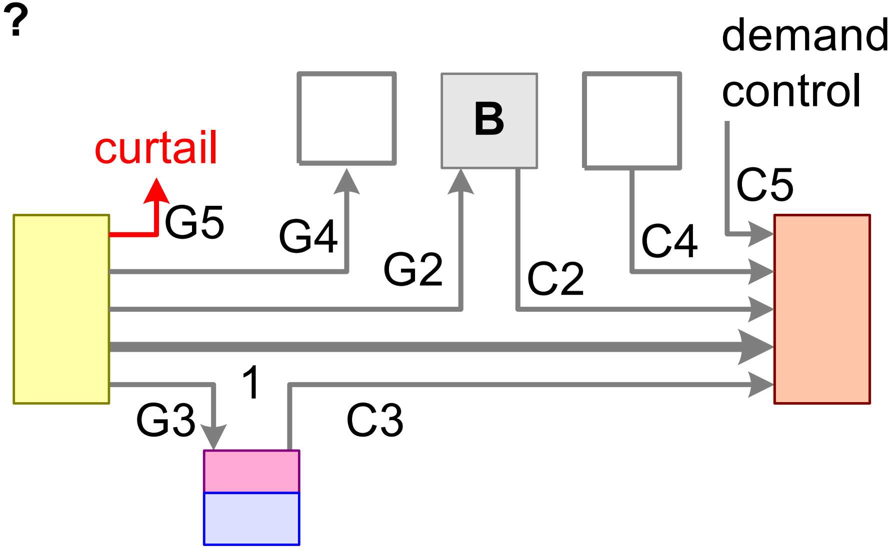
Functional Model



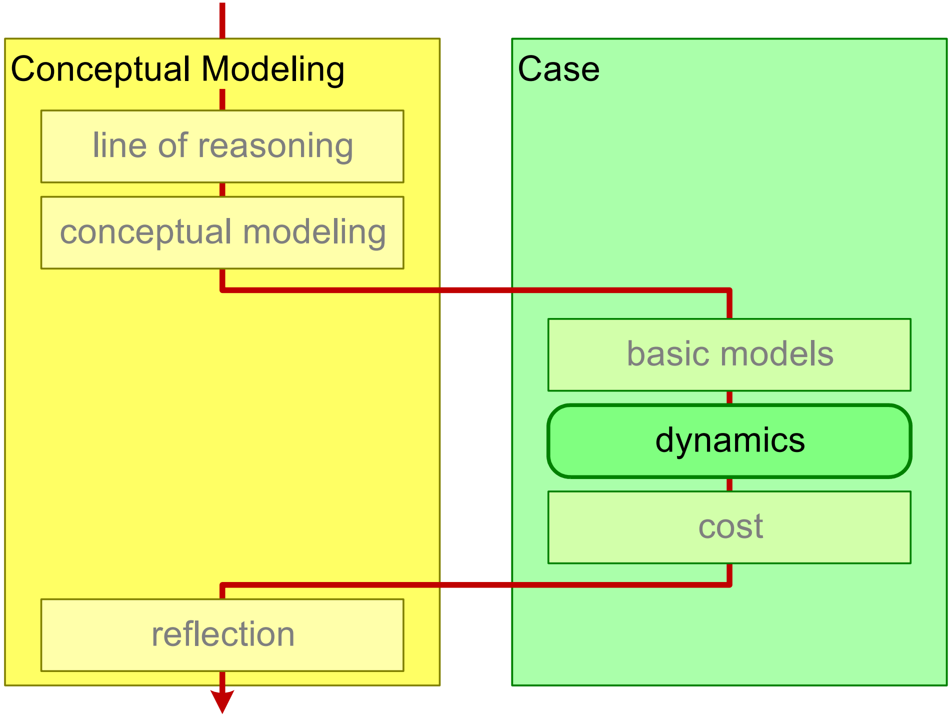
Scenarios for Energy Flows

How to utilize the options?

- *direct consumption*
- *battery storage*
- *Hydrogen storage*
- *over-sized generation*
- *import, export*
- *demand control*

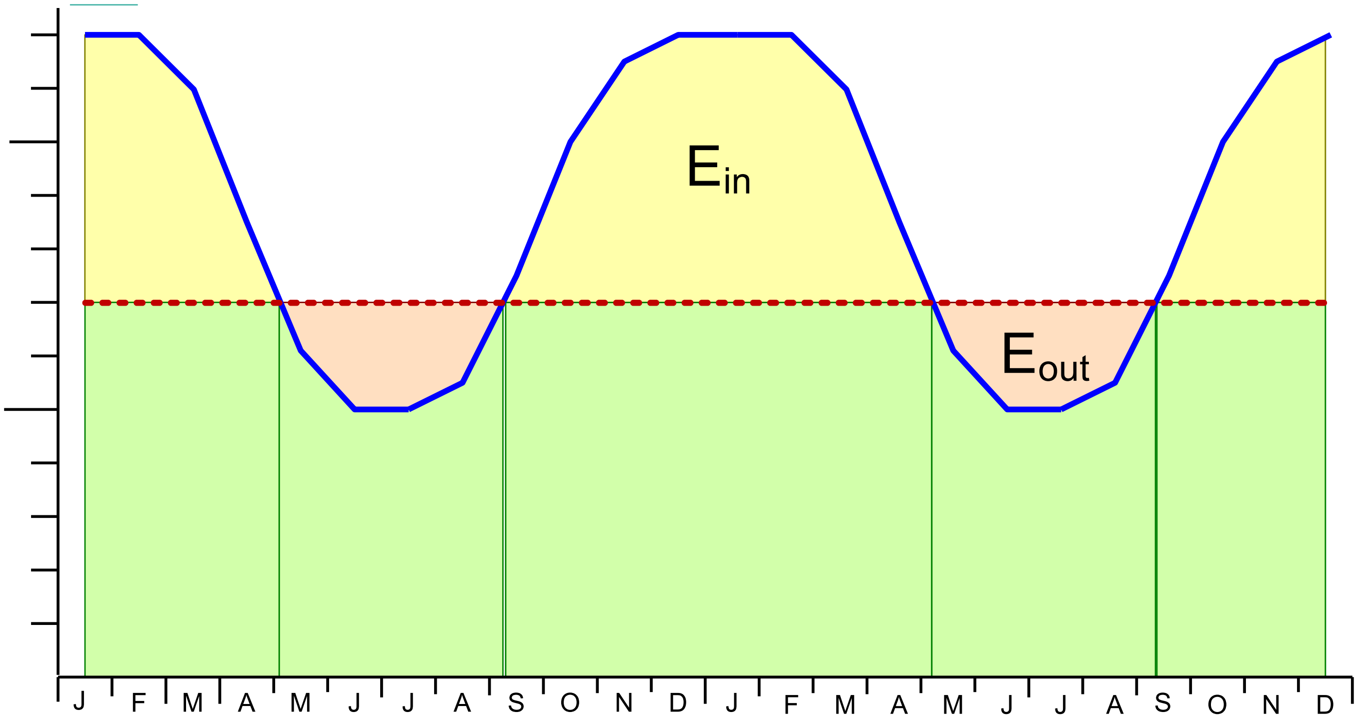


Dynamics

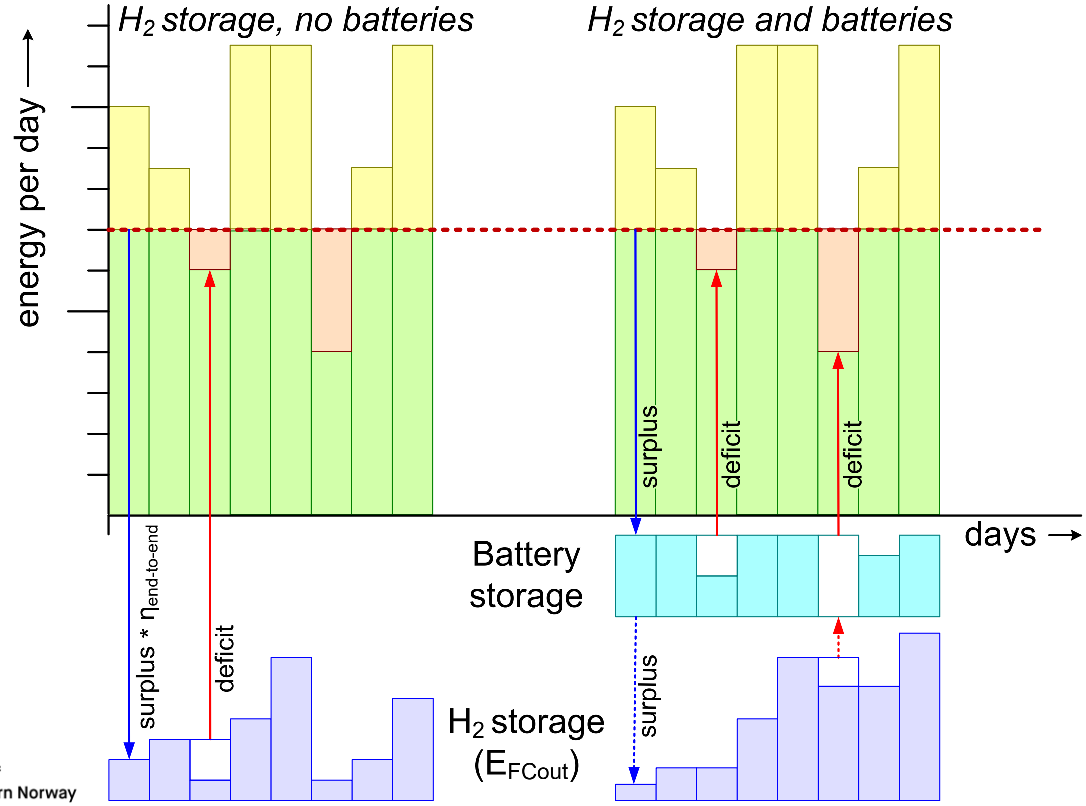


Conceptual Modeling
line of reasoning
conceptual modeling
reflection
Case
basic models
dynamics
cost

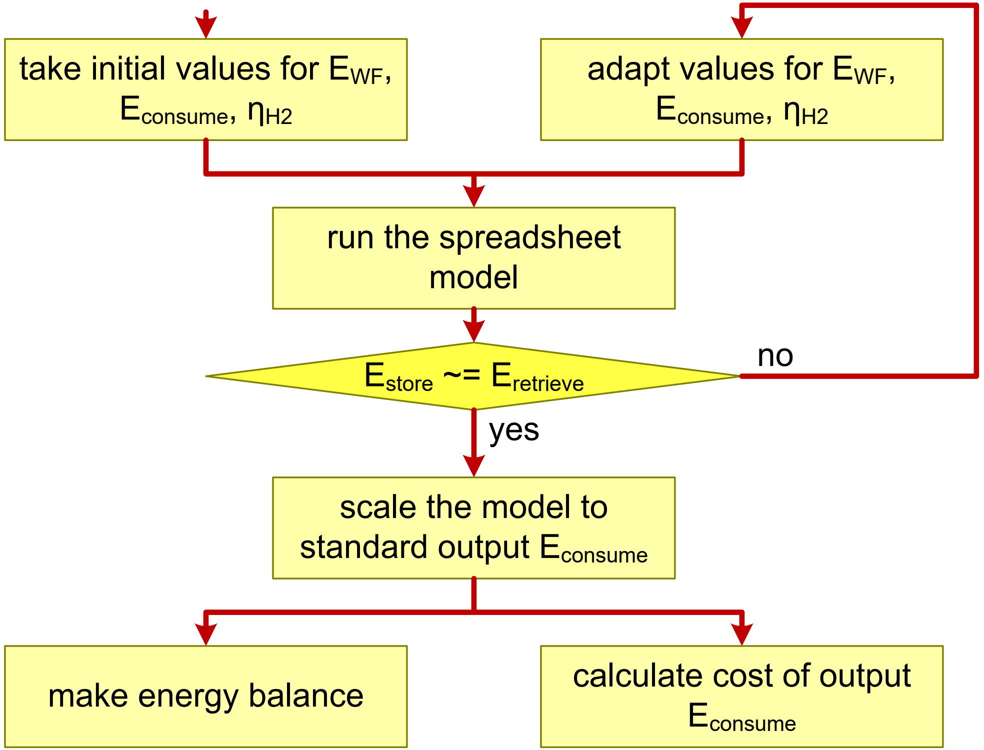
Idealized Production and Consumption



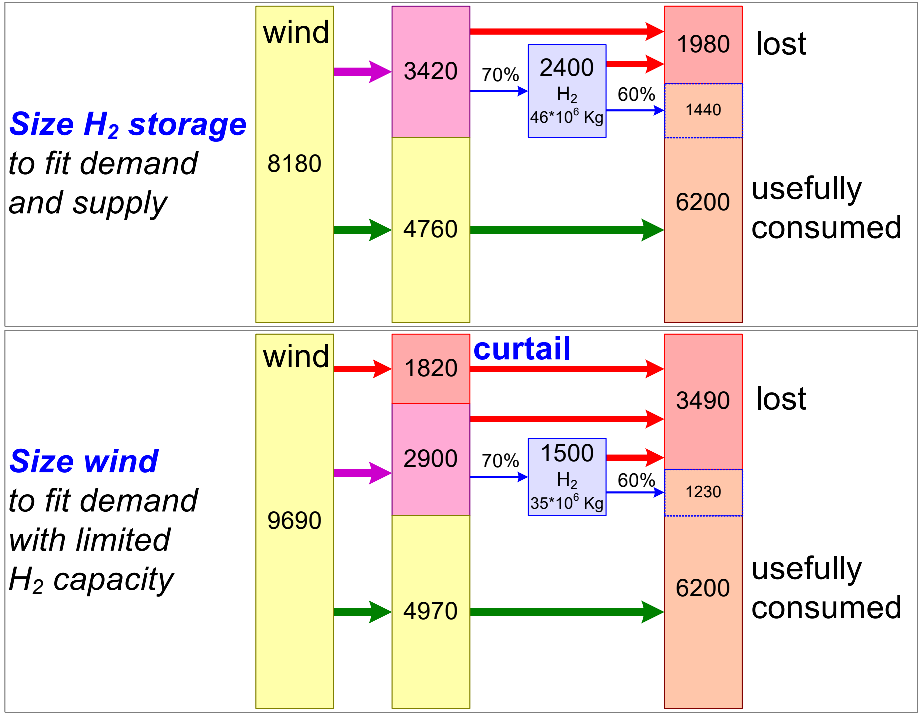
Zooming in on Days



Simulation Workflow

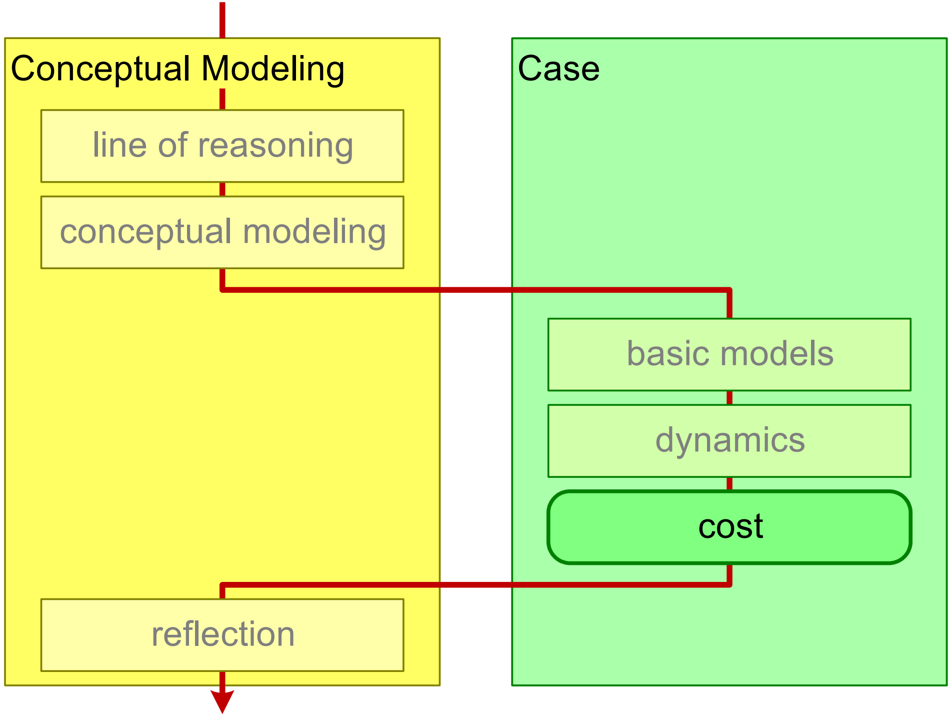


Energy Balance without and with Curtailment

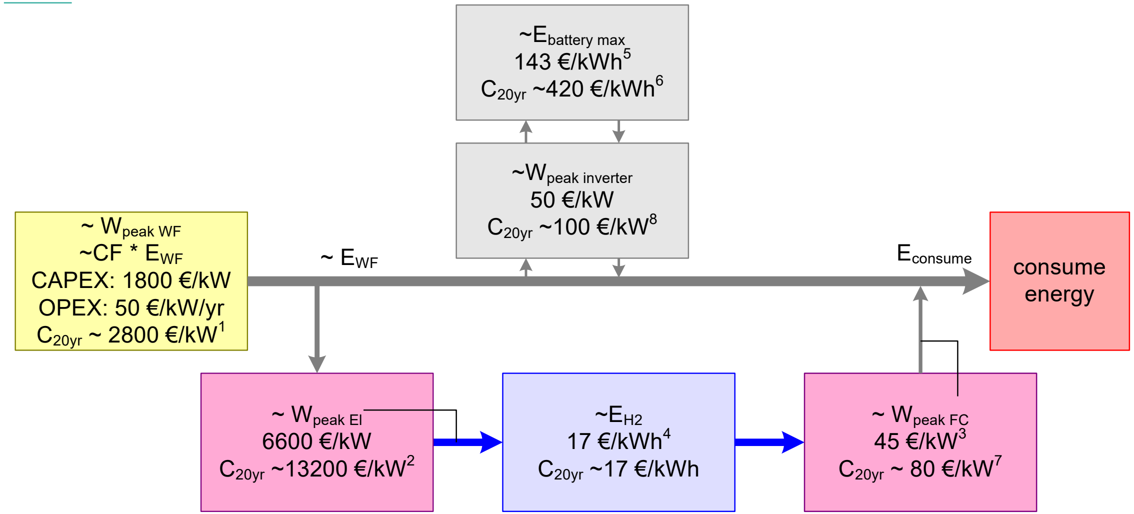


all numbers GWh/year

Cost


Conceptual Modeling
line of reasoning
conceptual modeling
reflection
Case
basic models
dynamics
cost

Cost Model; Guestimates, 2019 data



[1] https://www.pbl.nl/sites/default/files/downloads/pbl-2019-costs-of-offshore-wind-energy-2018_3623.pdf

[2] using 10 k$ for 1 KG H_2 in 24 hrs, 33.33kWh/Kg H2, and 0.92 €/$, 30000 hrs ~= 10 years https://pv-magazine-usa.com/2020/03/26/electrolyzer-overview-lowering-the-cost-of-hydrogen-and-distributing-its-productionhydrogen-industry-overview-lowering-the-cost-and-distributing-production/

[3] https://www.energy.gov/eere/fuelcells/fact-month-april-2018-fuel-cell-cost-decreased-60-2006

[4] https://energypost.eu/the-lowdown-on-hydrogen-part-1-transportation/

[5] https://www.greencarcongress.com/2019/12/20191204-bnef.html

[6] 1000 full cycles, let's assume 7 years, https://www.forbes.com/sites/arielcohen/2020/12/30/teslas-new-lithium-ion-patent-brings-company-closer-to-promised-1-million-mile-battery/

[7] 40000 hours at - 35 °C to 40 °C, ~12 years https://en.wikipedia.org/wiki/Fuel_cell

[8] assuming 10 years https://www.nrel.gov/docs/fy19osti/72399.pdf

Energy Cost; Curtailment is Lower in Cost!

*assuming 70% * 60% = 42% efficiency*

electrolyzer Fuel Cell

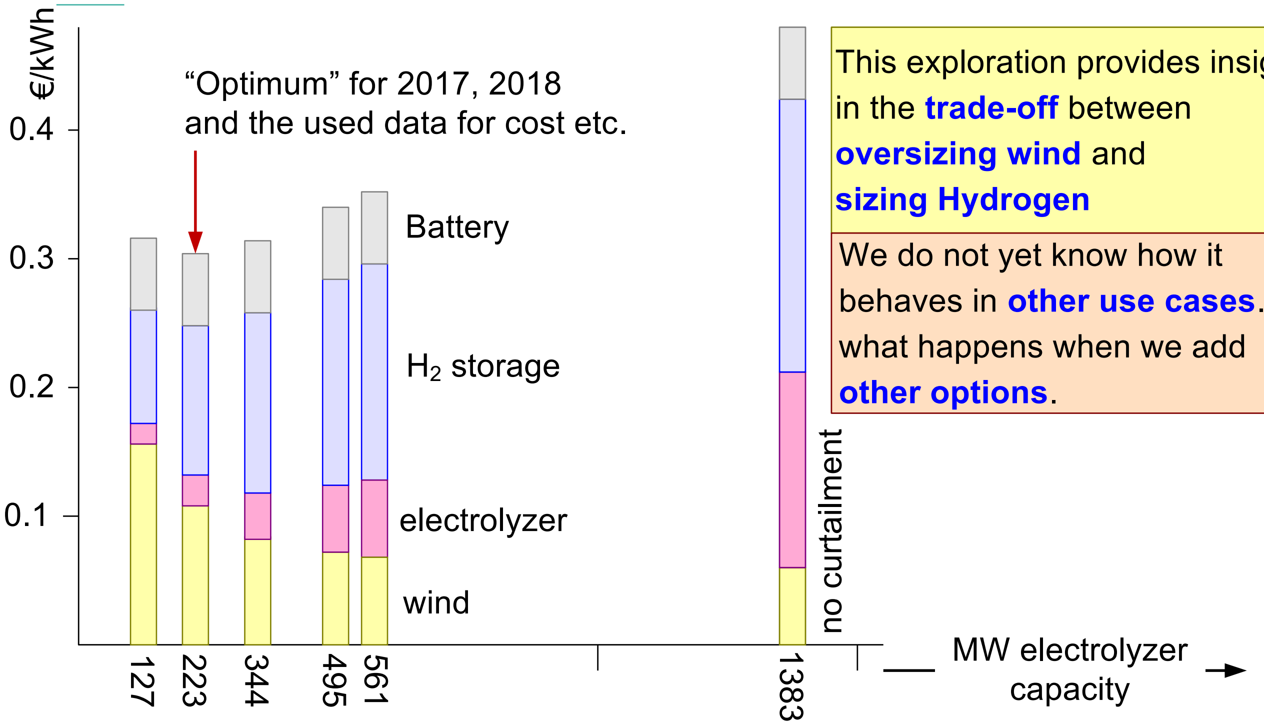
H2 storage	wind farm	Electrolyzer	H_2 storage	Battery
	0.061 €/kWh	0.147 €/kWh	0.211 €/kWh	0.058 €/kWh

~ 0.48 €/kWh

(over) sizing wind with curtailing	wind farm	Electro-lyzer	H_2 storage	Battery
	0.072 €/kWh	0.053 €/kWh	0.161 €/kWh	0.058 €/kWh

~ 0.35 €/kWh

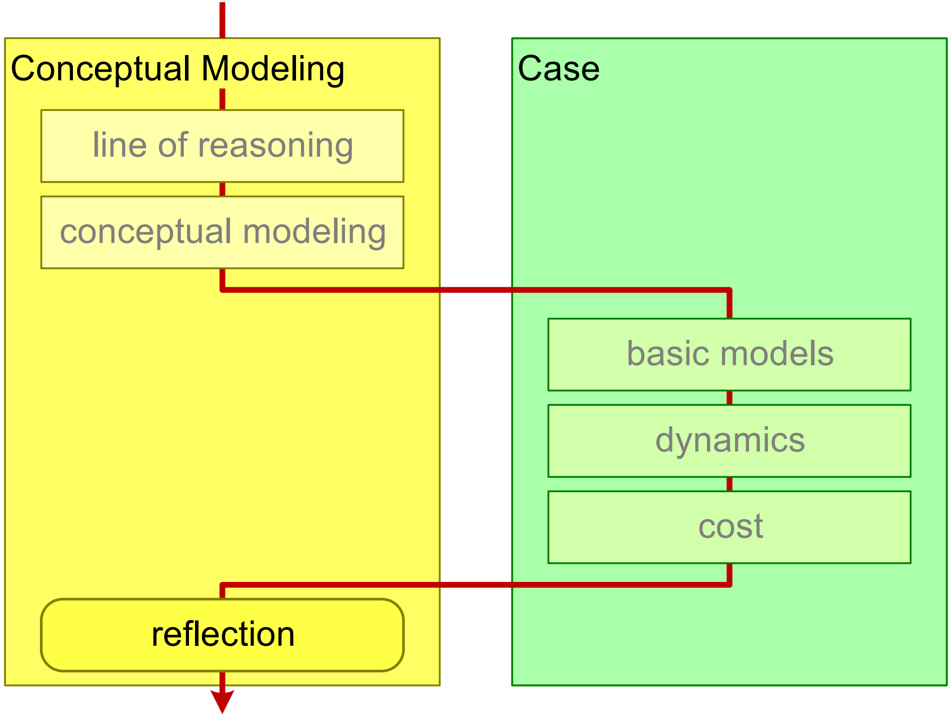
Energy Cost as Function of H2 Size



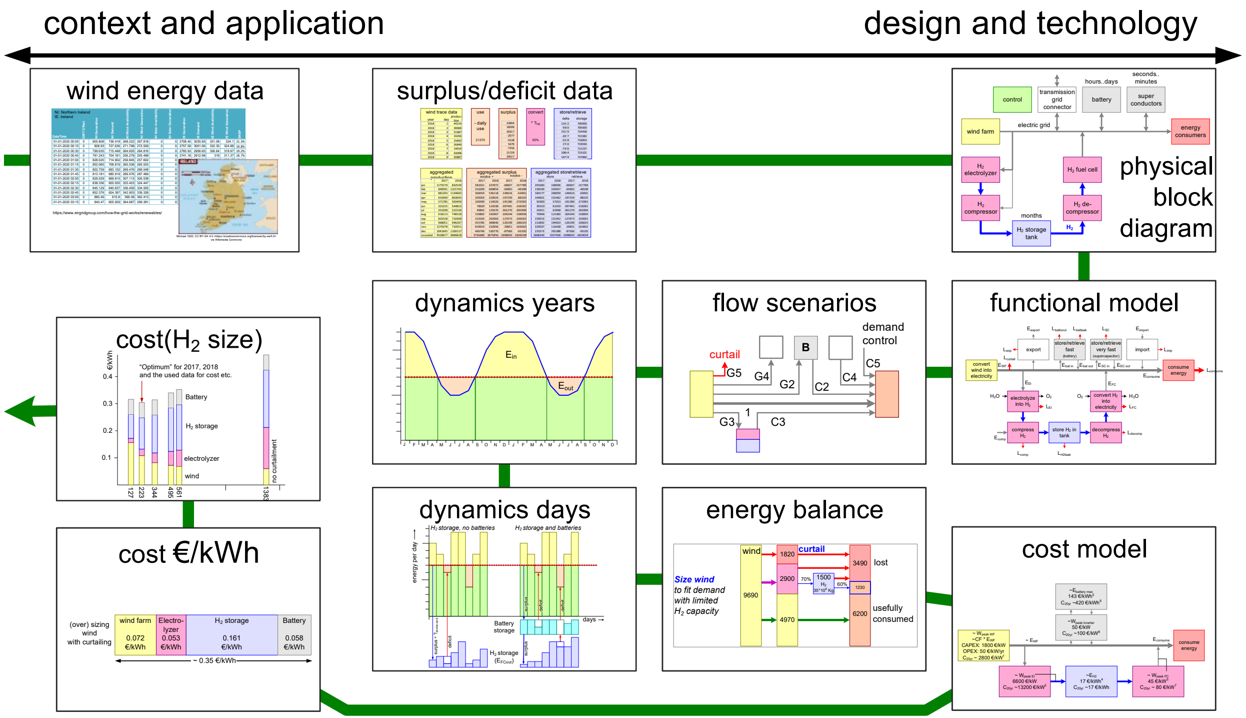
This exploration provides insight in the **trade-off** between **oversizing wind** and **sizing Hydrogen**

We do not yet know how it behaves in **other use cases**. Or what happens when we add **other options**.

Figure of Content



Case Summary



What Conceptual Modeling brings

- transforming **data** into **insights**
- using **visualizations** to **reason** and to **share**
- using a **wide variety of models**
- grasping the **dynamics** and the **emergent behavior** and **properties**
- translating a **problem** into **needs** into **solution concepts**
- transforming solution concepts into **application consequences**
- and keep **iterating** until sufficient insight is achieved

Questions?

You can reach me via email:

Gerrit.muller@usn.no

More information:

Gaudisite.nl

https://gaudisite.nl/Sustainability.html

https://gaudisite.nl/SEMAmaterial.html