Europäisches Institut für Klima und Energie
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The Heartland Institute

CFACT

COSTS OF ELECTRICITY AND CO_2 EMISSIONS IN THE PRESENCE OF RENEWABLES

- **Introduction: the renewable showcase and the logics behind the benefits**
- **Renewables expansion and the cost of electricity**
  - Generation LCOE (what is shown).
  - Grid cost of electricity (what is hidden).
  - The green trick.
- **Renewables expansion and CO_2 emissions**
- **Is there a limit for renewables?**
- **US CO_2 emissions abatement attributable only to renewables.**
- **How renewables hinder CO_2 emissions reduction.**
- **Conclusions & epilogue.**

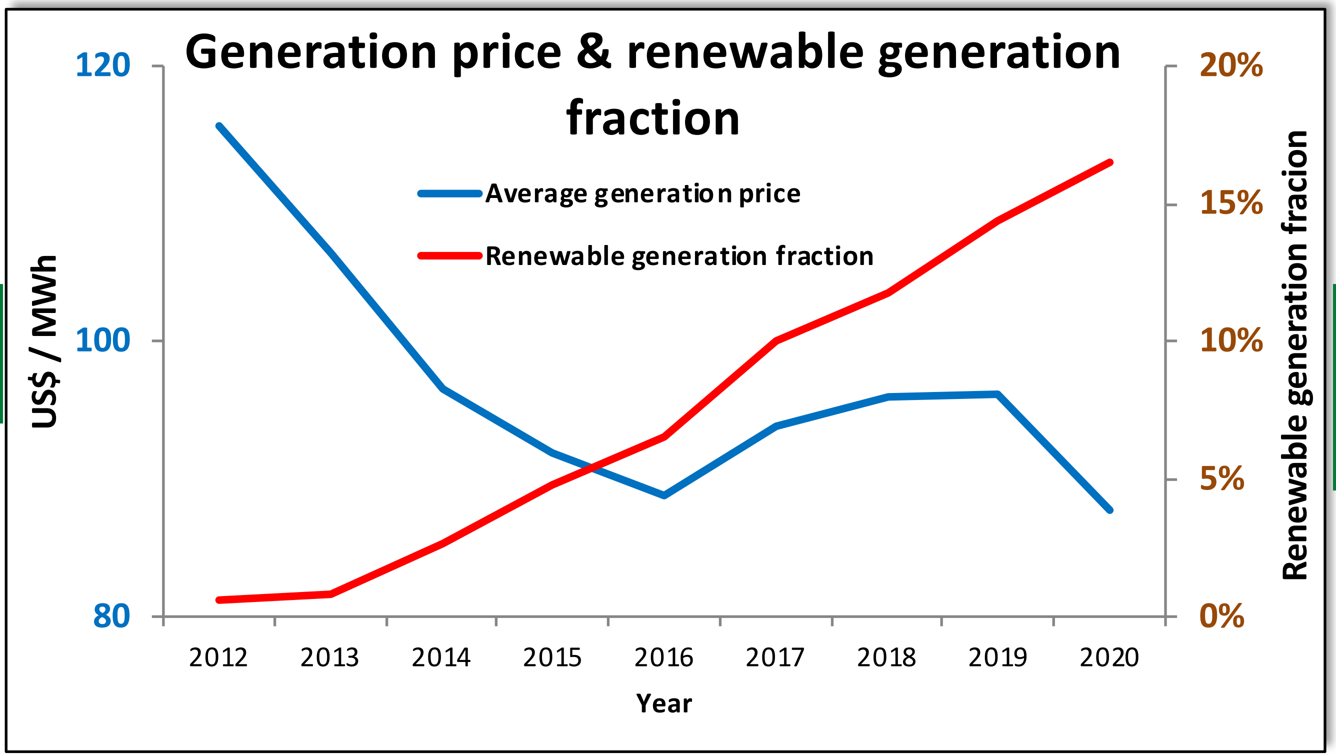
Douglas Pollock

The renewable showcase

The cost of electricity

What we are told to acknowledge…

Fuel cost of renewables is zero



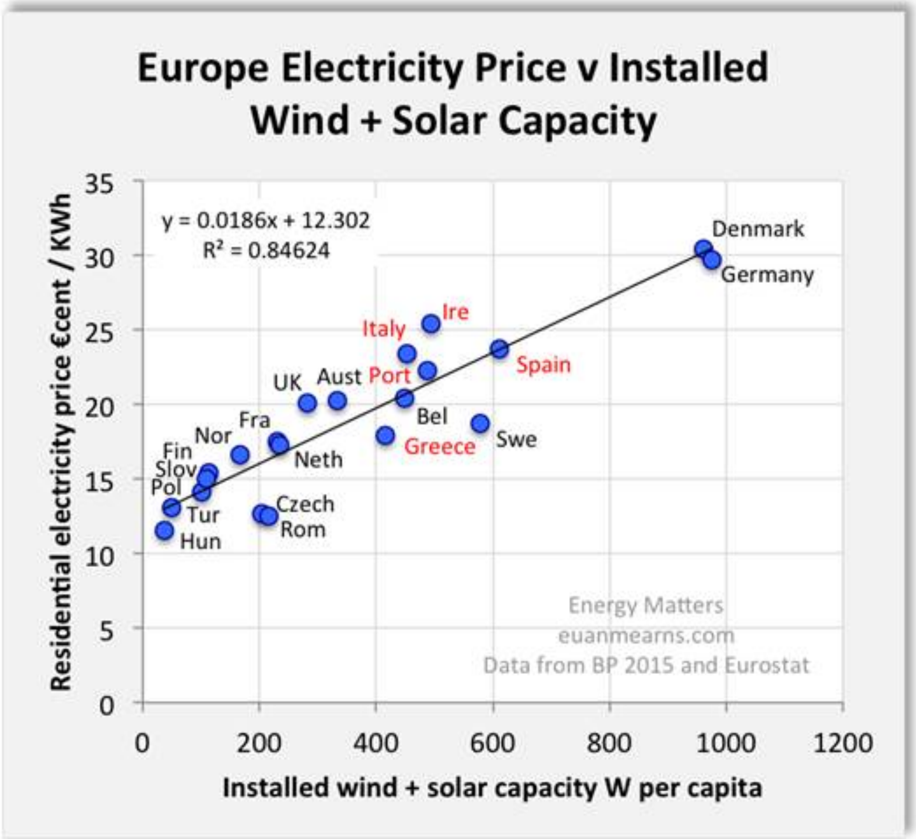
Cost of renewables have plummeted

Electricity generation price: Comisión Nacional de Energía, CNE; https://www.cne.cl/precio-medio-de-mercado-2/2020-2/

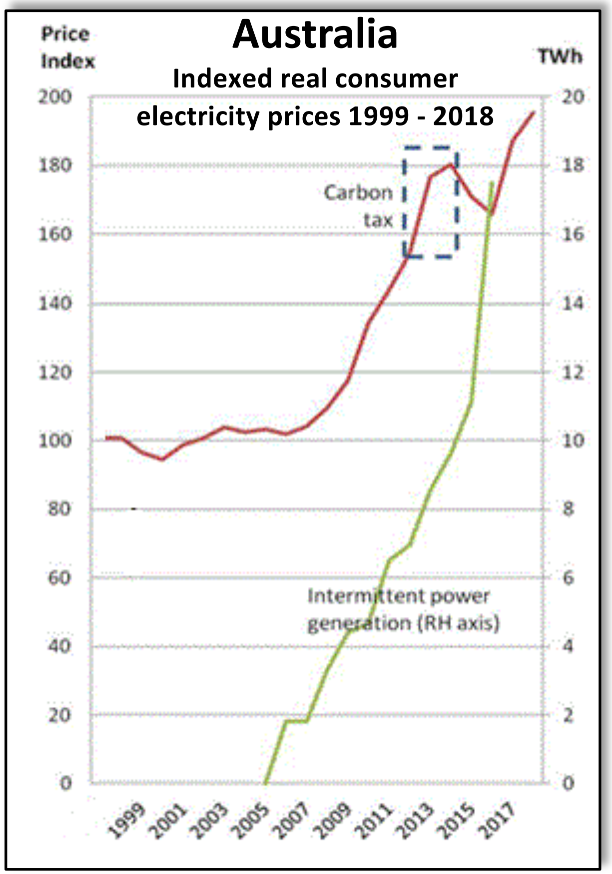
Renewable generation fraction: Generadoras de Chile; http://generadoras.cl/generacion-electrica-en-chile

The dissimilar costs of electricity

…versus facts

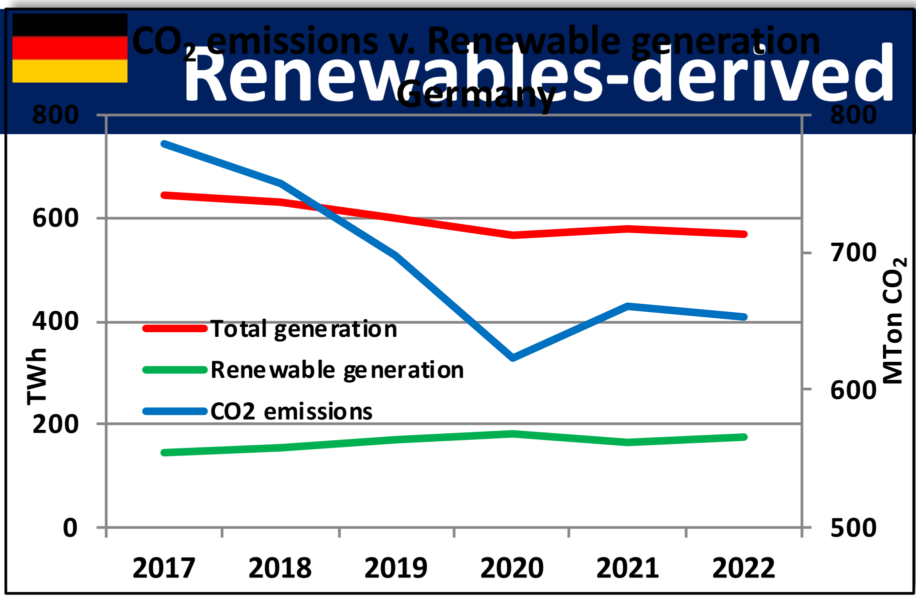


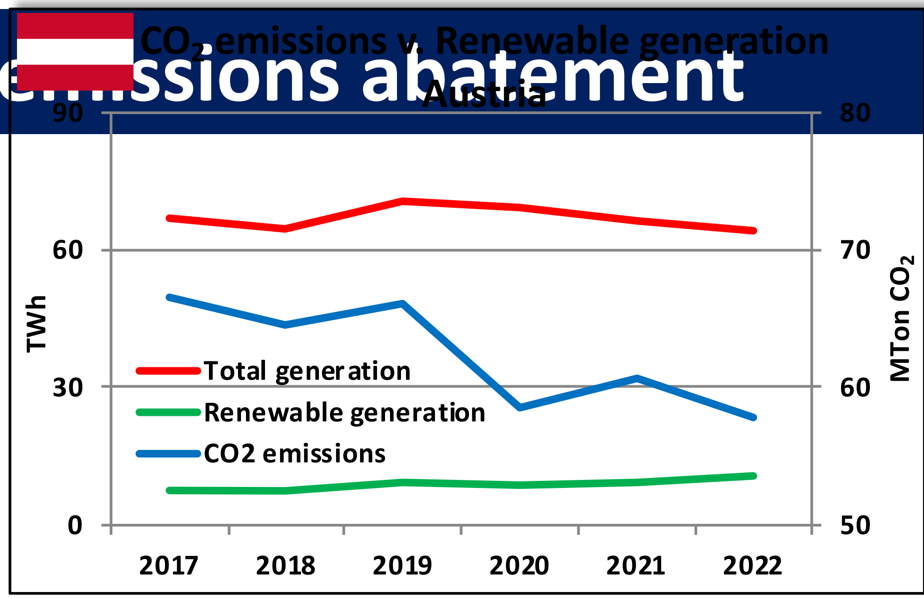
Energy prices in Europe. Energy matters: Green Mythology and the High Price of European Electricity

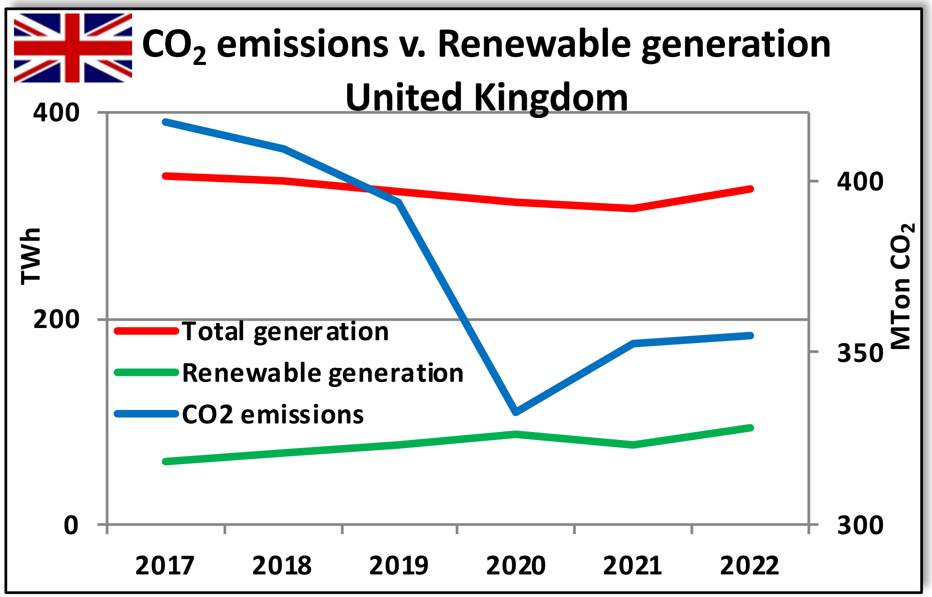


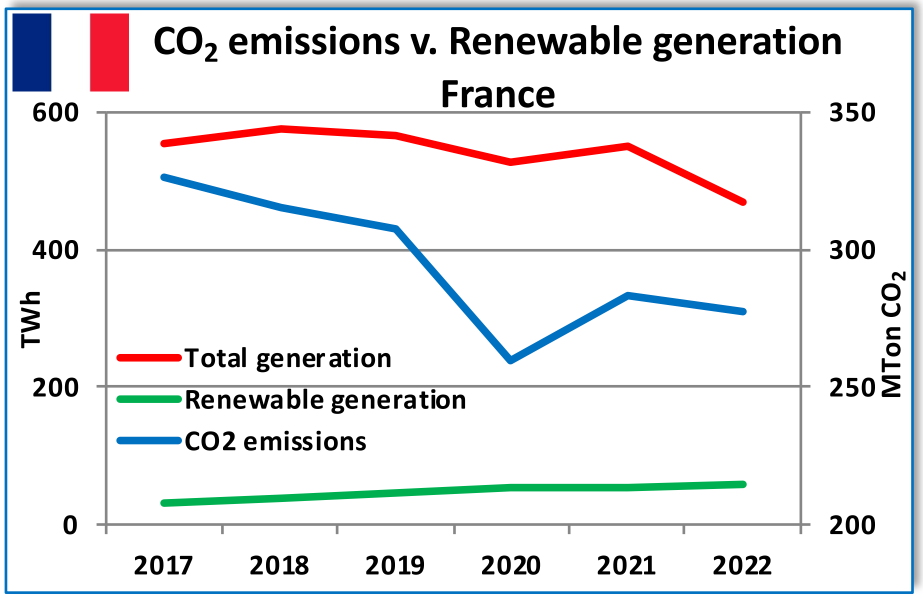
Bob Irvine, WUWT excerpt: Does Wind Intermittance Over Short Hourly Periods Gives a Clearer Picture?

Renewables-derived CO_2 emissions abatement

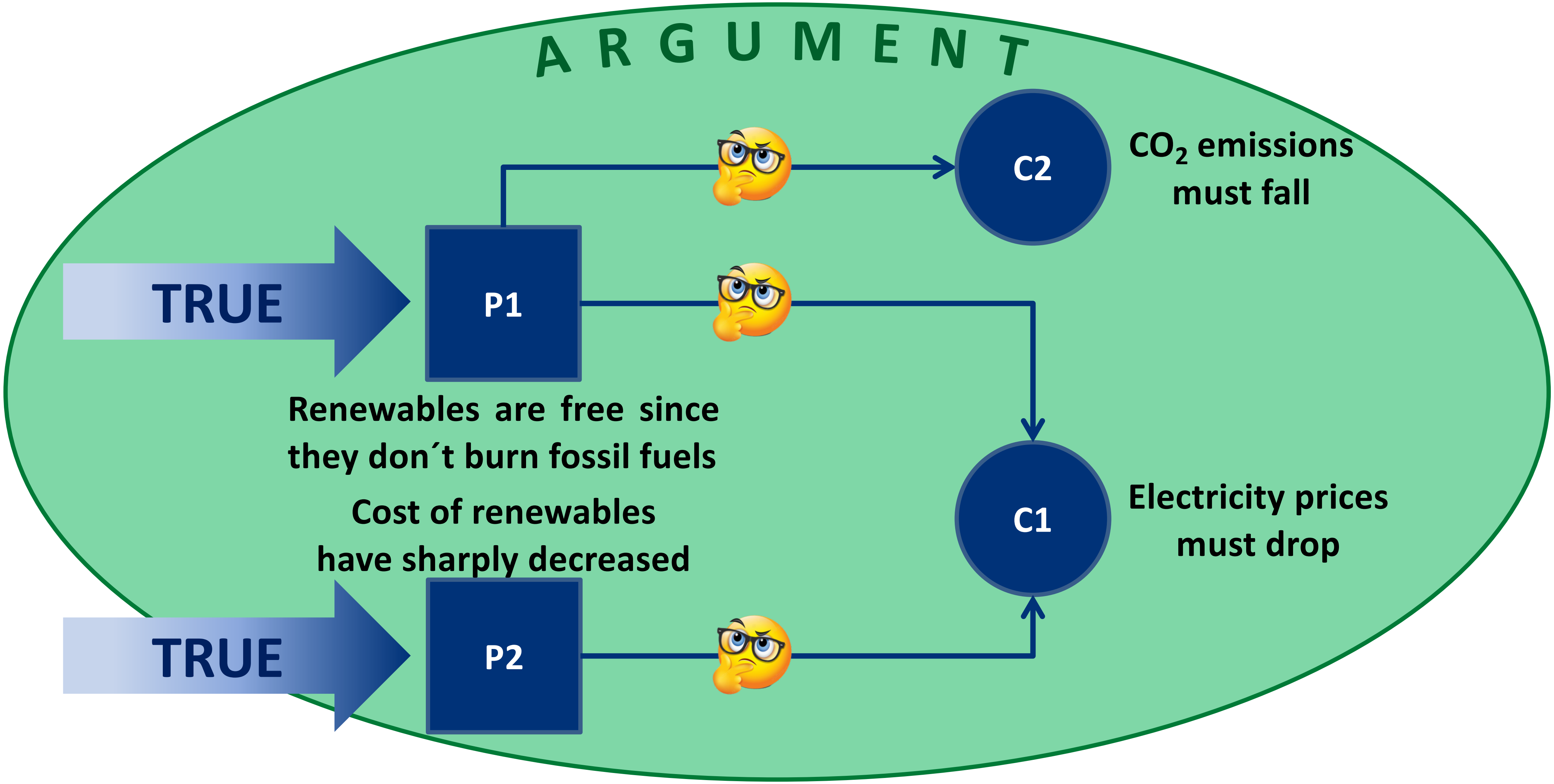






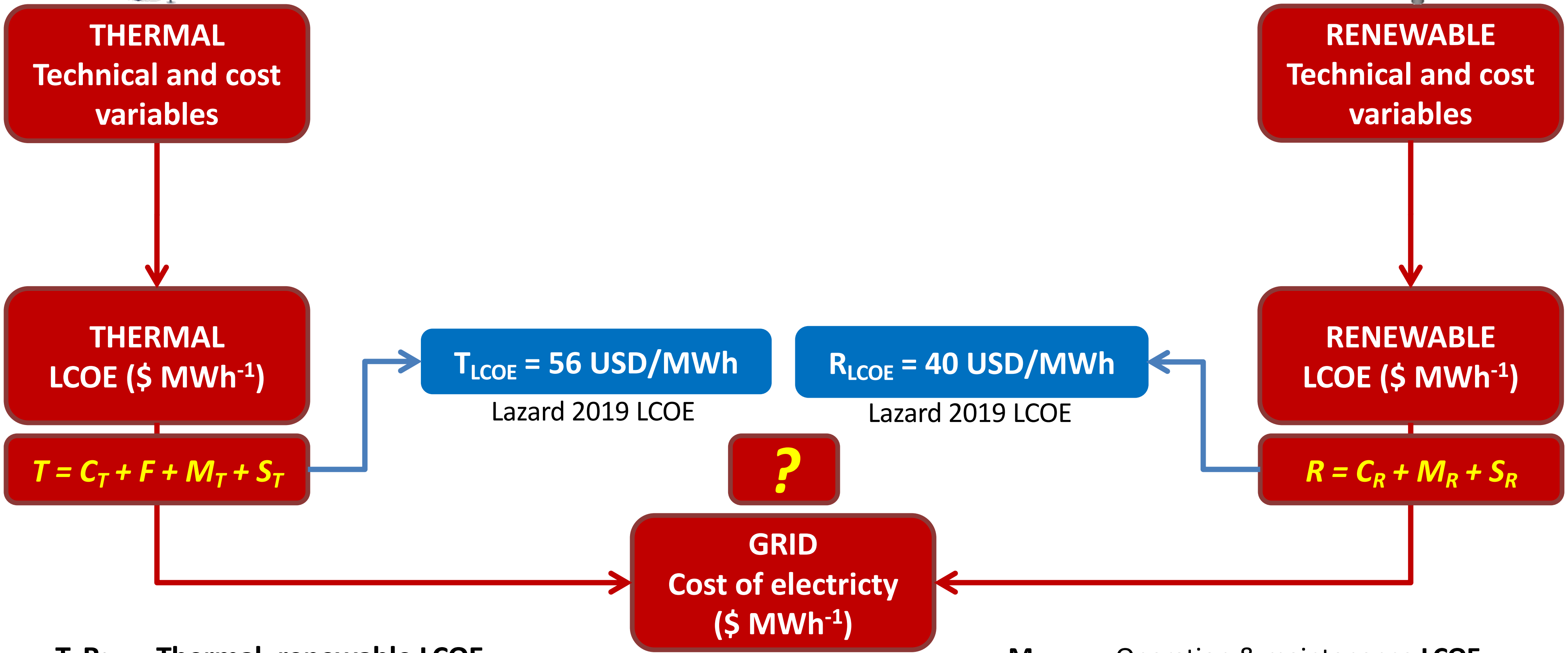


The logics behind the benefits: the green argument



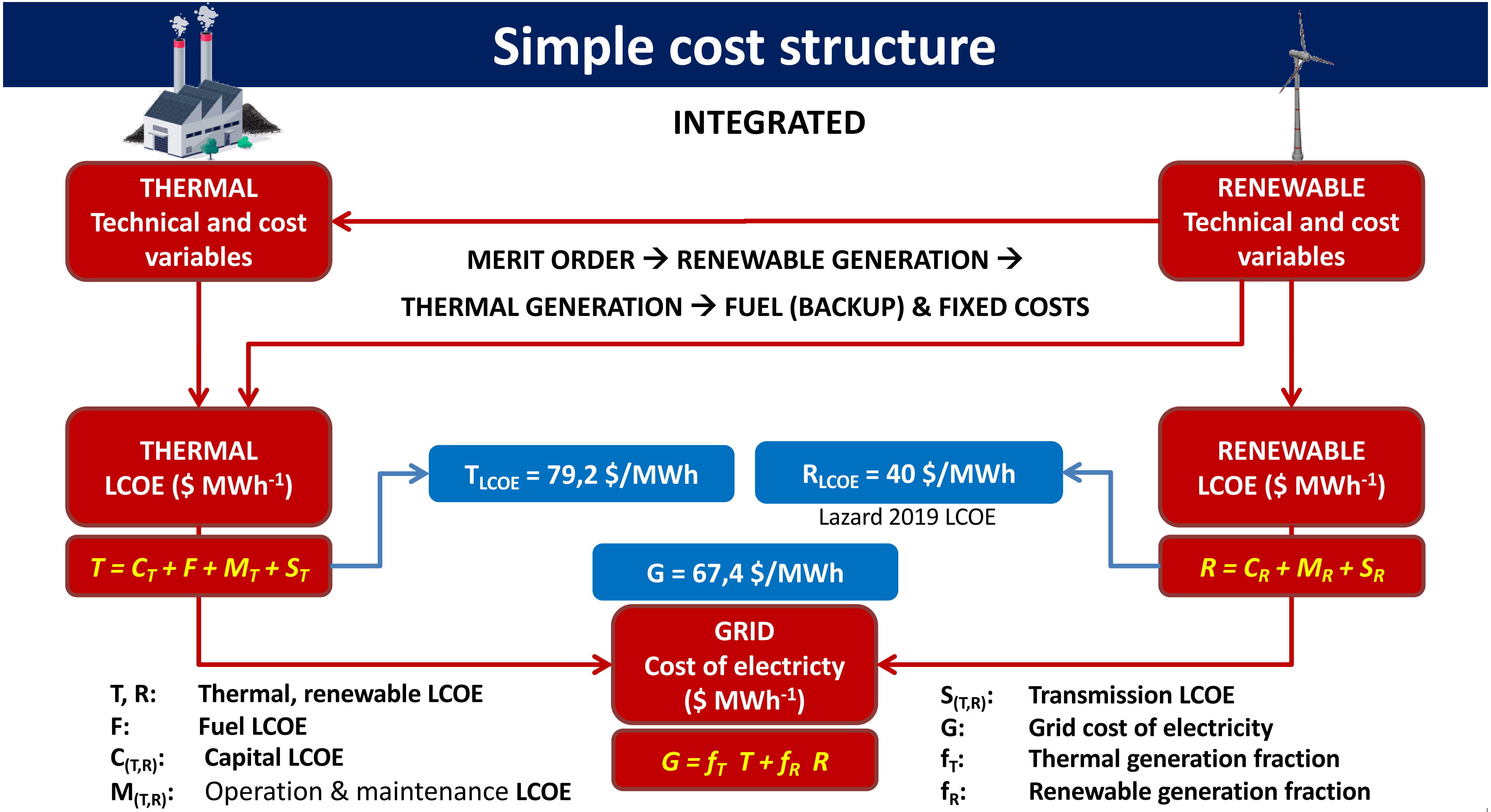
Simple cost structure

ISOLATED



T, R: Thermal, renewable LCOE
F: Fuel LCOE
$C_{(T,R)}$: Capital LCOE

$M_{(T,R)}$: Operation & maintenance **LCOE**
$S_{(T,R)}$: Transmission LCOE



Simple cost structure
INTEGRATED
THERMAL Technical and cost variables
RENEWABLE Technical and cost variables
MERIT ORDER → RENEWABLE GENERATION →
THERMAL GENERATION → FUEL (BACKUP) & FIXED COSTS
THERMAL LCOE ($ MWh^{-1})
$T = C_T + F + M_T + S_T$
T_{LCOE} = 79,2 $/MWh
R_{LCOE} = 40 $/MWh
Lazard 2019 LCOE
RENEWABLE LCOE ($ MWh^{-1})
$R = C_R + M_R + S_R$
G = 67,4 $/MWh
GRID Cost of electricty ($ MWh^{-1})
$G = f_T\ T + f_R\ R$
T, R: Thermal, renewable LCOE
F: Fuel LCOE
$C_{(T,R)}$: Capital LCOE
$M_{(T,R)}$: Operation & maintenance LCOE
$S_{(T,R)}$: Transmission LCOE
G: Grid cost of electricity
f_T: Thermal generation fraction
f_R: Renewable generation fraction

Generation in the absence of renewables

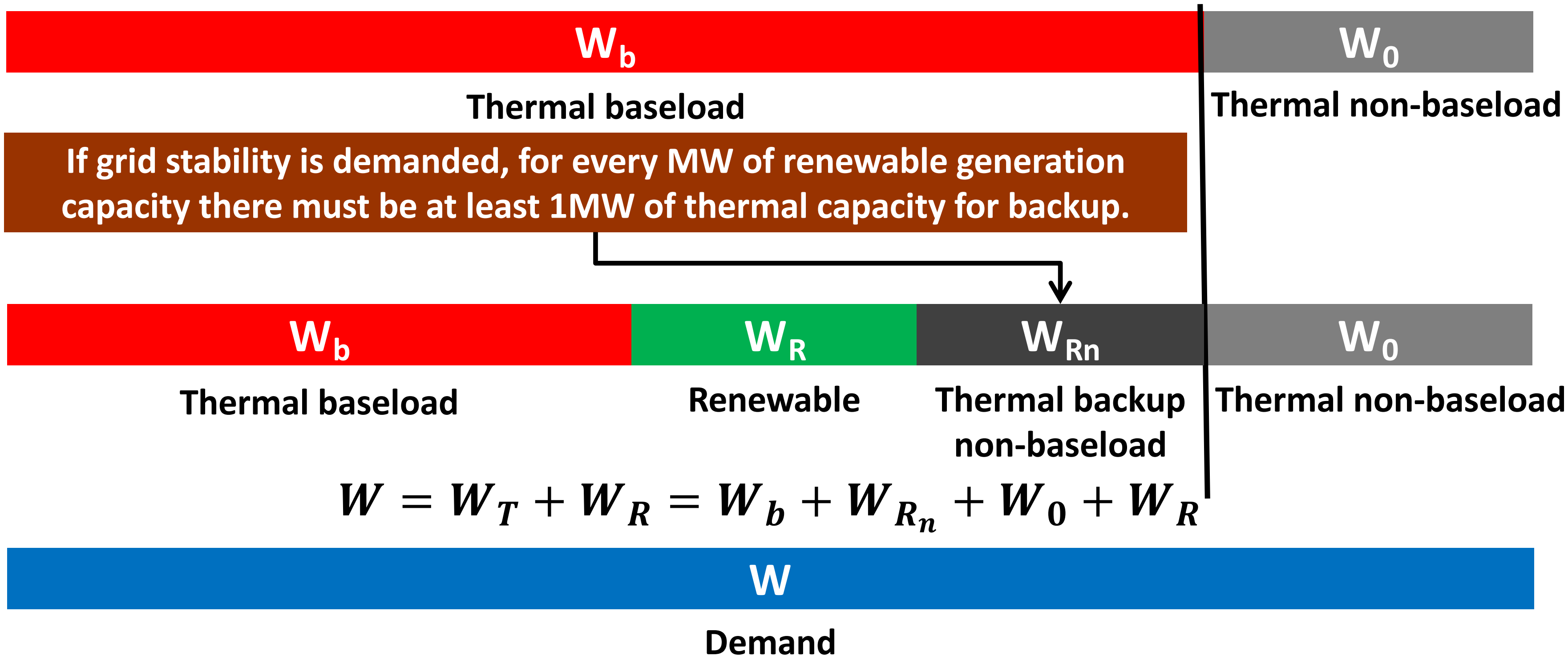
$$W = W_T = W_b + W_0$$

— Division between the normal or usual peak and off-peak demand non-baseload generation (right) and the baseload thermal generation (left)

- W_b: Thermal baseload generation
- W_0: Thermal non-baseload generation
- W: Total generation from all sources or annual demand [TWH Yr^{-1}]

W_T: Total thermal generation

Generation in the presence of renewables



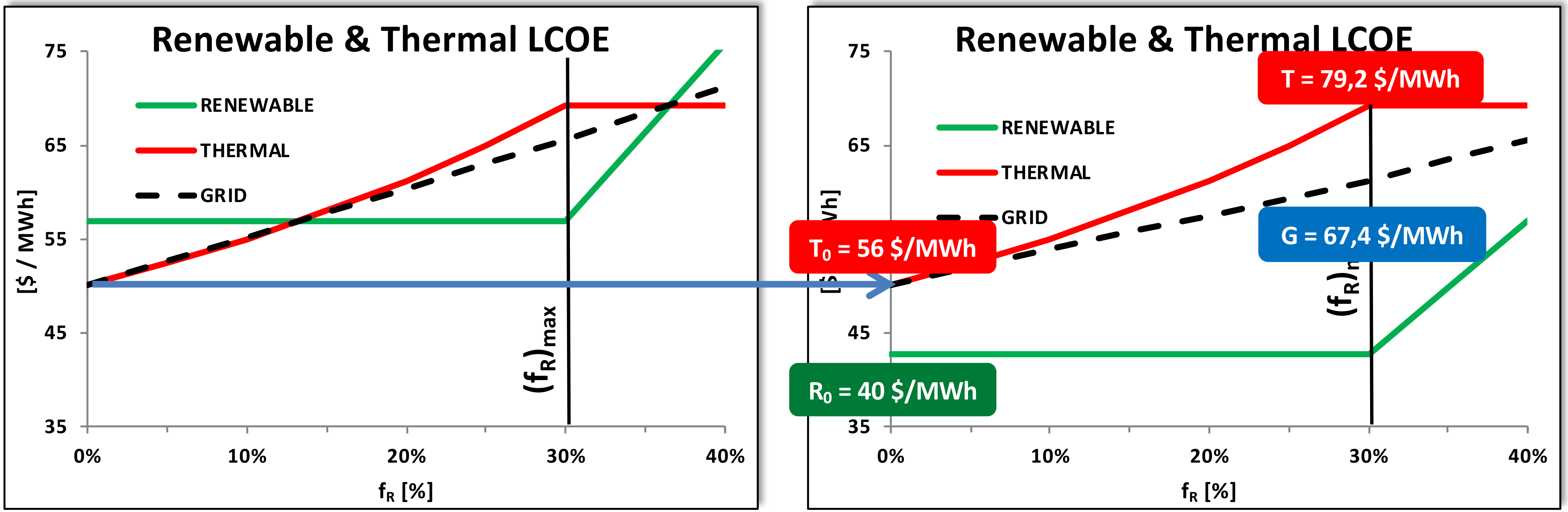
$$W = W_T + W_R = W_b + W_{R_n} + W_0 + W_R$$

— Division between the normal or usual peak and off-peak demand non-baseload generation (right) and the non-baseload generation to backup renewables, the renewable generation and the baseload thermal generation (left)

- W_b: Thermal baseload generation
- W_0: Thermal non-baseload generation
- W_R: Renewable generation
- W_{Rn}: Thermal backup non-baseload generation
- W: Total generation from all sources or annual demand or [TWH Yr^{-1}]

Generation cost (generator perspective)

$R_0 > T_0$ $R_0 < T_0$



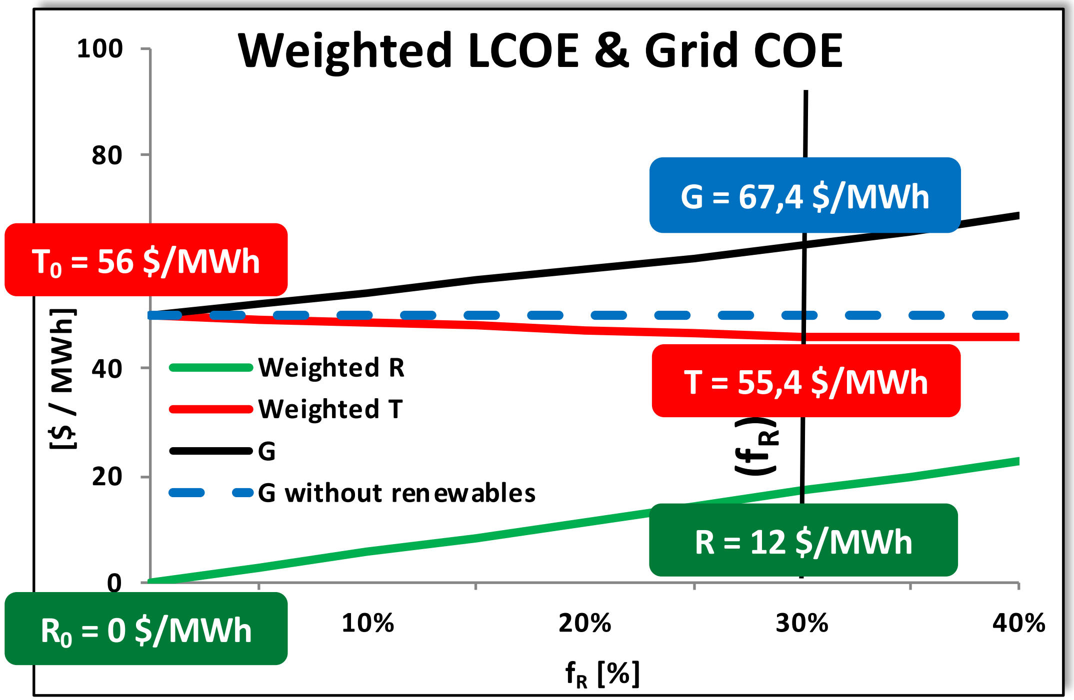
R_0: Renewable LCOE at $f_R = 0$
T_0: Thermal LCOE at $f_R = 0$

$$G = f_T \; T + f_R \; R$$

Generation cost (grid perspective)

Efficient scenario: k < 2

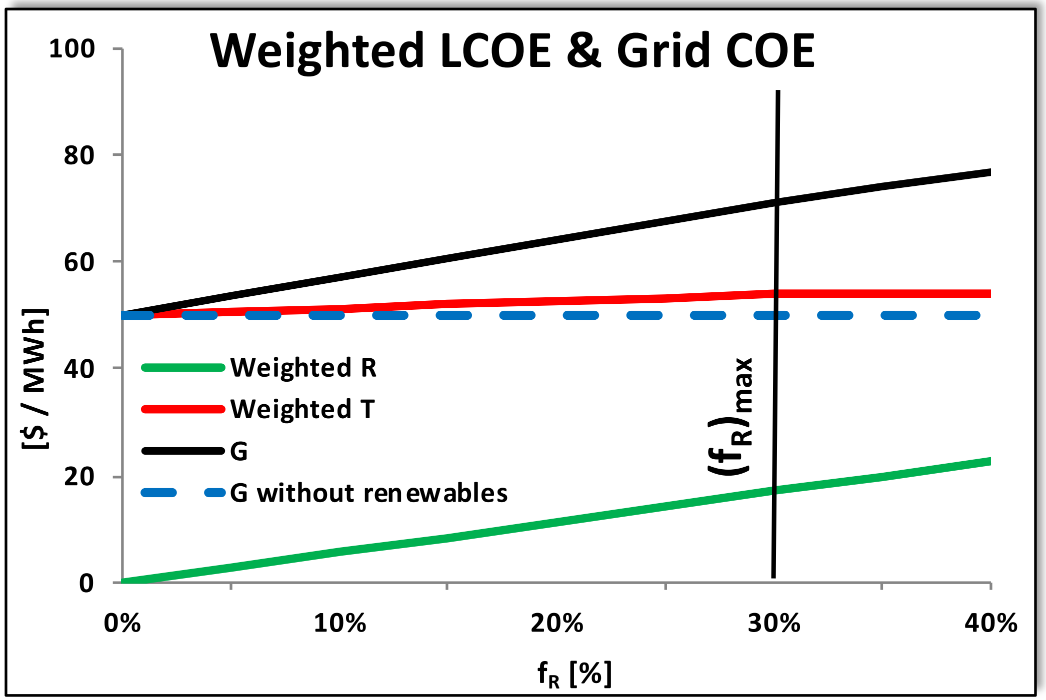
Backup: CCGT



Weighted thermal cost decreases with the renewable fraction.

Real scenario: k ≥ 2

Backup: CCGT, SCGT, oil, coal



Weighted thermal cost increases with the renewable fraction.

- ***k***: Inefficiency factor defined as the ratio between the non-baseload to the baseload operating heat rate $\boldsymbol{H} = \frac{\boldsymbol{h_n + g_0 h_0}}{\boldsymbol{h_b}}$; $g_0 h_0$ is the rotating reserve fraction (Mbu/MWh)

- ***R***: Renewable LCOE
- ***T***: Thermal LCOE
- ***G***: Grid cost of electricity

Generation cost (grid perspective)

$$F = e_g H$$

- F: fuel cost of generation ($/MWh)
- e_g: unit energy cost for natural gas ($/Mbtu)

Backup alternatives to CCGT

Suitable

Technology	Characteristic
CCGT (combined cycle gas turbines)	As such in the range 100% - 50% load capacity. CO_2 emissions are slightly reduced (k < 2).
SCGT (simple cycle gas turbines)	CO_2 emissions increase (k > 2).
Oil (Diesel, turbines)	Expensive, polluting and emit more CO_2 (k > 2)
Hydroelectric (dam)	Expensive, designed for electricity demand, not to backup renewables.
Lithium-ion batteries / green H_2	Extremely expensive, not enough minerals for large-scale backup.

Non suitable

Technology	Characteristic
Coal	Slow reaction to random weather variability (turtles and rabbits run at different speeds). (Coal, biomass: k > 2).
Biomass	
Geothermal	
Hydroelectric (run of river)	Flow-limited generation, used as baseload, designed for electricity demand, not to backup renewables.
Nuclear	For security

Investment versus capital cost of electricity
The green trick

- The investment cost in $ MW^{-1} **is not** an electricity cost.
- The capital cost in $ MWh^{-1} **is**.
- Although the capital cost is proportional to the investment cost, it is **inversely proportional to the capacity factor**.
- The capacity factor of a thermal generator can be 2 to 6+ times greater than that of renewables.

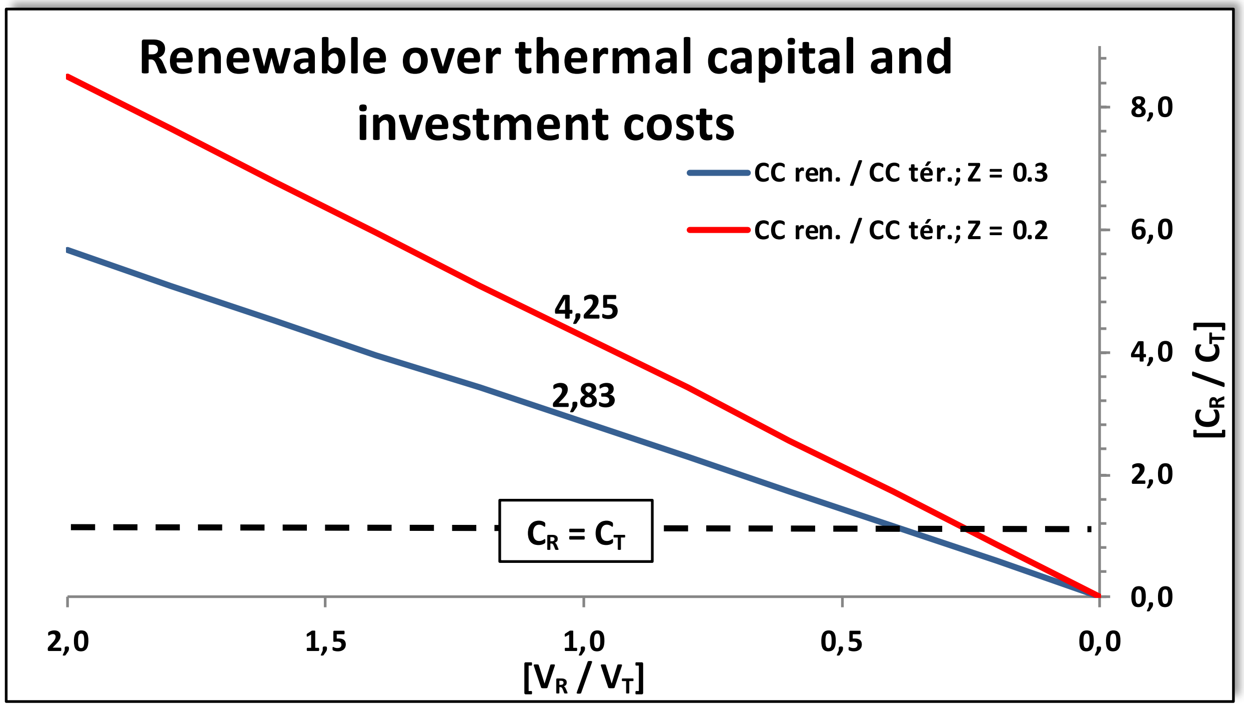
- $\boldsymbol{A} = Payment = \frac{r\,V}{(1-(1+r)^{-n})}$ $[\$\,(Yr\;MW)^{-1}]$

- $\boldsymbol{C} = Capital\ cost = \frac{A}{8760\,Z}$ $[\$\,MWh^{-1}]$

$\boldsymbol{r}$ = *Weighted average capital cost (WACC)*
$\boldsymbol{V}$ = *Investment cost*
$\boldsymbol{n}$ = *Project lifetime*
$\boldsymbol{Z}$ = *Capacity factor*

Investment versus capital cost of electricity

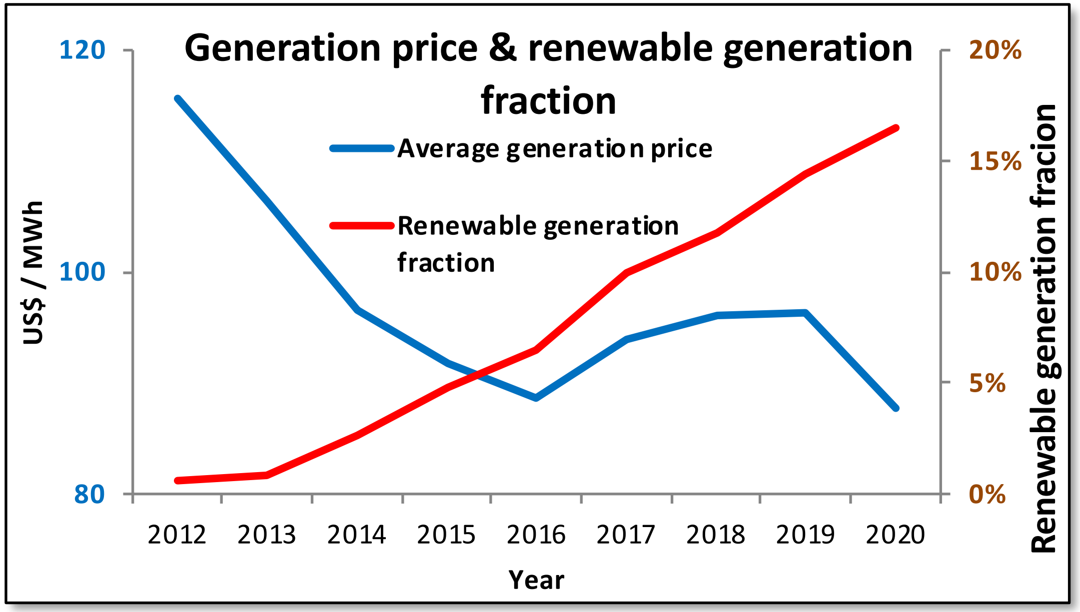
The green trick

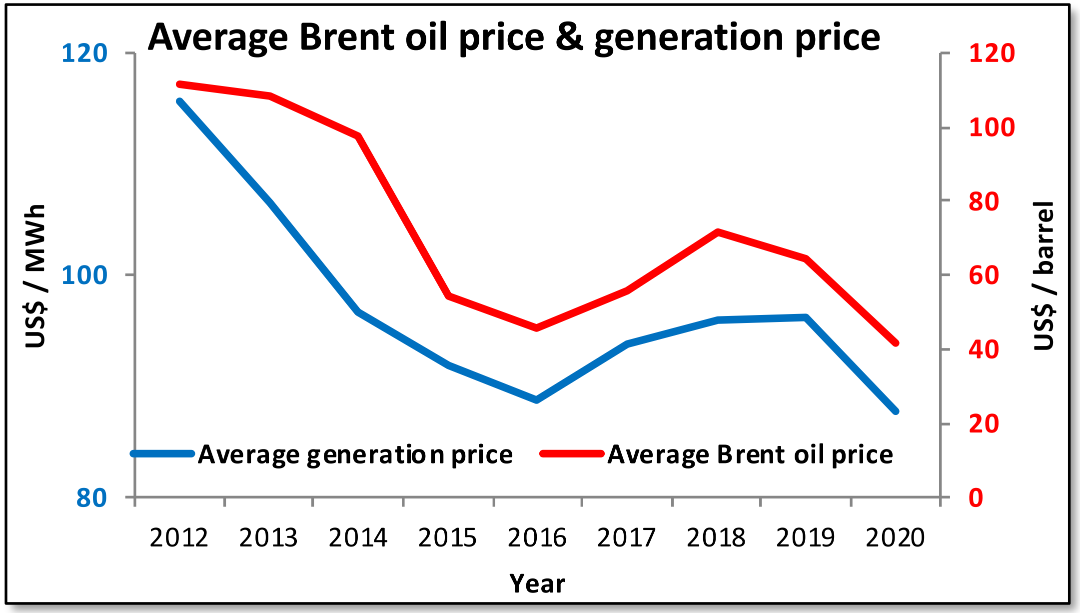


No matter how low the renewable investment cost may drop, its capital cost will still be much higher than that of a thermal source.

- **$V_{R,T}$**: renewable and thermal investment costs.
- **$C_{R,T}$**: renewable and thermal capital costs.
- **Z**: renewable capacity factor.

Green versus actual cause





Precios de generación eléctrica: Comisión Nacional de Energía, CNE; https://www.cne.cl/precio-medio-de-mercado-2/2020-2/
Fración de generación renovable: Generadoras de Chile; http://generadoras.cl/generacion-electrica-en-chile
Brent oil price: University of British Columbia; https://fx.sauder.ubc.ca/data.html

CO_2 emissions

There are three ways to reduce grid CO_2 emissions:

1. By generating less electricity.
2. By replacing coal generation with natural gas.
3. In theory, by increasing renewables while proportionally reducing fossil fuel-based generation.

CO_2 emissions

$$e = 0,06\ H$$

Natural gas CO_2 output emission rate at 100% efficiency

$$\frac{0,205\ [Tn\ MWh^{-1}]}{3,412[MBtu\ MWh^{-1}]}\ H[MBtu\ MWh^{-1}] = e\ [Tn\ MWh^{-1}]$$

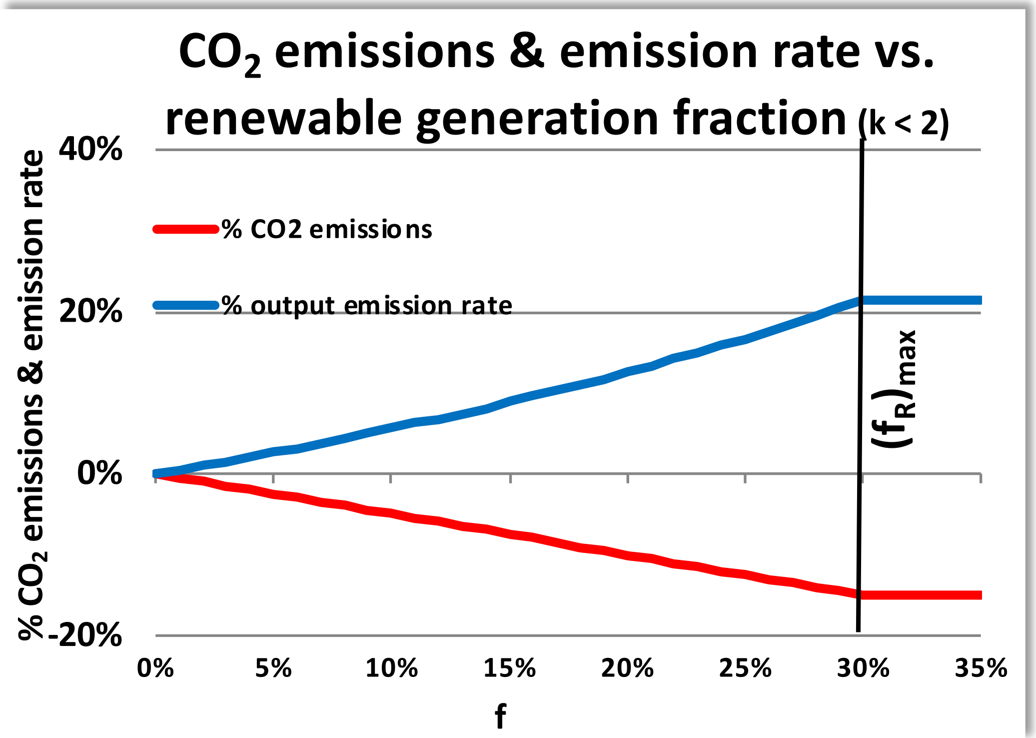
Fuel operating heat rate at 100% efficiency

- ***e***: CO_2 output emission rate *[Tn/MWh]*
- ***H***: operating heat rate *[MBtu/MWh]*

CO_2 emissions

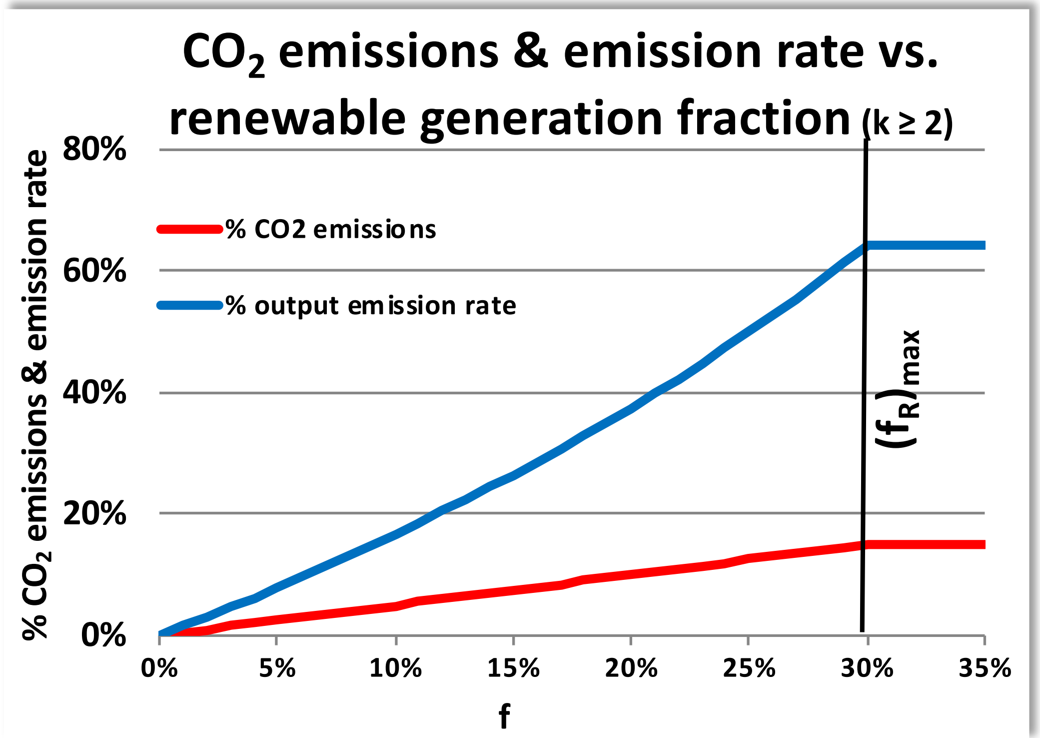
Efficient scenario: k < 2

Backup: CCGT



Real scenario : k ≥ 2

Backup: CCGT, SCGT, oil, coal



k: Inefficiency factor defined as the ratio between the non-baseload to the baseload

CO_2 output emission rate $= \frac{\omega_n + g_0\omega_0}{\omega_b}$; $g_0\omega_0$ is the rotating reserve fraction.

CO_2 emissions

$$e = \frac{\omega_b W_b + \omega_n W_0}{W_T} \; (Ton\; MWh^{-1})$$

$$W_T = W_b + W_0 \; (MWh)$$

$$E = e\, W_T \; (Ton\; Yr^{-1})$$

$$e = \frac{\omega_b W_b + \omega_n (W_0 + W_{R_n}) + R}{W_T} \; (Ton\; MWh^{-1})$$

- W_T: thermal generation $(MWh\; Yr^{-1})$
- E: CO_2 emissions $(MTn\; Yr^{-1})$
- e: CO_2 output emissions rate $(Tn\; MWh^{-1})$
- ω_b: baseload CO_2 output emission rate $(Tn\; MWh^{-1})$
- ω_n: non-baseload CO_2 output emission rate $(Tn\; MWh^{-1})$
- R: rotating reserve fraction $= g_0 \omega_0 W_{R_n}\; (Tn)$

Is there a limit to renewable generation on a grid?

1.- $$Q = \frac{10^6\, W}{8760\, Z} = \frac{D}{Z}$$

Installed or nameplate capacity (MW) to satisfy the demand W. D is the hourly demand (MWh/h = MW).

2.- $$N = fQ = f\frac{D}{Z}$$

Installed or nameplate capacity of a generation source to satisfy the fraction f of W (MW).

$f_{max} = Z$

3.- $$N = D \implies f = f_{max} = Z$$

Point at which the generator operating at full load matches the hourly demand.

$E = N - D$

4.- $$q = \frac{N}{D} = \frac{f}{Z}$$

Penetration factor or specific installed capacity of a generation source.

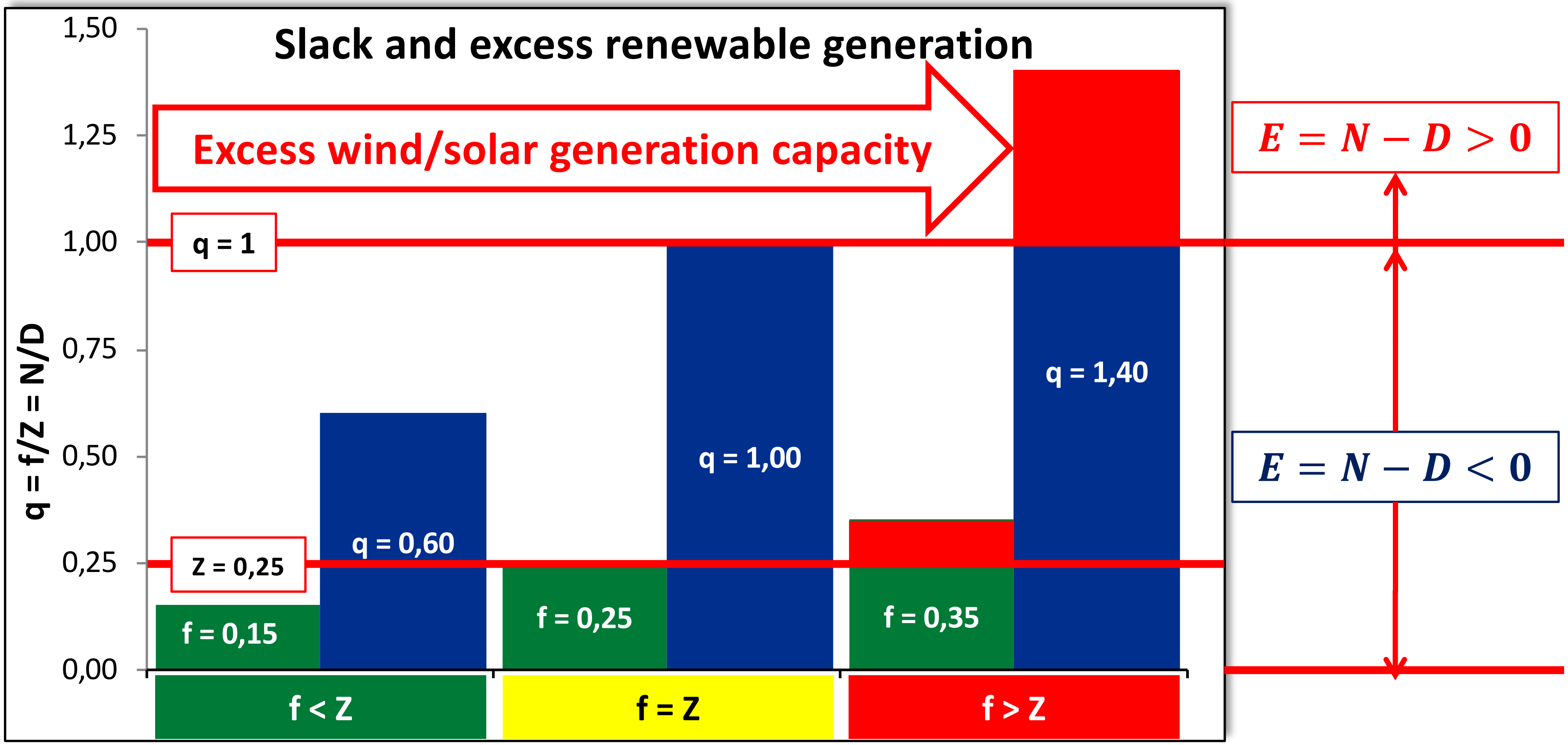
5.- $$f = f_{max} \implies q = 1$$

The penetration factor is equal to 1 when the source reaches its maximum generation fraction in the grid.

6.- $$E = N - D$$

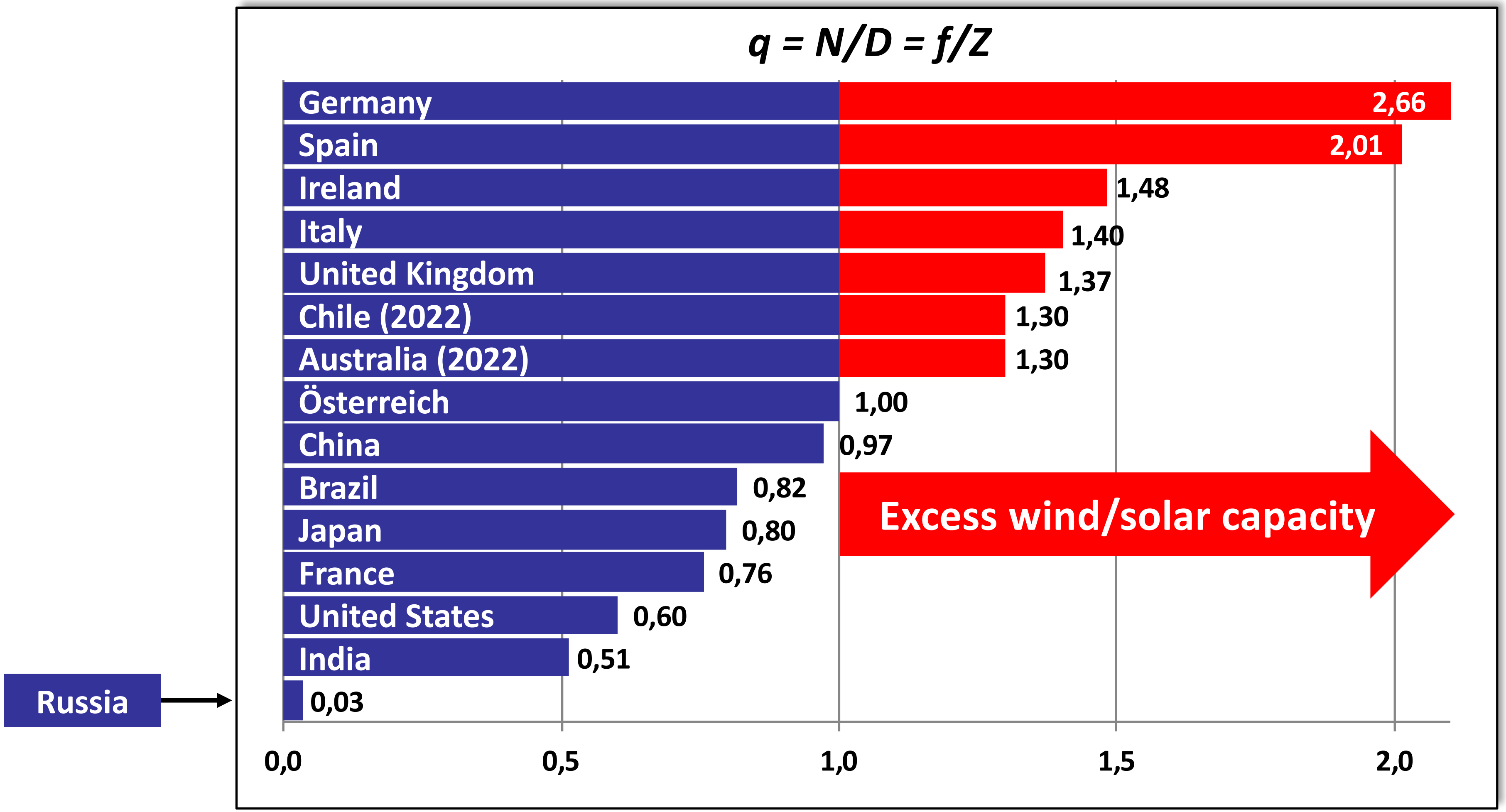
E represents the excess (positive) or slack (negative) generation capacity (MW).

Slack and excess of renewable generation



Renewable generation limit for 15 countries

2023 electricity generation



US CO_2 emissions abatement attributable to renewables

2022 US electricity generation

Reduction in CO_2 emissions according to backup fuel type				
Variable	Description	Unit	Fuel	
			Gas	All
e	Natural gas CO_2 output emission rate	Tn/MWh	0,426	0,496
ΔE	Change in US CO_2 emissions (w/ — w/o renewable generation)	MTn/Yr	-105,0	-15,9
ΔE_{grid}	Change as % US grid CO_2 emissions	%	-5,7%	-0,9%
ΔE_{US}	Change as % US all-source CO_2 emissions	%	-1,9%	-0,3%
ΔE_{global}	Change as % global all-source CO_2 emissions	%	-0,3%	0,0%

Source: EPA 2022 generation, CO_2 output emission rate and non-baseload CO_2 output emission rate; https://www.epa.gov/egrid/data-explorer

f_{total}	f_{backup}	Z
W/r total generation	W/r backup generation	
13,6%	25,0%	25,8%

Renewables hinder CO_2 emissions abatement

2022 US electricity generation

Reductions in CO_2 emissions in some countries have largely been achieved because of replacing coal by gas and not because of replacing coal by renewables.

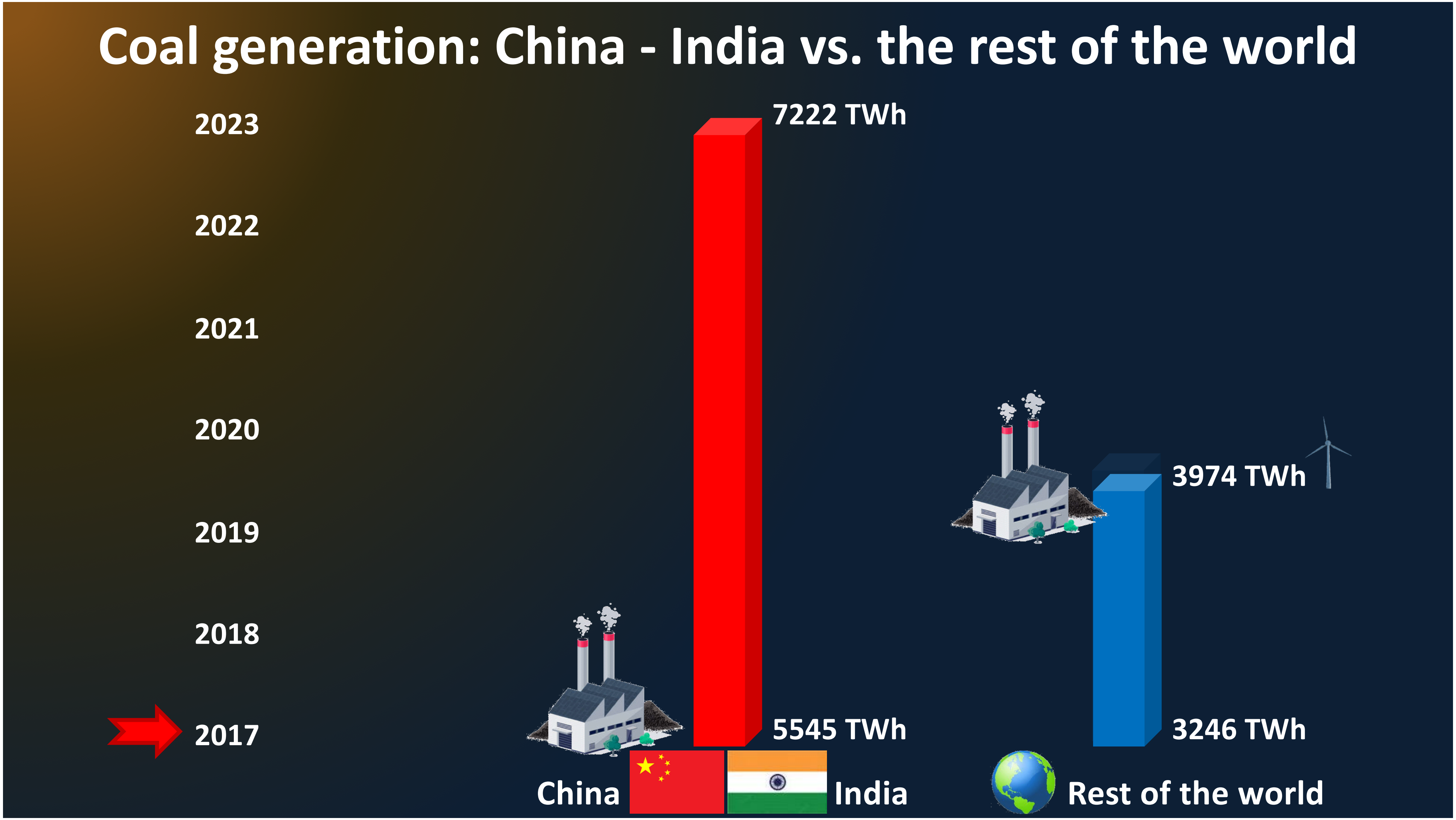
Coal → renewables v. coal → natural gas				
Fuel	**Variable**	**Description**	**Unit**	**Value**
Natural gas	**% $\delta(\Delta E_{CO2})$**	CO_2 emissions percentage difference (natural gas backup)	%	22,2%
All	**% $\delta(\Delta E_{CO2})$**	CO_2 emissions percentage difference (all fuels backup)	%	83,9%

Variable	Description	Unit	Value
W_R	Coal generation replaced by renewables	TWh/Yr	574,7
E_C	CO_2 emissions abated by coal generation reduction	Mtn/Yr	566,2
E_R (natural gas)	CO_2 emissions added by backup generation (only natural gas)	Mtn/Yr	300,8
E_R (all fuels)	CO_2 emissions added by backup generation (all fuels)	Mtn/Yr	389,9
E_G	CO_2 emissions from natural gas generation (no renewables)	Mtn/Yr	241,9

Source: EPA 2022 generation; https://www.epa.gov/egrid/data-explorer

Conclusions

- By increasing renewable generation:
  - The cost of electricity inevitably increases.
  - CO_2 emissions increase in non-ideal grids, i.e., almost everywhere.
- There is a fundamental limit to renewable generation.
- Replacing coal by renewables hinders CO_2 emissions abatement.
- The West's biggest mistake: asymmetric renewable expansion by decommissioning fossil fuels-based power plants without consistently Increasing backup gas-fired generation capacity.
- Net-zero: an insane utopia trying to become true.


Coal generation: China - India vs. the rest of the world
2023
2022
2021
2020
2019
2018
2017
7222 TWh
5545 TWh
3974 TWh
3246 TWh
China
India
Rest of the world

Since 2017, for every 1 TWh of coal generation capacity dismantled in the West, 2.3 TWh of that same generation capacity has been added in China and India.