Enhancing the flexibility of existing coal power plants

Technical, economics and climate considerations

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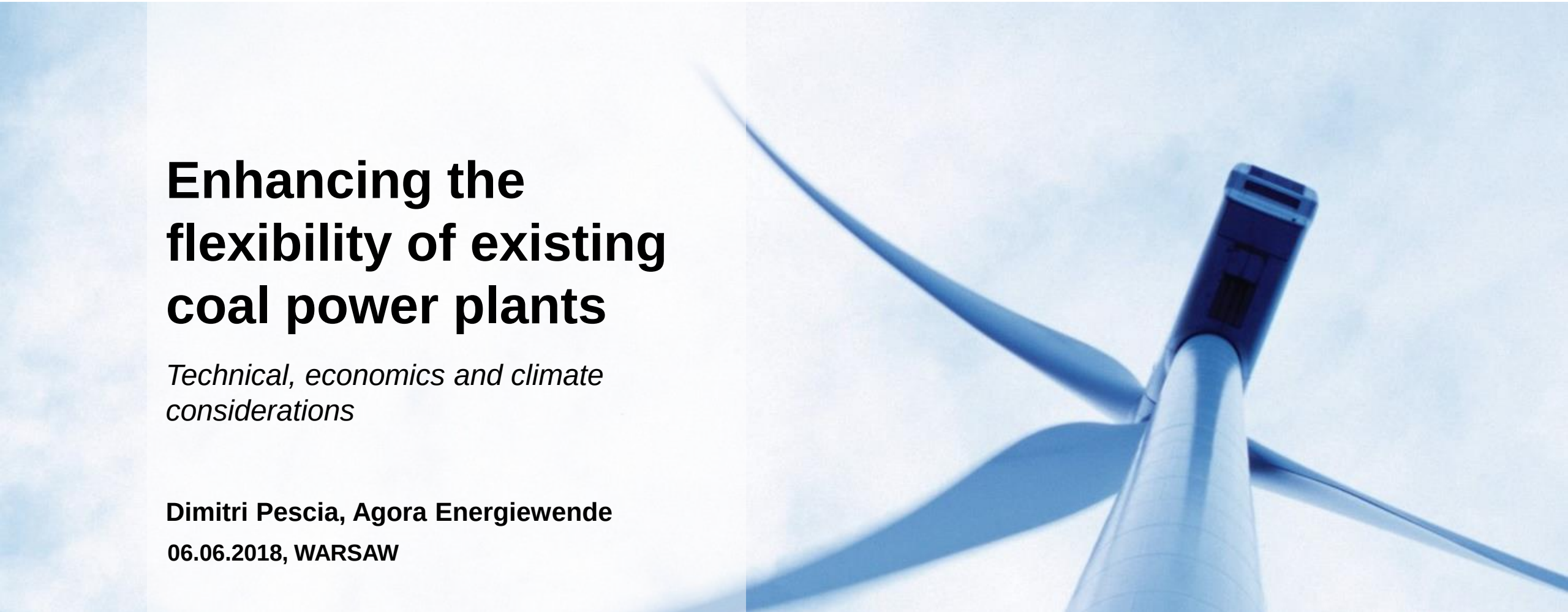
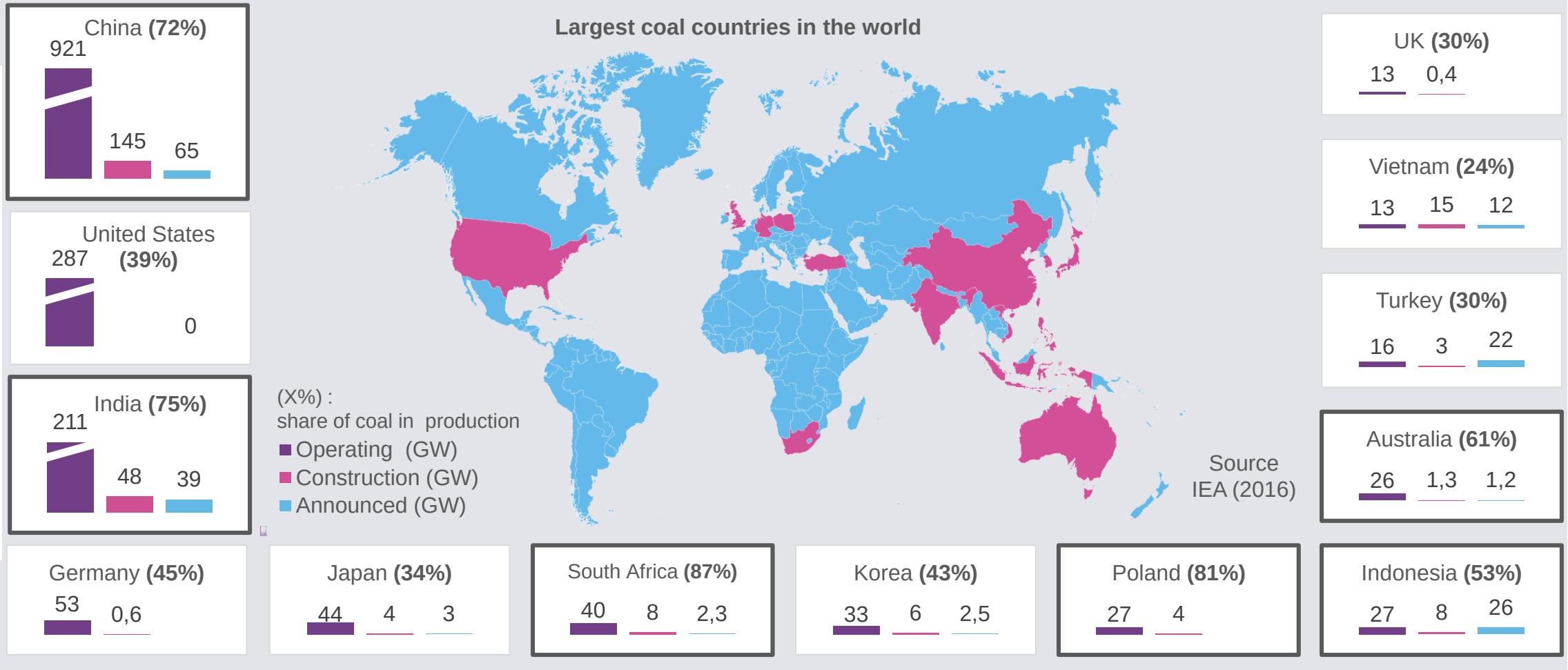
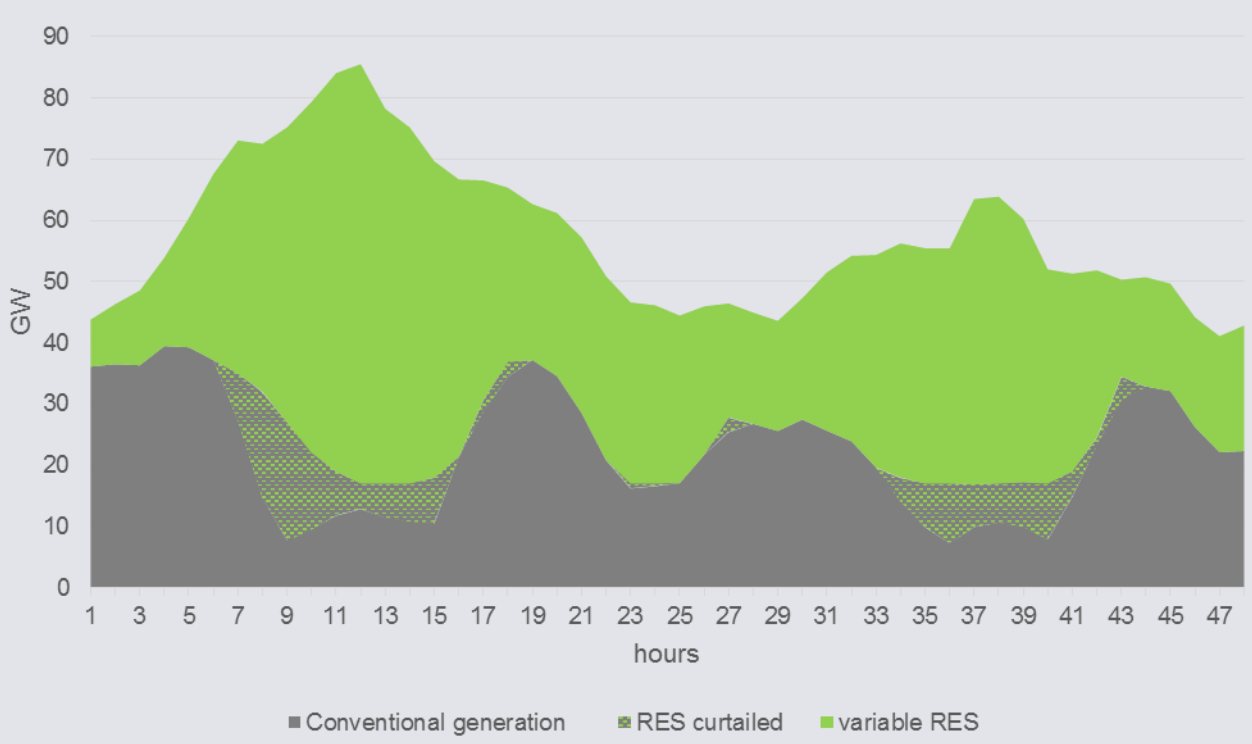


Limiting global warming well below 2° can only be achieved through deep decarbonization of the power system in the long run. However, existing coal power plants are likely to continue to play a role in several countries during the transition period.



Making conventional power plants more flexible can be a key strategy to integrate large shares of renewables more effectively in power systems dominated by coal assets.

Renewable and conventional power production during two exemplary days in a system with 60% RES in 2030



Agora Energiewende (2017)

In several countries, the development of renewables is often hampered after reaching a certain level, because of the claim that the existing power system cannot cope with the weather dependent electricity generation of wind and solar plants.

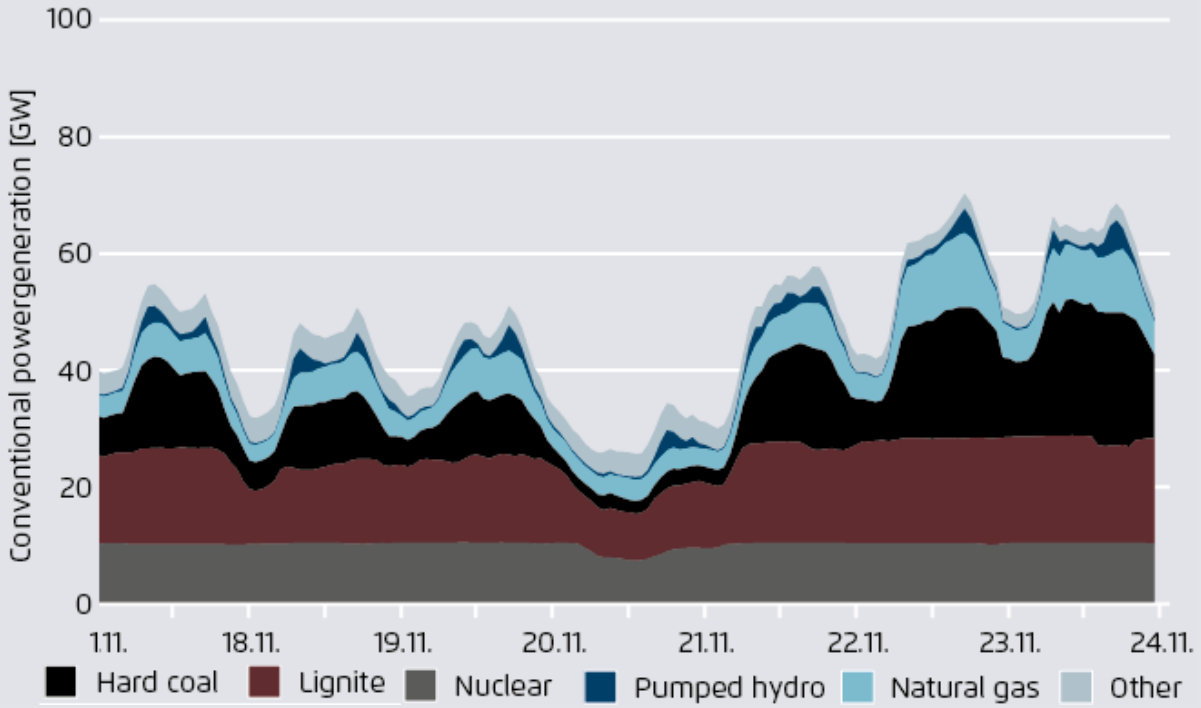
An obvious illustration of this trend is the high level of renewable energy curtailment occurring in certain power system (for example China), where the priority is given to baseload operation of conventional generators.

Different systems possess different flexibility options for integrating higher shares of renewables (grid, DSM, storage technologies, flexible biomass/biogas, flexible operation of conventional generation).

In markets characterized by few other flexibility options, making conventional power plants more flexible can be a key strategy to integrate higher shares of renewables.

Existing thermal power plants can provide much more flexibility than often assumed, as experience in Germany, Denmark and the US shows

Power generation from nuclear, hard coal and lignite power plants and demand in Germany, in one week in November 2016



Agora Energiewende (2017)

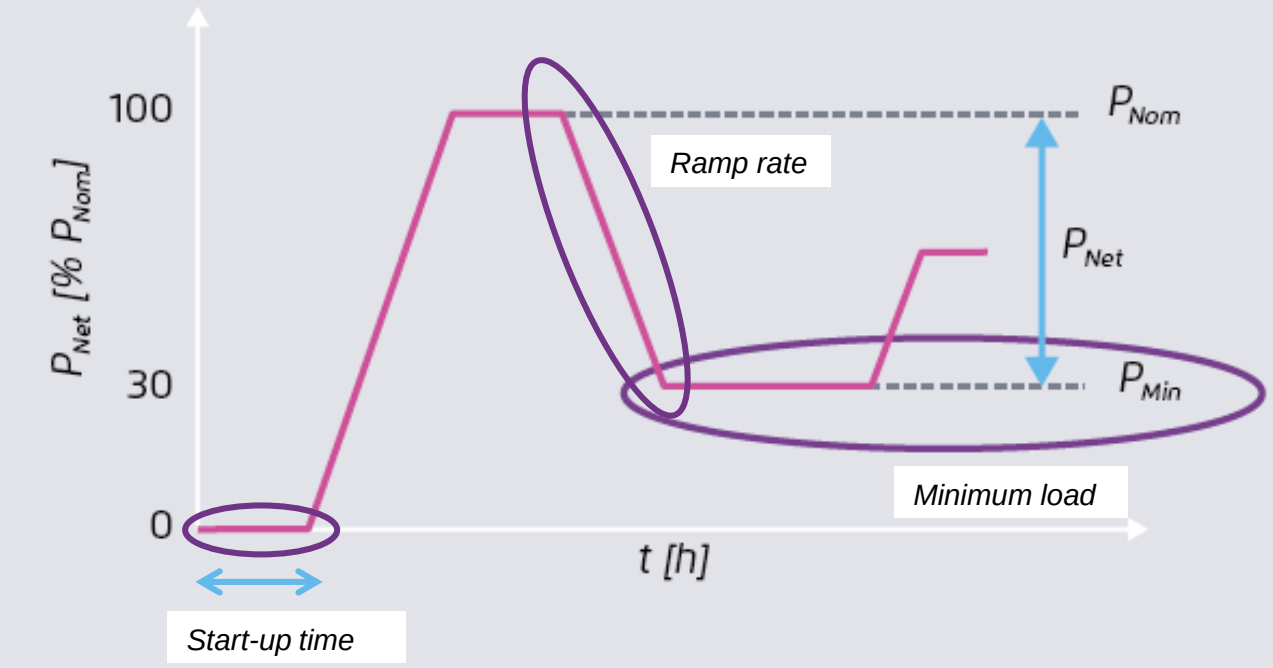
In Germany, hard coal (and even some lignite-fired) power plants are already today providing large operational flexibility to the power system.

But keeping (flexible) coal-fired power plant in the system is also pushing less emitting gas power plants out of the system. In the absence of proper pricing of CO2 emissions, German emissions are stagnating, despite a consequent increase of RES!

Furthermore, an inflexible “must-run” block still remains in the system (in the form of CHP-plants and power plants providing balancing reserves).

Flexibility of a power plant is 1/ the overall bandwidth of operation, 2/ the speed at which net power feed-in can be adjusted, 3/ the time required to attain stable operation when starting up from standstill

Qualitative representation of key flexibility parameters of a power plant



Fichtner (2017)

The 3 key features of operational flexibility are :

1/ **minimal load**. The lower the minimum load, the larger the range of generation capacity*. Disadvantages : At minimum load, the power plant operates at lower efficiency. Limitations : The lower the load, the more difficult it is to ensure a stable combustion without supplemental firing.

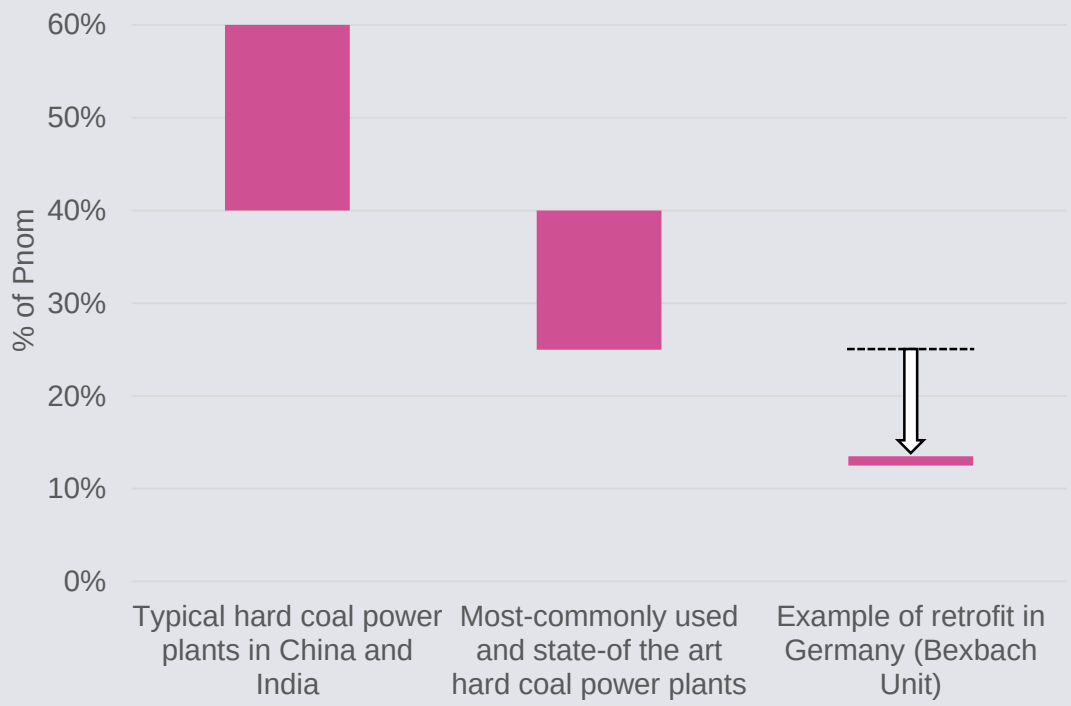
2/ **start-up time**. The shorter the start-up time, the quicker a power plant reach minimum load. Disadvantages : faster start-up times put greater thermal stress on components (reducing their lifetime). Limitations : allowable thermal gradient for components.

3/ **ramp rate.** A higher ramp rate allows a power plant operator to adjust net output more rapidly. Disadvantage : rapid change in firing temperature results in thermal stress. Limitations : allowable thermal stress and unsymmetrical deformations, storage behavior of the steam generator, quality of fuel used, time lag between coal milling and turbine response.

* A low minimum load can also avoid expensive start-ups and shutdowns.

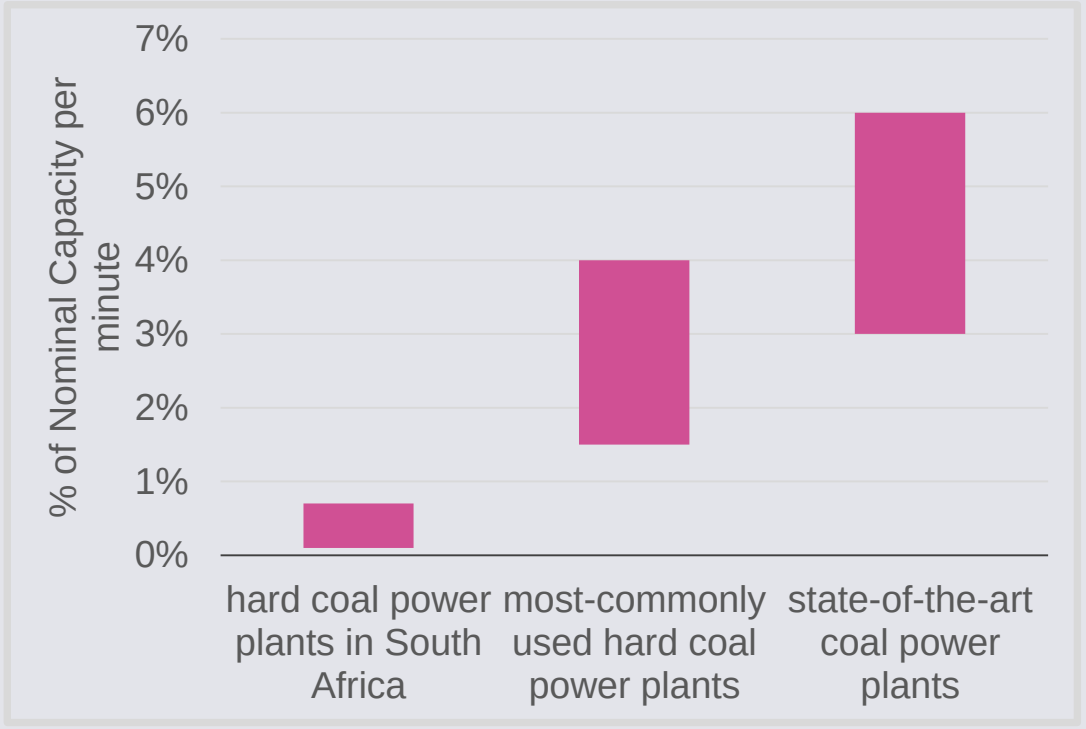
State-of-the-art-design improves significantly the flexibility characteristics of fossil-fuel power plants

Minimum load of different hard coal power plants (as a percentage of nominal capacity)



DEA, NREL, Fichtner

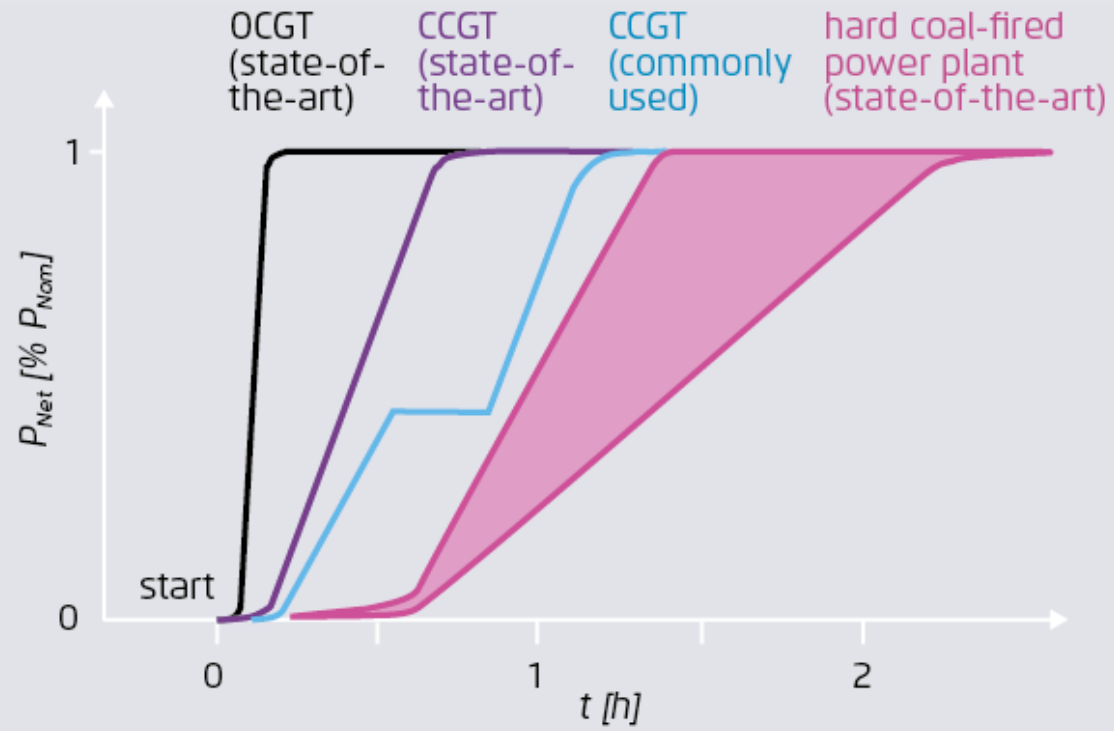
Ramp rates of hard coal power plants in South Africa compared to most-commonly used and state-of-the-art designs



Prognos, Fichtner

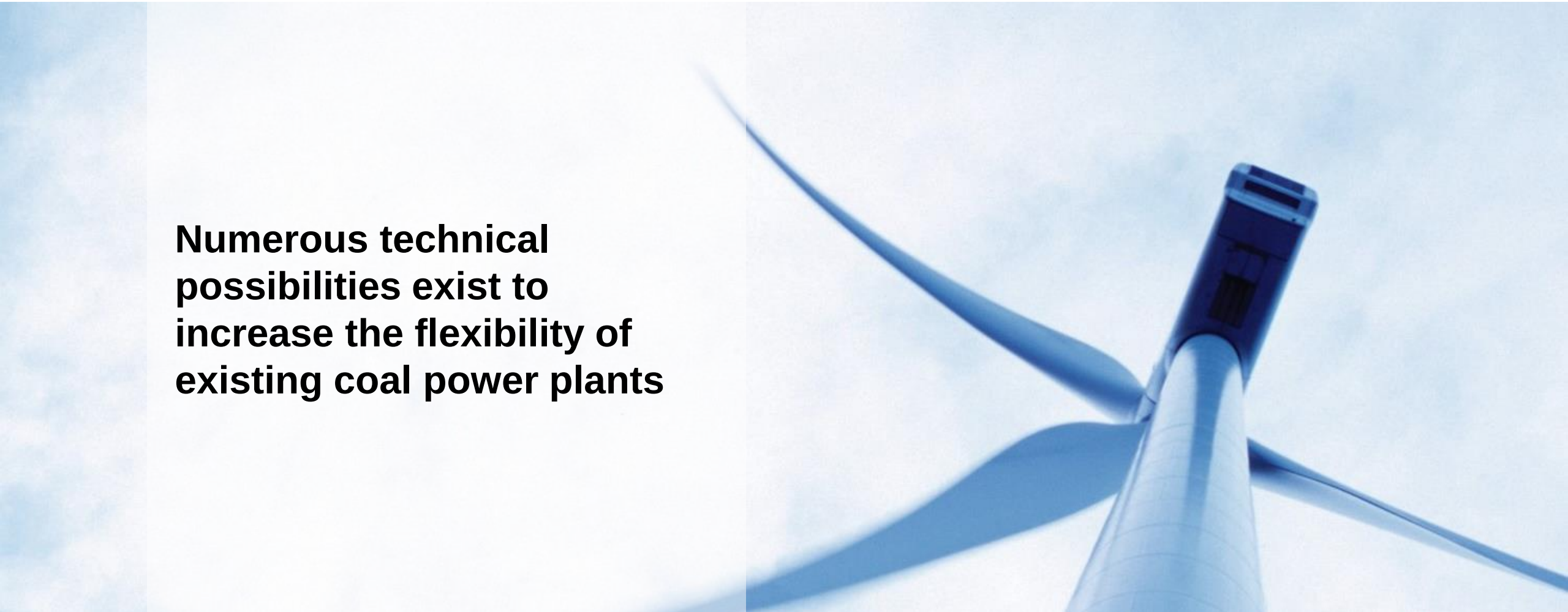
Coal-fired power plants are in most case still less flexible compared to gas-fired generation units

Ramp rates and start-up of gas VS coal power plants



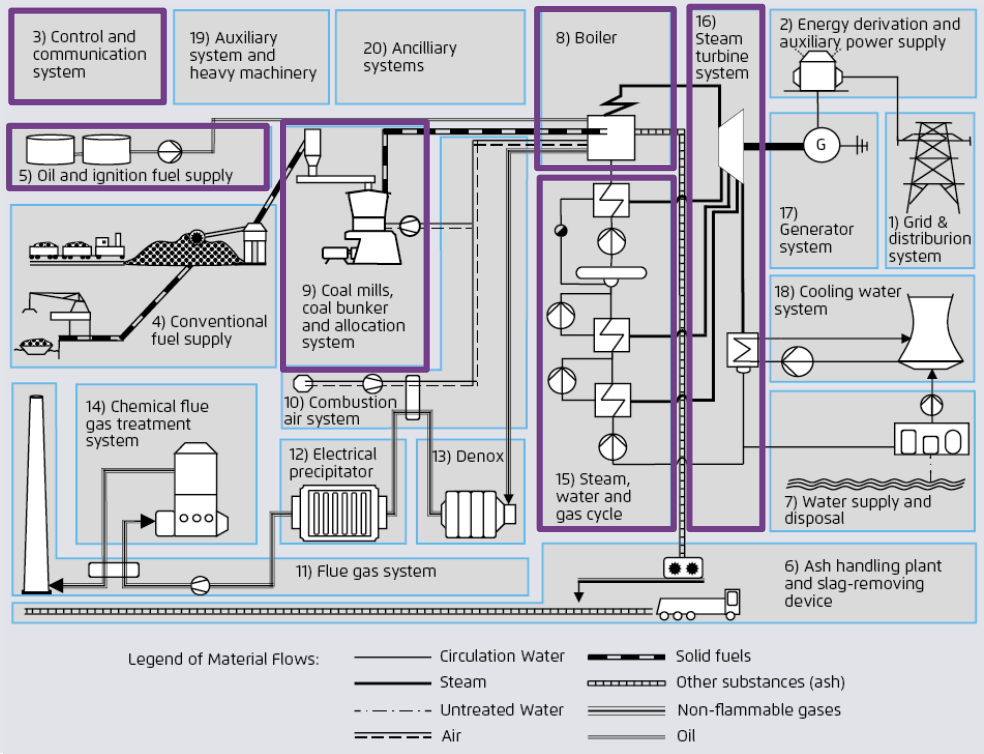
Fichtner (2017), based on VDE (2012)

Numerous technical possibilities exist to increase the flexibility of existing coal power plants



Numerous technical possibilities exist to increase the flexibility of coal power plants

Illustrative subdvision of a coal power plant (purple indicates key components to improve flexibility)

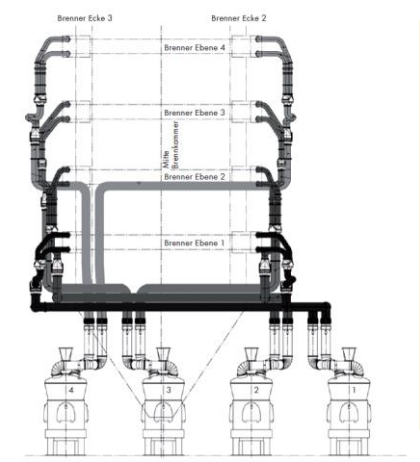


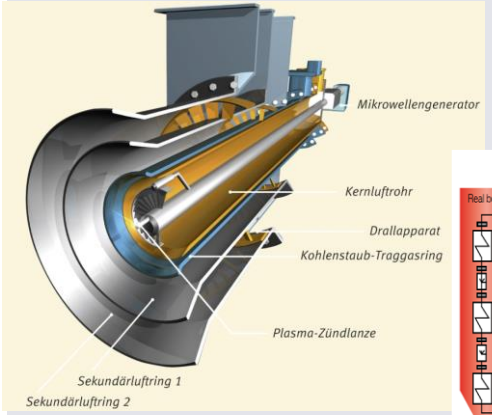
Klumpp (2009)

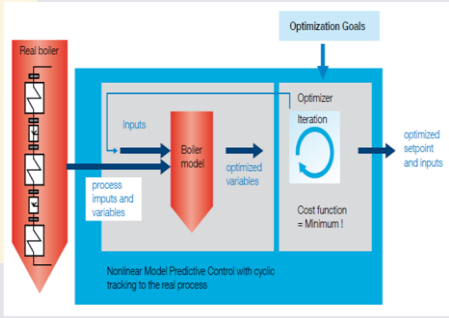
Retrofit measure for reducing:	Minimum load	Start-up time	Ramp rate	Limitations
Indirect Firing	✓		✓	Fire stability
Switching from two mill to single mill operation	✓			Water-steam circuit
Control system and plant engineering upgrade	✓		✓	Fire stability/ thermal stress
Auxiliary firing with dried lignite ignition burner	✓		✓	Fire stability and boiler design
Thermal energy storage for feed water pre-heating	✓			N/A
“Repowering”		✓	✓	N/A
Usage of optimized control system		✓		Thermal stress
Thin-walled components /special turbine design		✓		Mechanical and thermal stresses
“New” turbine start		✓		Turbine design
Reduction of wall thickness of key components			✓	Mechanical and thermal stresses

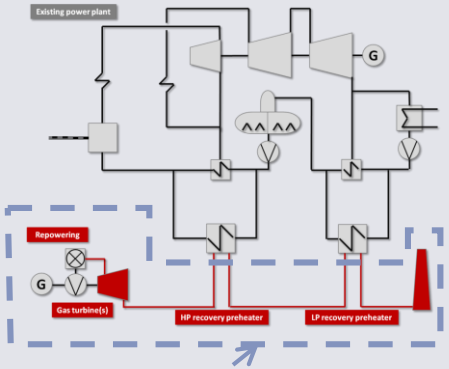
Fichtner (2017)

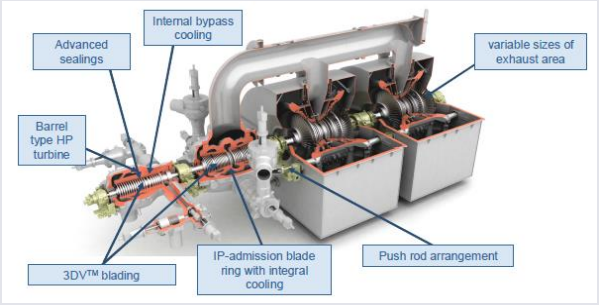
Retrofit measures to increase flexibility were employed in numerous coal-fired plants in recent years. The flexible operation of coal power plant reduces however its lifetime.











Reducing min. load levels has proven to bring the most benefits. Important enabling factors : adoption of alternate operation practices, rigorous inspection, training programs.

Several retrofit measures were implemented on German power plants for enhancing their flexibility, for example :

→ Coal power plant **Bexbach** (780 MW) : reduction of minimum load from 170 MW (22% of PNom) to 90 MW (11% of PNOM) by switching from two mills to single mill operation.

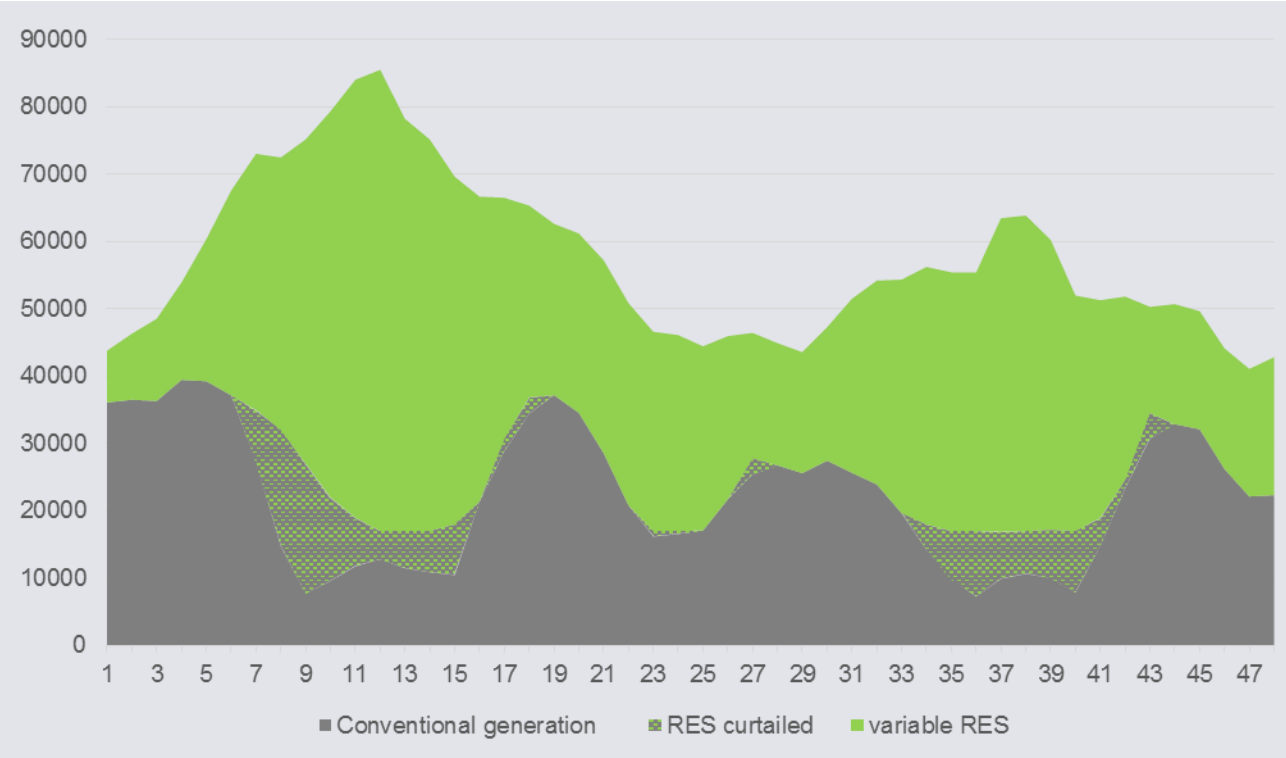
→ Unit G and H of hard coal power plant **Wesweiler** : upgrades in plant engineering and control reduced the minimum load of 170 MW and improved the ramp rate (increased by 10 MW/min). Total retrofit cost amounted to ~60 M€ for each units. (source : RWE)

Investment costs for retrofit in flexibility can be roughly estimated in a range from 100 to 500 €/kW (must be evaluated case by case). Retrofit usually increase the technical lifetime of a power plant by about 10-15 years*

* For comparison, the investment in a new power plant ranges between 1.200 €/kW and more than 3.000 (with CCS), for a lifetime of more than 40 years.

What are the impact of flexible coal on CO2 emissions ?

Flexible coal is not clean, but making existing coal plants more flexible enables the integration of more wind and solar power in the system, contributing to decrease CO2 emissions.



Agora Energiewende (2017)

In a system with high share of vRES, the flexible operation of coal power plants generally reduce its overall CO2 emissions, since the coal power plants produces in general less electricity over the year, avoiding wasteful curtailment of RES

In some power systems, especially when gas is competing against coal, the flexible operation of coal power plants can lead to increased CO2 emissions. In those systems, an effective climate policy is key for achieving a net reduction in CO2 emissions.

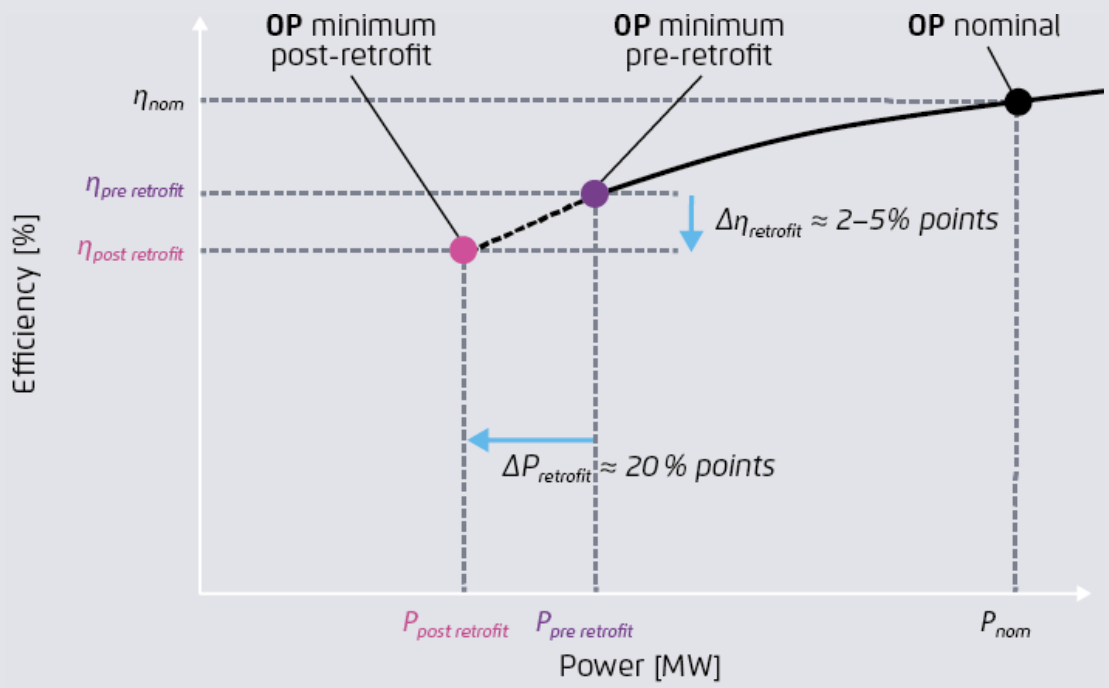
To measure the CO2 effect comprehensively, it is important to assess the emissions of the power plant under characteristic dispatch conditions and over the entire operation cycle of the power plant.

Embracing this comprehensive view shows that in many cases, the gained flexibility of the power plants outweighs the CO2 emission drawbacks at low operating points.

[1] without being compensated by the avoided CO2 emissions of start-up processes.

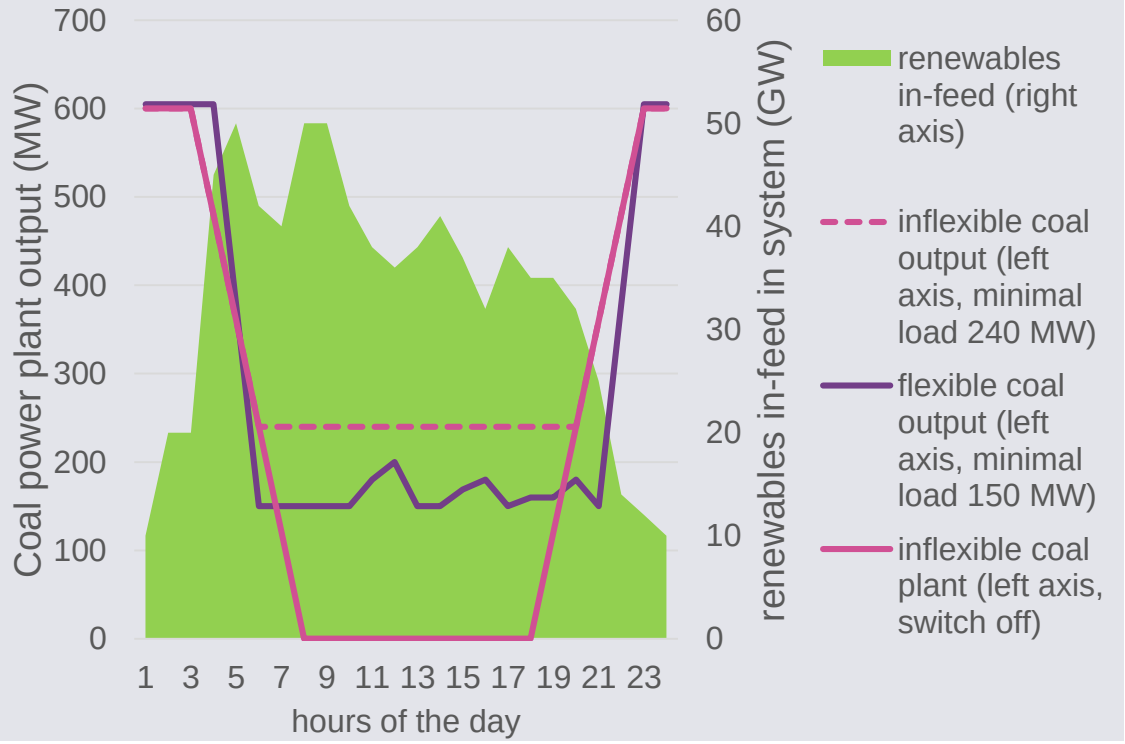
The flexible operation of coal power plants can have a negative impact on CO2 emissions at very low load operation points and if lower minimum load prevents the power plant to shut-down during some period

Relation between operating point and power plant efficiency



Fichtner (2017)

Illustrative power production of one coal power plant in a day with high share of renewables (comparison of a flexible and inflexible power plant)



Agora Energiewende (2016)

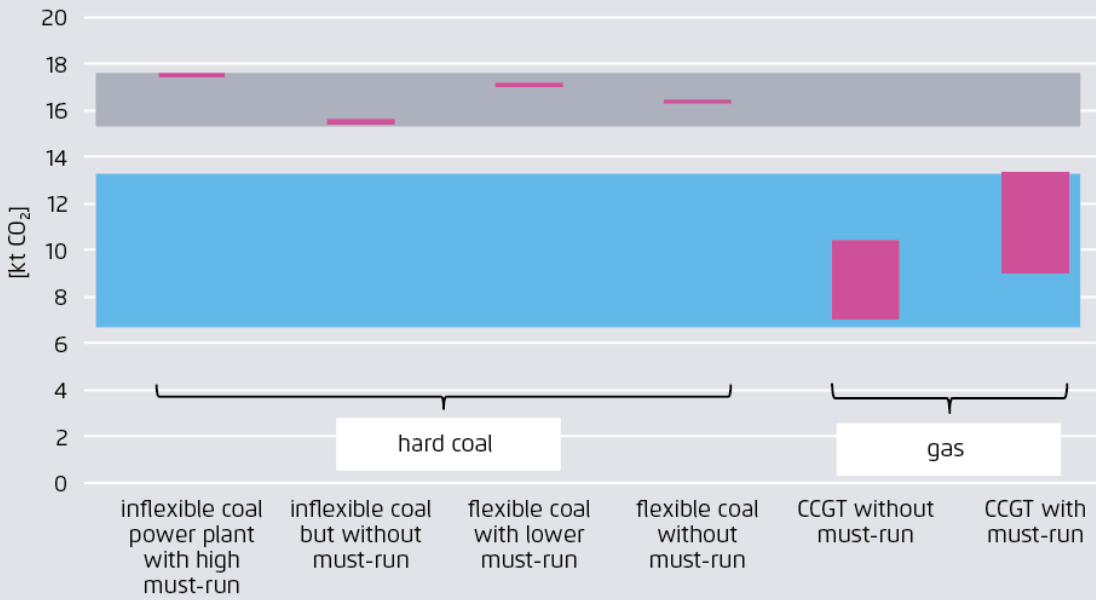
Flexible coal power plants emit more CO2 per electricity output than flexible gas power plants, even when taking into account the overall lifecycle emissions of the fuels.

Efficiency of hard coal and CCGT gas power plants (600 MW nominal power) at different operating points (up, illustrative) and specific ranges of CO2 emissions for different fuels.(down)

Fuel	Natural gas	Hard coal	Lignite
Range of specific emissions [gCO_2/kW_{th}]	202–300	325–350	340–410
Lower limit specification	Pipeline gas	Bituminous coal	Pulverised lignite
Upper limit specification	Shale gas	Anthracite	Raw lignite

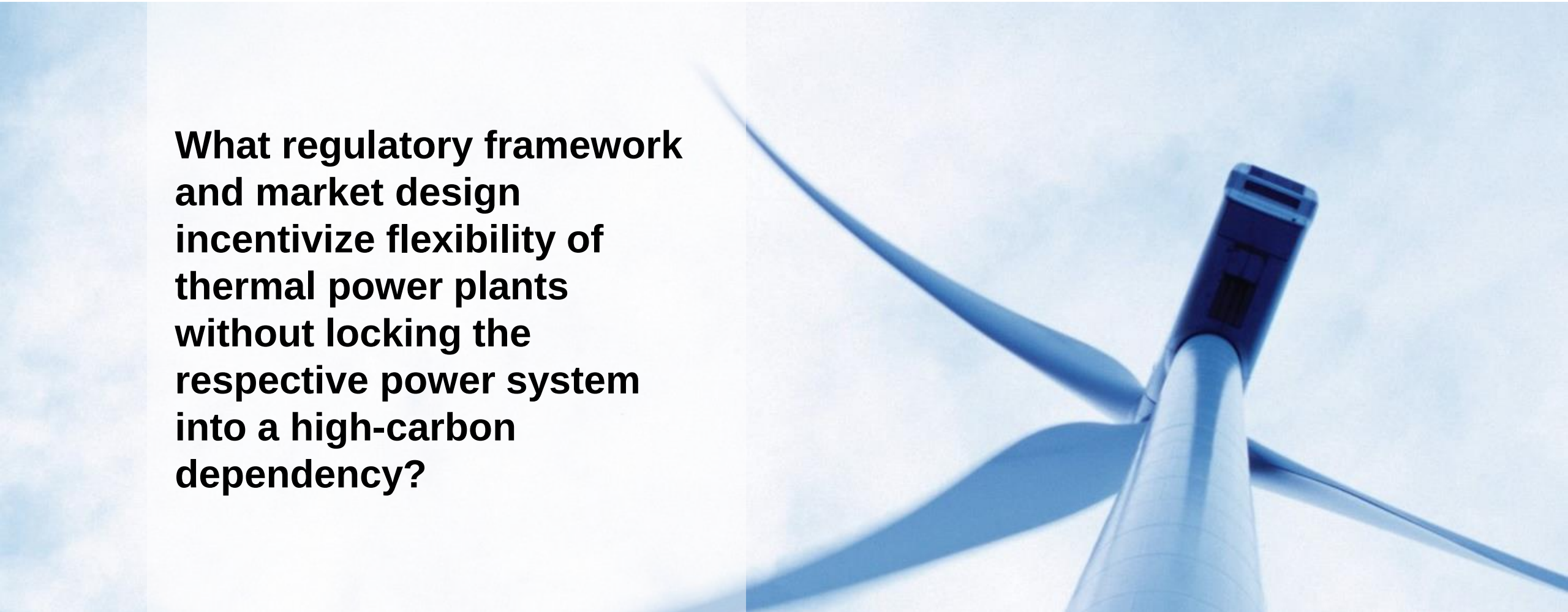
Fichtner & Prognos (2017)

Co2 emissions of CCGT and hard coal power plants under similar dispatch conditions but with different flexibility features during 2 exemplary days



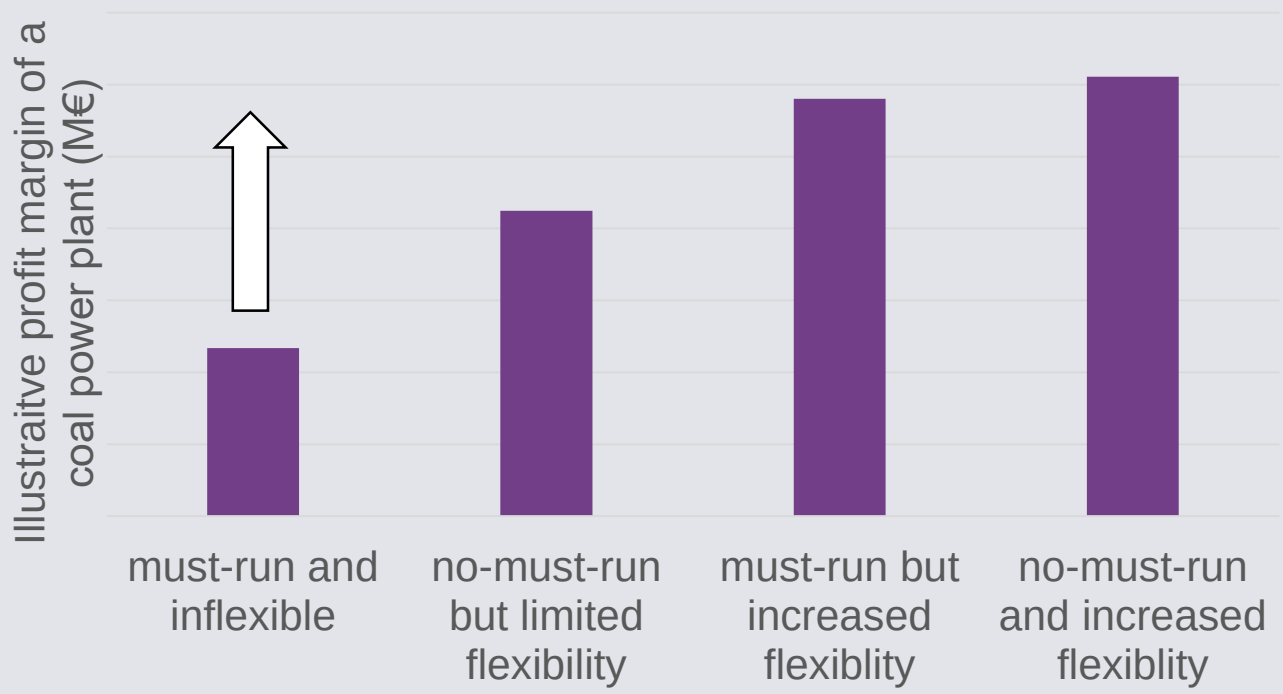
Agora Energiewende (2017)

What regulatory framework and market design incentivize flexibility of thermal power plants without locking the respective power system into a high-carbon dependency?



Enhancing the flexibility parameters of coal power plants can improve significantly their economic situation within a proper market environment

Illustrative profit margin of a coal power plant in a short-term market with high shares of renewables under different flexibility and must-run conditions.



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Flexible operation of coal power plants can increase operating costs **but** it minimizes the losses coming from the increasing shares of renewable energies (and the associated decreased utilization of the coal power plants).

The reduction of the minimum load is in many cases key for an increased profitability.

In markets with a mixed portfolio of coal power plants and other lower emission technologies, such as natural gas, flexible coal retrofit improves the competing position of the coal plants, compared to the other technologies.

→ **Therefore, the goal to limit the CO2 emissions in the power sector must also be specifically addressed with an effective CO2 policy.**

In order to fully tap the technical potential for increased flexibility, it is crucial to adapt the power market conditions.

Lignite generation in Germany in December 2012 (up) and December 2017 (down)

Agora Energiewende (2018)

Economics of flexible coal (retrofit) is significantly influenced by the availability of remuneration options for flexibility. A market design which hampers the investment in flexibility is constraining the realization of retrofit in coal power plants, as well as alternative flexibility options.

With high shares of renewable power generation, electricity markets should help to fully integrate market players that provide valuable flexibility options.

Shorter electricity markets (e.g. intraday) and products, as well as the adjustment of the balancing power arrangements, are among the necessary measures. In doing so, renewables can be integrated more easily and in an economically efficient way into the power systems, limiting in particular wasteful renewable energy curtailment.

Flexible operation of coal power plants is an interim solution in power systems characterized by very high shares of coal generation.

Open lignite mine in Nochten, Germany

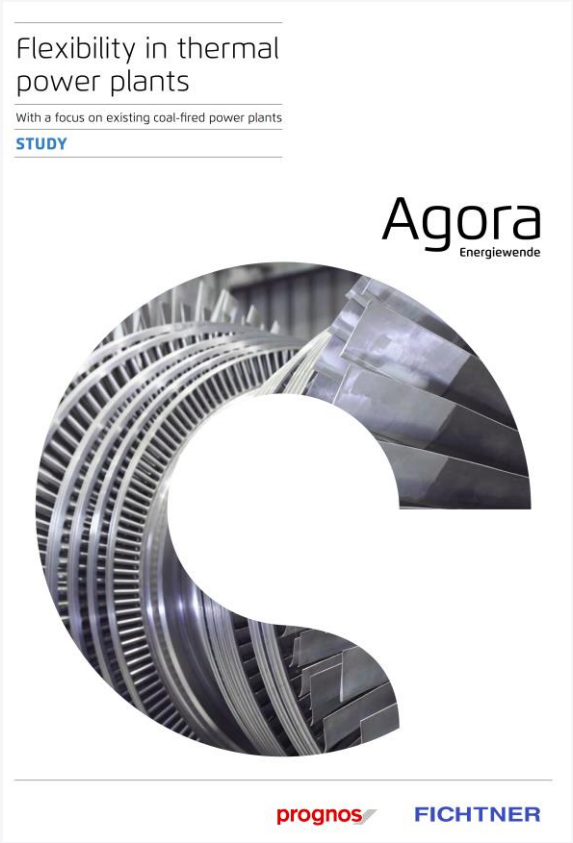
www.markowski.de

Decarbonizing the power systems means giving priority to the development of renewables. Flexible operation of existing coal power plants allows to integrate more renewable energy into the power system, by reducing the output of existing coal assets.

Making coal generation “flexible” doesn’t make it “clean”. In the mid- to long-run, fossil-fuel power plants, especially coal-fired, will need to be replaced all together with less CO2 intensive technologies, if one wants to meet international climate targets.

The priority must be given to curb the pipeline of new coal projects and manage well the socio-economic impact of the fossil decline.

Key Findings



1	**Existing thermal power plants can provide much more flexibility than often assumed, as experience in Germany and Denmark shows.** Coal-fired power plants are in most cases less flexible compared to gas-fired generation units. But as Germany and Denmark demonstrate, aging hard coal fired power plants (and even some lignite-fired power plants) are already today providing large operational flexibility. They are adjusting their output on a 15-minute basis (intraday market) and even on a 5-minute basis (balancing market) to variation in renewable generation and demand.
2	**Numerous technical possibilities exist to increase the flexibility of existing coal power plants. Improving the technical flexibility usually does not impair the efficiency of a plant, but it puts more strain on components, reducing their lifetime.** Targeted retrofit measures have been implemented in practice on existing power plants, leading to higher ramp rates, lower minimum loads and shorter start-up times. Operating a plant flexibly increases operation and maintenance costs — however, these increases are small compared to the fuel savings associated with higher shares of renewable generation in the system.
3	**Flexible coal is not clean, but making existing coal plants more flexible enables the integration of more wind and solar power in the system.** However, when gas is competing with coal, carbon pricing remains necessary to achieve a net reduction in CO2. In some power systems, especially when gas is competing against coal, the flexible operation of coal power plants can lead to increased CO2 emissions. In those systems, an effective climate policy (e.g. carbon pricing) remains a key precondition for achieving a net reduction in CO2 emissions.
4	**In order to fully tap the flexibility potential of coal and gas power plants, it is crucial to adapt power markets.** Proper price signals give incentives for the flexible operation of thermal power plants. Thus, the introduction of short-term electricity markets and the adjustment of balancing power arrangements are important measures for remunerating flexibility.

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