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Imprint

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Title picture (2023)

The ODIAC (Open-source Data Inventory for Anthropogenic CO_2) is a global high-resolution (1x1km) emission data product for fossil fuel carbon dioxide (CO2) emissions.

Source**:** NASA’s Scientific Visualization Studio

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Introduction

Scope (by Frank Haferkorn, OatGrain-InnovationS)

SwitchCoal shows a profitable path to reduce 25% of the human-made (10Gt/yr) Carbon-Dioxide emission by replacing Power-Electrification from Coal-Fired approach with wind/solar plants combined with battery storage.

AS SAD AS IT IS…
ALMOST NOTHING in our planetary society "WORKS WITHOUT PROFITs".

The SwitchCoal-project is one of the first strategic approaches with a chance to succeed worldwide by UNLEASHING the forces of ECONOMY.

SwitchCoal shows an analysis of a way to

- SAVE 25% of human made CARBON-DIOXIDE emissions
- in a PROFITABLE INVESTMENT STRATEGY
- by replacing Coal-fired electric-power generation
- with renewable **solar**- & **wind**-parks combined with b**atteries**,
- localized around each replaced coal plant site.

RESULT: The "replacement" **is feasible and profitable**

- **For 90 %** of the worldwide >7.500 coal-plants at 2500 plant-sites

ADVANTAGES:

- Use of existing Power-Lines reduces project approval time and costs.
- Some coal power plants can remain as a backup for the renewables.
- It is implementable worldwide in less than 1 Decade.

However, A WORLWIDE IMPLEMENTATION
will require (and bind) a huge amount of investment capital.

BUT it allows us to do this in a profitable way.
For a single, "best-suited" power plant site

- An extra pay-off of 9 billion US-Dollar ($9.000.000.000)
- Over a runtime of 30 years
- While selling electric power at regular prices
- Including construction and maintenance costs

is possible.

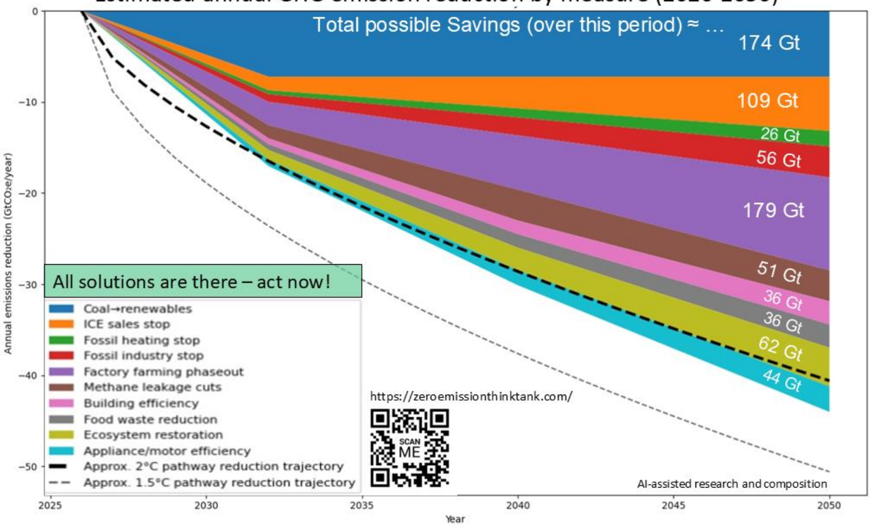
Abstract / relevance for human-being (Thomas S.)

(German dipl.-engineer and SwitchCoal data Scientist)

SWITCHCOAL IS NOT JUST ANOTHER RENEWABLE ENERGY INITIATIVE;
IT'S A GAME-CHANGER.

In our concern, the new research (see ref. [2] and ref. [3]) clearly shows that only one measure would be even more effective: putting an end to industrial factory farming and the associated intensive agricultural landscape (purple curve).

Estimated annual GHG emission reduction by measure (2026-2050)



(2)

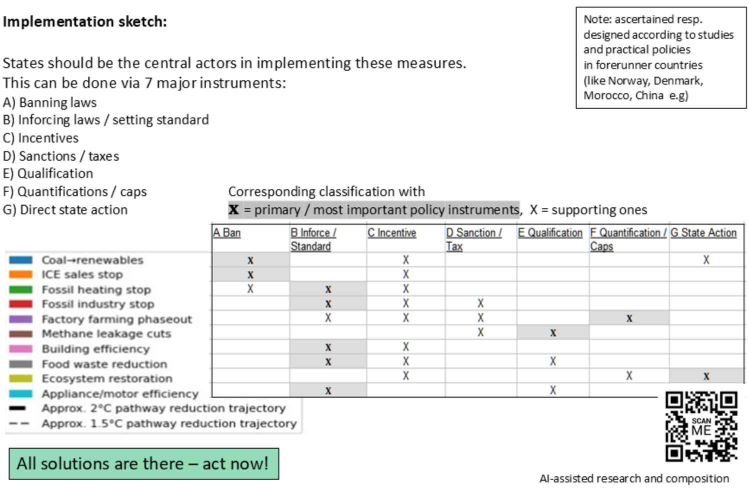
However since this is not a minimal intervention – rather, a massive one (both economically and socially) – it seems completely unrealistic to expect to make a significant difference within seven years; means that SwitchCoal has – compared with the other 9 measures – **the best increase rate and can be finished after 7 years, saving the whole amount of Gt / year from 2033 to 2050 continuously**.

---

[2] (theoretical) **possible solution contribution**, if all human being Act NOW, means under condition of deciding e.g. not to produce any more combustor car (ICE) and as well a full stop of every economic growth on average (= 0% moratorium) worldwide; **minimally invasive global climate protection measures** (generated by ChatGPT), and <u>note</u>: if global economic growth continues at 3.2% (as it has for the past 25 years), in 2025 our GDP will have roughly doubled (by factor 2.18) meaning that, given current energy consumption level, there is absolutely no chance of meeting the 2°C or even the 1.5°C target, because decoupling of energy use from economic growth is missing.

The reuse of existing grid connections is a clever move and saves up to three years on project timelines. Switch Coal offers a win-win solution (see Unique Selling Points). It's backed by studies from Bloomberg NEF, the IEA and IRENA, proving that the operational costs of renewables are lower and the profits are higher (see the Executive Summary of our 2023' release, we published under time pressure ahead of COP28).

Estimated annual GHG emission reduction by measure (2026-2050)



Implementation sketch:

States should be the central actors in implementing these measures.
This can be done via 7 major instruments:
A) Banning laws
B) Inforcing laws / setting standard
C) Incentives
D) Sanctions / taxes
E) Qualification
F) Quantifications / caps
G) Direct state action

Note: ascertained resp. designed according to studies and practical policies in forerunner countries (like Norway, Denmark, Morocco, China e.g)

Corresponding classification with
X = primary / most important policy instruments, X = supporting ones

	A Ban	B Inforce / Standard	C Incentive	D Sanction / Tax	E Qualification	F Quantification / Caps	G State Action
Coal→renewables	**X**		X				X
ICE sales stop	**X**		X				
Fossil heating stop	X	**X**	X				
Fossil industry stop		**X**	X	X			
Factory farming phaseout		X	X	X		**X**	
Methane leakage cuts				X	**X**		
Building efficiency		**X**	X				
Food waste reduction		**X**	X		X		
Ecosystem restoration			X			X	**X**
Appliance/motor efficiency		**X**			X		

(3)

In short, **SwitchCoal can also be seen as a "litmus test" for the climate action** that is urgently needed in the short term (as climate scientists always emphasize: "Emissions must be cut – now, drastically, no matter what"). No other solution is presented quite so readily on a silver platter.

So if those in charge (currently SB64/COP31 delegates) themselves ignore something like this, what good will all the many smaller, protracted measures – if they are even tackled with determination – actually do?

'**We have a choice**. Collective action or collective suicide. **It is in our hands.**'[4]
'Delay means death' - UN climate report urges immediate, drastic action.[5]

---

[3] **Ranking of** the minimally invasive **global climate protection measures** (according to 2, generated by ChatGPT), comparing the amount of Gt/year CO_2 reduction (in 20250) and **the (most) relevant criteria**: simple/complex, cheap/expensive and min./max. public disruption (taking opposition into account)

[4] See e.g. https://www.theguardian.com/environment/2022/jul/18/humanity-faces-collective-suicide-over-climate-crisis-warns-un-chief (António Guterres at COP27)

[5] See e.g. Reuters' from 28.02.2022: https://www.reuters.com/business/cop/delay-means-death-un-climate-report-urges-immediate-drastic-action-2022-02-28/

Answers to 1st Questions

What is "SwitchCoal"?

The *SwitchCoal-Project* is a solution-oriented project to generate profits, while saving 10 Gigatons (10Gt) or more than one quarter (25%) of the worldwide carbon dioxide emissions.

Why is SwitchCoal possible now (2023), and not earlier?

Since 2017, the Cost of energy production (LCOE) for PV energy (in Europe) is cheaper than the costs of Coal-fired electricity-power production.

What are the Base Data-Resources of "SwitchCoal"?

All used online database resources are funded by the World Bank and are scientific rock-solid.

- www.globalenergymonitor.org – Database
  about all **relevant data** of all the worldwide **coal plants**.
- https://globalsolaratlas.info – Online resource
  about all worldwide **regional solar energy** potential.
- https://globalwindatlas.info – Online resource
  about all worldwide **regional wind energy** potential.

What is the OUTCOME of Switch Coal?

The "SwitchCoal" 2023 project calculated

- how profitable it is for each of the worldwide 2500 Coal-Plant sites to replace electric power generation
- of coal-fired plants by Wind/Solar-Plants, combined with battery storage

What is "ZETT"? What is "Zero Emission Think Tank"?

ZETT is an abbreviation for "Zero Emission Think Tank".

Zero Emission Think Tank is an international think tank with a solution-oriented approach and the objective of developing essential, decisive solutions and approaches to allow effective targeting of the escalating climate crisis.

Foreword (Pao-Yu Oei, Prof. at Europe-University Flensburg for department „Sustainable Energy Transition")

"THE GLOBAL ENERGY TRANSITION AT A CROSSROADS: PROFITABILITY, JUSTICE, AND THE CHALLENGE OF COAL PHASE-OUT"

The transformation of global energy systems has become one of the defining challenges of our time. Scientific evidence has long established that limiting the climate crisis requires rapid and far-reaching reductions in greenhouse gas emissions across all sectors. Within this context, coal-fired power generation remains one of the most significant and structurally persistent sources of emissions worldwide, accounting for a substantial share of global energy-related CO_2 emissions. At the same time, recent geopolitical developments - including the war in Ukraine and Iran - have starkly exposed the systemic risks associated with continued dependence on fossil energy resources. Energy systems reliant on coal, oil, and gas are not only environmentally unsustainable but also economically and politically vulnerable.

Against this backdrop, the transition towards renewable energy sources is no longer solely a climate imperative; it is increasingly recognized as a cornerstone of energy security, economic resilience, and geopolitical stability. A growing body of literature, including this new volume, highlights that renewable energy systems, especially solar and wind, offer not only substantial emissions reduction potential but also cost advantages over fossil-based alternatives in many regions. Moreover, the decentralized nature of renewable technologies can reduce exposure to geopolitical supply disruptions, thereby strengthening national and regional autonomy.

The present volume contributes to this debate by examining the replacement of coal-fired power plants with locally integrated wind-solar-battery systems, showcasing that this can be achieved not only at scale but under economically favorable conditions. Drawing on a global dataset of 2,500 coal plant sites, the authors argue that around 90% of these facilities could be profitably substituted by renewable systems, potentially reducing global CO_2 emissions by up to 10 gigatonnes annually. This framing is notable in that it reframes decarbonization not as a cost burden, but as an economic opportunity - an argument that aligns with recent research emphasizing the role of market dynamics and cost competitiveness in accelerating energy transitions.

At the same time, it is important to situate these findings within the broader academic discourse on energy transitions, which increasingly stresses issues of justice, distribution, and political feasibility. Energy transitions are not merely technological substitutions; they are deeply socio-economic transformations that generate both winners and losers. While renewable energy expansion can create new employment opportunities, these new employment opportunities might vary in quality, skill level, salary and regional disaggregation. While the needed transition will reduce long-term system costs on an (inter-)national level, it can therefore still lead to structural disruptions in regions historically dependent on coal production.

Empirical studies show that the distributional impacts of decarbonization policies can disproportionately affect lower-income households if not carefully designed, highlighting the importance of compensatory mechanisms and inclusive policy frameworks. Consequently, the concept of energy justice has gained prominence as a guiding framework to ensure that the benefits and burdens of energy transitions are distributed fairly across societies.

These considerations are particularly critical in the context of the Global South. While many developing and emerging economies possess abundant renewable resources, the deployment of renewable energy technologies is often hindered by high financing costs, macroeconomic constraints, and sovereign debt burdens. Recent research underscores that access to affordable capital is a decisive factor in enabling low-carbon transitions in these regions, often outweighing purely technological considerations. Without targeted international support through concessional finance, risk-sharing mechanisms, and institutional capacity building, the global energy transition risks reinforcing existing inequalities rather than alleviating them.

In this regard, the approach presented in this book offers both answers and questions alike. On the one hand, the emphasis on profitability and the reuse of existing infrastructure, such as grid connections and plant sites (see ref. [(Fehler! Textmarke nicht definiert.)]), addresses some of the techno-economic barriers to implementation and may facilitate faster deployment. On the other hand, as with any large-scale modelling exercise, the results depend on assumptions regarding costs, resource availability, and system integration, which may vary significantly across local contexts, and do not sufficiently include additional socio-political aspects of the affected regions. This showcases the need for additional interdisciplinary and context-specific work.

(6)

Nevertheless, the central contribution of this work lies in its pragmatic and economically grounded perspective on coal phase-out strategies. By linking climate mitigation with investment incentives, it speaks directly to policymakers, investors, and industry stakeholders who play a crucial role in shaping the pace and direction of the energy transition. Importantly, it also highlights that delaying the transition carries substantial external costs - ranging from climate damages to health impacts and economic risks, which are often insufficiently reflected in current market prices.

Ultimately, the transition from coal to renewable energy systems is not only an environmental necessity but a broader societal transformation with far-reaching implications. If managed effectively, it can deliver multiple co-benefits: reduced emissions, improved air quality, enhanced energy security, and new economic opportunities. However, achieving these outcomes requires deliberate policy design to ensure that the transition is both efficient and equitable.

This volume provides a valuable contribution to this endeavor by offering a concrete, globally scalable pathway for accelerating coal phase-out. It invites further discussion, critical engagement, and empirical validation - all essential steps in translating analytical insights into actionable strategies. In doing so, it underscores a fundamental insight of contemporary energy research: that the success of the energy transition will depend not only on technological feasibility, but on the alignment of economic incentives, political will, and social acceptance.

[6] Screenshot from AI-generated Video, see Serviceplan Group (https://www.house-of-communication.com/de/de/cases/switchcoal-from-coal-to-clean.html)

Authors' Preface (Claudia Kemfert, Prof. of Energy Economics and Energy Policy at Leuphana University AND Head of the **Energy, Transport & Environment Division** at the German Institute for Economic Research, DIW Berlin)

"A POWERFUL BLUEPRINT FOR ACCELERATING THE GLOBAL SHIFT TOWARD A CLEAN, RESILIENT, AND SUSTAINABLE ENERGY SYSTEM."

The global climate crisis requires solutions that are effective, rapidly deployable, and economically viable. For a long time, the decarbonization of energy systems was perceived as complex, costly, and politically difficult. Today, however, the situation has fundamentally changed: renewable energy technologies have become dramatically cheaper and are increasingly able to compete with — and often outperform — fossil fuels, even when existing coal plants are already built and operating.

This creates a historic opportunity to accelerate the global energy transition.
This study presents a pragmatic and impactful pathway: replacing coal-fired power plants with a combination of wind energy, solar power, and battery storage. A key advantage of this approach is the strategic use of existing infrastructure. By repurposing coal plant sites and grid connections, new renewable capacity can be deployed faster, with lower costs and fewer permitting barriers. In many cases, the transition can occur within the same energy system structures that have historically supported fossil generation.

The results are striking. A large share of the world's coal-fired power plants could be economically replaced by renewable energy systems while maintaining a reliable electricity supply. Such a transformation could avoid a substantial portion of global carbon emissions and contribute significantly to meeting international climate targets. Importantly, this pathway is not only environmentally beneficial but also economically attractive.

The transition away from coal, therefore, represents not merely a climate necessity but also a strategic economic opportunity. Renewable energy investments can deliver stable returns, create new industries, and support regional economic transformation. Workers and communities currently dependent on coal can be part of this transition through retraining and participation in building the energy infrastructure of the future.

The technologies are available, the economics are compelling, and the urgency of climate action is undeniable. What is required now is decisive leadership and coordinated investment from governments, industry, and financial institutions. If implemented at scale, the approach outlined in this study could become a powerful blueprint for accelerating the global shift toward a clean, resilient, and sustainable energy system.

Preface for the public audience (Thomas Ladwig)

Fast and powerful, profitable global solutions for the climate crisis are rare: SwitchCoal is definitely one!

So have a quick look at its merits

Let us face it: the climate crisis is getting worse rapidly, day by day; we have not got it under control at all so far[7]. Most importantly, we are now utterly short of time to bring it under control, so in an unprecedented 'irreversible climate disaster'[8].

In about 2017, a new economic turning point emerged. Renewable energies (wind, solar, batteries), including related products (like heat pumps and electric cars), started to get cheaper than their fossil counterparts. As the energy costs tend to develop further in favor of renewables[9], new economic opportunities arise.

For almost all other fossil energy sectors (buildings / industry / mobility / others), rapid reductions of CO_2 emissions are very hard to achieve. Therefore, SwitchCoal addresses the subsector of Coal-based power-production (with 29% of all energy-related CO_2 emissions).

The SwitchCoal initiative analyzes the path how to replace worldwide Coal-based Power Production with an appropriate combination of renewable power production.

The project wording "SwitchCoal" stands for the process of "switching" away from "Coal"-based power production. It works on a global scale.

This document ("SwitchCoal 2025/26")
analyzes for how many of the worldwide about 2.500 Coal-Plant-Sites it is profitable to replace coal-fired electrical power generation by renewable wind/solar parks combined with battery storage solutions.

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[7] See e.g. and quite comprehensively: https://unfccc.int/news/new-un-climate-change-report-shows-national-climate-plans-fall-miles-short-of-what-s-needed

[8] See e.g. this recent report: https://yaleclimateconnections.org/2024/10/the-planet-is-on-the-brink-of-an-irreversible-climate-disaster-scientists-warn

[9] See: https://rmi.org/affordability-not-volatility-renewables-cost-advantage-grows

The results of SwitchCoal are outstandingly promising[10]:

- A majority of all worldwide COAL power plants
  - can be **profitably** (!) replaced
  - by **wind-solar-battery** facilities **in its vicinity**,
  - reusing the grid connections in place.
- Unique-pivot: Coal plants can be cleverly switched, not just phased out, so without a waste of resources.
- Collaborations with plant owners are possible.
- Faster: This allows a speed-up of up to 3years (due to shorter approval procedures).
- Integration: in existing power-production/distribution structures.
- Profit: additional to selling electric power, huge extra profits can be achieved after a few years.
- Feasibility: In terms of resource demands, this would also be feasible (when worldwide efforts are taken) in only appr. 7 years.
- CO_2 Reduction: When unrolled worldwide, SwitchCoal would reduce **human-caused CO2 emission** by about 1/4th, which was almost half (50%) of what was regarded as needed in 2023 for the Climate Goals around 2030[11].

By the by: there is another single means implementable likewise fast for the other half too, yet this is another story[12].

---

[10] For a comprehensive assessments what has been out there in the last 20 years, see: https://www.sciencedirect.com/science/article/pii/S2405844023077526

[11] See https://www.un.org/sustainabledevelopment/climate-change e.g. This target has to be reached against the backdrop of global emission developments as depicted in detail in: https://ourworldindata.org/co2-emissions. Yet, considering the latest findings and developments, even this reduction might be insufficient already.

[12] This lever is the overcome of industrial livestock farming. Though estimations about the total effect vary widely, many studies classified it in the range of at least overall 30% of all human caused $C0_2$ emissions (in particular due to indirect and side-effects, by transportation e.g.). For some recent, thorough assessments, see https://www.josephpoore.com/Science%20360%206392%20987%20-%20Accepted%20Manuscript.pdf e.g.
and https://journals.plos.org/climate/article?id=10.1371/journal.pclm.0000010

However, for a sufficient climate action benefit and for gaining extra profits soon, the implementation, to begin with projecting at scale, should start without delay.

Up to now, SwitchCoal representatives attended at the International Climate Congress in 2023 (COP28) and in 2024 (COP29), talked to many delegates plus politicians, apart from that, and always found great interest, even a lot of enthusiasm. Yet, irrespective of that, SwitchCoal has not been able to trigger any relevant political action in favor of this initiative so far. That is a pity since politics should clearly be its 1st addressee. While its saving potential may be appealing to climate activism, its economic opportunities are interesting for investors and plant owners[13], politics has by far the largest lever for action at hand here.

Politics has proven repeatedly that it can achieve quite a lot for climate action concretely (see e.g. the German EEG, recently the IRA boom in the USA, or the Chinese promotion of electric vehicles (EVs)[14].

Here, it could decisively help to overcome the tradeoff that is coming along with SwitchCoal:

- Reusing the grid connection and credit instruments like a PPA[15] in place is a huge advantage, also proven in practice repeatedly (e.g., in the USA).
- Another big advantage is the fact that this transformation is minimal invasive for the general public (before and after, electricity comes simply from the socket).
- However, on the downside, the intended sites for solar and wind may be good, but not always optimal or easily applicable (as restricted to the vicinity of the coal plant).
- The potential collaboration with plant owners would mean shared profits, too.

[13] The SwitchCoal concept intends to keep the plant owners concretely and durably in the game, benefiting from the switch, whereas in standard scenarios, coal plants are bluntly crowded out of the market by competitors.
[14] "China has used a wide range of tools to promote the EV sector" is e.g., a clear conclusion of a recent report in this regard, see https://www.csis.org/blogs/trustee-china-hand/chinese-ev-dilemma-subsidized-yet-striking.
[15] PPA = Power Purchase Agreement

- Politics could alleviate the initiation hurdle of SwitchCoal: the study states good and sufficiently large sites for solar and wind.
- Nevertheless, detailed project planning is mandatory, expected to cost about $500.000 per site on average, so summing up to a total of ca. $ 1.5 billion[16].
- That is a large sum, yet still an excellent bargain for an important step to save our world[17].

All the more since beyond that initial hurdle, things could evolve straightforwardly: the deployment of those huge solar, wind and battery capacities is just industry standard, the reuse of the grid connection, too[18].
Likewise, **applying credit instruments in place (PPA) is just a formal issue, respectively, a matter of will and action**.

---

[16] This per-site assessment is largely based on the concrete expertise and experiences made in this scope by the lead author of the Switch Coal study. Notably, this shall comprise only the detailed very initial planning, not the entire site development cost, which is usually way higher, classified in the range of 8-15% of the total project capex, see for details e.g. https://www.irena.org/Publications/2024/Sep/Renewable-Power-Generation-Costs-in-2023.

[17] The pathway to a 100% decarbonized economy is long, winded, and complicated. According to studies vary considerably again about methods and scope of assessment, and so the total costs. Yet at least they are in the range of several $ trillions per year at least. See e.g. https://www.iea.org/reports/net-zero-by-2050 or https://www.mckinsey.com/capabilities/sustainability/our-insights/the-net-zero-transition-what-it-would-cost-what-it-could-bring.
In contrast, the SwitchCoal initiative is a win-win-win... opportunity, so a unique bargain also from a pure economical perspective.
Note also that studies tend to be outdated from the very start – i.e., not reflecting enough of the latest technical developments. In particular, the IEA is infamous for having blatantly underestimated the potential of renewable energies for decades.

[18] Here, a recent only though: Moorburg (Hamburg) — implemented repurposing of a former coal plant grit connection into a green-hydrogen hub:
Project reporting (examples): https://fuelcellsworks.com/2024/11/12/h2/hamburg-advances-towards-becoming-a-hydrogen-hub-with-strategic-demolition-of-moorburg-plant
Progress reporting/context: https://energynews.biz/hamburg-moorburgs-transition-from-coal-to-hydrogen/ or https://www.offshore-energy.biz/hamburg-green-hydrogen-hub-project-moves-forward

How can all this be pushed ahead concretely? As said, politicians have already achieved much for climate action, often nationally, though always with global consequences and benefits. Likely the same approach could be a means here, at best supported by an international alliance, say, the SwitchCoal climate cooperation (also for gaining economies of scale and coordinated action).

In any case: accomplishing this would not only be a huge leap forward for climate action, but could be a blueprint and door-opener in global collaboration for climate protection, too.

All the more as - due to giant progresses with renewable energies and related products - we are closer to a technical solution of the climate crisis than ever before[19]. Recap what is at stake: large regions of the world may literally become uninhabitable by 2100, lest we take massive action now[20].
So spread the message and

- Discuss,
- Debate,
- Dispute,
- and most importantly, Take Action

for SwitchCoal now. Briefly regard SwitchCoal also as a survival kit for human civilization and maybe our last chance to avert the climate crisis from getting out of control.

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[19] This is reflected in a couple of recent studies, though they struggle - as mentioned above - to keep pace with the pace of technological progress for solar and wind energy, battery storage, etc. See e.g.
https://www.sciencedirect.com/science/article/abs/pii/S0959652624033912
And more recent for focusing on the technology aspects:
https://about.bnef.com/insights/clean-energy/new-energy-outlook/
(Bloomberg NEF's New Energy Outlook 2025).

[20] How critical this can be or become, is at best visible in recent interactive maps - depicting where the globe becomes uninhabitable due to climate change:
https://interaktiv.morgenpost.de/klimawandel-hitze-meeresspiegel-wassermangel-stuerme-unbewohnbar/en.html
In the same direction goes this interactive map on food insecurity due to climate change: https://www.metoffice.gov.uk/food-insecurity-index.

Preface for investors/plant owners (Prof. Pietro Altermatt)

SwitchCoal: A High-Return Climate Investment Opportunity, and Return-of-Renewable-Investment (RoRI)

A significant financial turning point has been reached:

Generating electricity with renewable energy sources and battery storage is now more cost-effective than traditional fossil fuels or nuclear power. Furthermore, electric vehicles and heat pumps are also becoming economically superior to their fossil-based counterparts.

This economic shift guarantees market dominance for solar, wind, batteries, heat pumps, and electric vehicles, even if they are driven not by climate action but by sheer financial incentives.

Yet, under business-as-usual scenarios, the transition away from fossil fuels is occurring too slowly, leaving substantial risks on the table – including increasing economic impacts from climate disasters. Accelerating this transition is imperative – and profitable, provided investments are structured wisely.

SwitchCoal presents an unparalleled investment opportunity: replacing coal power stations with wind-solar-battery systems with the same power output. Not only is the initial investment recoverable, but the ongoing operational savings significantly enhance profitability.

In numerous global markets, maintaining coal plants is already more expensive than investing in modern renewable alternatives, even accounting for capital repayments. Where financing conditions are less favorable, strategic government-backed financial guarantees can further reduce investment risk, enhancing investor security and return potential.

Globally, coal power stations account for about one quarter of total CO_2 emissions and are substantial sources of methane emissions from coal mining. The SwitchCoal initiative offers a high-impact climate solution by directly addressing this critical emissions source.

Importantly, the physical infrastructure required for renewable alternatives – solar panels and battery storage – can typically be constructed on existing coal plant sites, and wind turbines nearby. With this, the same grid connection can be used, and fewer accompanying permits are necessary.

Likewise, power purchase agreements (PPAs) can be reused or redesigned. This strategic advantage reduces permit and approval times by approximately three years, substantially accelerating project timelines and making investor returns safer.

Moreover, most existing employees can be trained to do the groundwork of the Switch, and once the Switch is done, they are skilled workers and can install solar and wind park technology.

To seize this exceptional opportunity, early-stage project planning funding is essential. Investors partnering with governments and relevant stakeholders can benefit from significantly reduced risks and strong financial returns while contributing directly to rapid climate mitigation efforts.

SwitchCoal is a unique opportunity for owners of coal power plants to remain in the power-production business for a long time, not being forced out of the market by prices that will soon no longer be competitive.

And this is a scenario already encountered in many regional markets (since the start of the 2020ies renewable energies have been just cheaper than fossil energies, and the price gap tends to widen further in favor of renewable energy).

To profit from the price shift towards renewables, owners of coal power plants just have to act as investors for themselves or partner with appropriate investors, by bringing in their valuable assets for this (i.e., grid connection, PPAs, well-established sites, backup capabilities, etc.).

Joint ventures are the most promising way to succeed here.

SUMMARY: **Now is the optimal time for visionary investors and owners of coal power plants to engage in the SwitchCoal initiative**

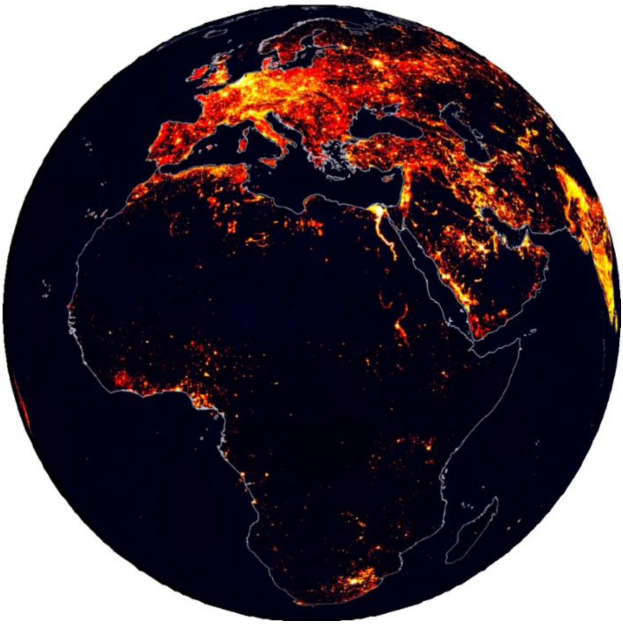
- Accelerating a sustainable transition,
- Securing an attractive return,
- Making a profound impact on global climate outcomes.

Ultimately, a short sketch of how this may work from an investor's perspective can be found in chapter [Outlook – how to implement SwitchCoal].

SwitchCoal

Switch coal profitably to renewable energy

2023



The FOLLOWING CONTENT
(up the [Addendum (2025/26)])
is the Original Pre-Release from 2023
(of our intended scientific study, written for the COP28)

Executive Summary

Installing and operating wind and solar farms, together with large-scale batteries in some cases, is already cheaper than the operating costs of many existing coal-fired power plants, see red arrows in Figure 1a-c.

This has been assessed by trustworthy sources on purely economic grounds, such as Bloomberg NEF, the International Energy Agency (IEA), and the International Renewable Energy Agency (IRENA).[1-3]

This implies that investments in replacing such coal-fired power plants with wind-solar-battery systems not only offer the regular investment returns of a stand-alone renewable energy project but also generate additional profits through lower operational costs, if compared to existing coal plants.

We assessed the approximately 2500 coal-fired power plant sites in operation and in construction worldwide and came to the following conclusions:

- Approximately **90% of the world's coal-fired power plants can profitably be switched** to wind-solar-battery systems with equal energy output (see Figure 2).
- **Billions in additional profits** can be achieved by the local (coal) power companies over the lifetime of the wind-solar-battery systems in many cases, shortening amortization times (see Figure 1a, Figure 1b and Figure 1c).
- 10 Gigatons of CO_2 emissions can be reduced prior to 2030[4], **because the existing grid connection of the coal plants is used, shortening planning times**.

Figure 1a:

LCOE (China) from 2013–2021

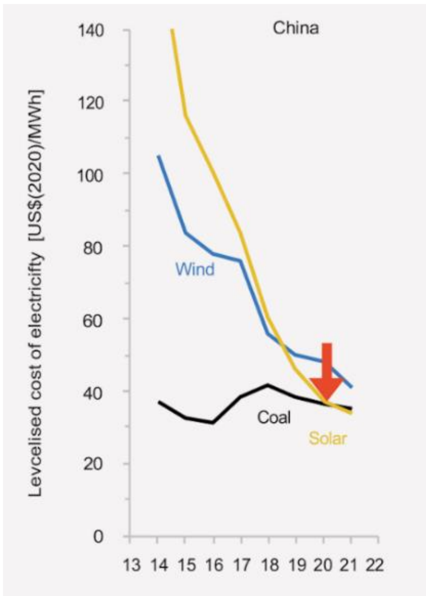


Figure 1b:
LCOE (India) from 2013–2021

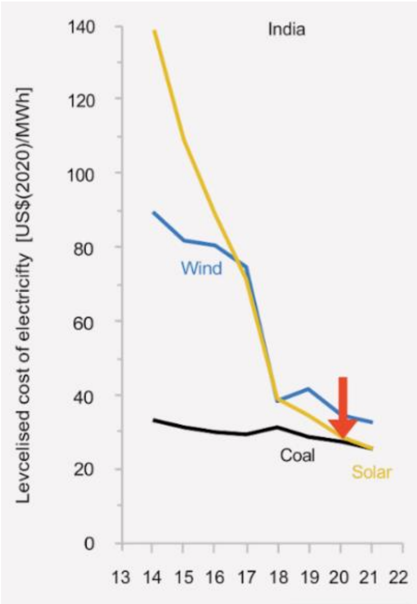


Figure 1c:
LCOE (Germany) from 2013–2021

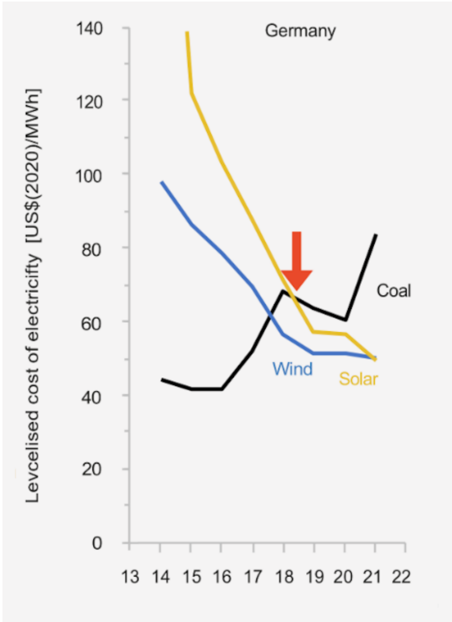
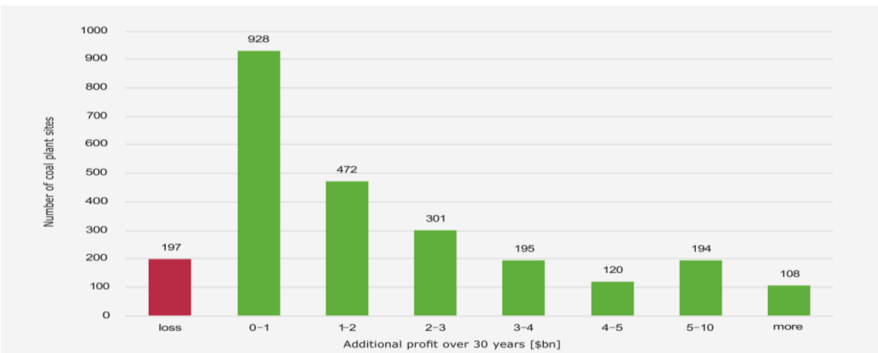


Figure 2:
After switching from coal to renewables and batteries, additional profits can be gained due to the lower operating cost of renewables.



Source: SwitchCoal, 2023

The employees of the coal plants can continue to be employed after short retraining, while they assemble and install the solar modules locally and elsewhere.

To practically support delegates at COP28[21] and political stakeholders with these solutions, we present the results on a country-by-country basis as a COP28 guide.

Delegates are encouraged to "Act-Borrow-Cash in":

1. **Act: pledge additional coal plant retirements** for their Nationally Determined Contributions (NDCs) for the Global Stock Take process,
2. **Borrow: find financing for investments** at COP28 to switch from coal to renewables,
3. **Cash in**: catalyze the local implementation at home with billions of US$ of additional profits.

Note: Historically, countries have used prospective additional profits to lower electricity rates or boost investment returns.

SwitchCoal's "low-hanging fruit" is indeed more than a highly profitable way to reduce greenhouse gas emissions before 2030: It may be the last chance to control a favorable climate for us humans,[5-7] as global climate tipping points are predicted if 1.5° Celsius is exceeded.[8]

The study is a blueprint for a pragmatic approach that is profitable and feasible. Therefore, instead of "act on climate", like the UN has done so far, it is far more engaging to adopt "act on climate and make profits".

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[21] REMARK from the PUBLISHER: The original pre-release was written in the year 2023 to be published for the International Congress of People (COP28) in Dubai.

Main results by country

The table below shows COP28 delegates the number of coal-fired power plant sites in their country that can be profitably switched to a wind-solar-battery system, with billions of dollars in additional profit (see green numbers) due to the lower operating costs of renewables.

These profits are calculated over the 30-year service life of the renewable system with a battery replacement after 15 years. The table also shows the annual CO_2 emissions saved, the expected investments and regular profits.

Table 1 (see Appendix)

Key SwitchCoal study results on the country level, using a physics-based optimization model.

Country	Number of coal plants profitably switchable **profitable / all**	Annual CO2 emissions saved by switching **Mt/yr**	Invest-ments Into WSB farms **US$bn**	Regular profits At 5–6% IRR, approx., not compounded **US$bn**	Addi-tional Profits from switch-ing over 30 years **US$bn**
Argentina	2 / 2	3.2	1.2	2.5	**2.3**
Australia	16 / 19	98.6	43.8	87.7	**60.8**
Bangladesh	7 / 7	34.6	16.8	33.6	**15.0**
Bosnia and Herz	0 / 5	0.0	0.0	0.0	**0.0**
Botswana	2 / 2	3.6	1.6	3.3	**2.8**
Brazil	7 / 7	15.7	7.2	14.4	**9.1**
Brunei	1 / 1	1.2	0.5	1.1	**0.8**
Bulgaria	10 / 10	28.3	15.2	30.4	**77.4**
Cambodia	5 / 5	8.0	4.0	8.1	**3.0**
Canada	10 / 10	17.2	10.0	20.0	**13.4**

Country	Number of coal plants profitably switchable **profitable / all**	Annual CO_2 emissions saved by switching **Mt/yr**	Invest-ments Into WSB farms **US$bn**	Regular profits At 5–6% IRR, approx., not compounded **US$bn**	Addi-tional Profits from switch-ing over 30 years **US$bn**
Chile	8 / 8	22.6	10.7	21.4	**13.5**
China	1162 / 1187	5261.1	2671.0	5341.9	**2826.7**
Colombia	5 / 5	8.8	4.4	8.9	**5.3**
Croatia	1 / 1	1.2	0.7	1.4	**4.1**
Czech Rep	25 / 25	43.6	21.8	43.7	**123.1**
Denmark	4 / 4	8.0	4.0	8.0	**27.6**
Dominican Rep.	3 / 3	5.2	2.1	4.2	**3.8**
Finland	7 / 7	8.0	5.1	10.2	**25.3**
France	6 / 6	13.1	7.2	14.5	**41.7**
Germany	58 / 58	204.7	106.3	212.6	**616.5**
Greece	4 / 4	15.0	7.5	15.1	**42.4**
Guadeloupe	1 / 1	0.4	0.2	0.3	**0.3**
Guatemala	12 / 12	5.7	2.5	5.1	**4.0**
Honduras	1 / 1	0.6	0.3	0.6	**0.2**
Hong Kong	2 / 2	32.0	18.0	35.9	**17.0**
Hungary	2 / 2	5.8	3.2	6.4	**15.5**
India	274 / 291	1133.0	548.5	1097.0	**146.0**
Indonesia	88 / 99	264.3	126.2	252.4	**43.9**

Country	Number of coal plants profitably switchable **profitable / all**	Annual CO2 emissions saved by switching **Mt/yr**	Invest-ments Into WSB farms **US$bn**	Regular profits At 5–6% IRR, approx., not compounded **US$bn**	Addi-tional Profits from switch-ing over 30 years **US$bn**
Iran	1 / 1	2.8	1.0	2.1	**1.9**
Ireland	1 / 1	5.1	2.4	4.8	**17.8**
Israel	2 / 2	21.9	10.9	21.8	**12.9**
Italy	6 / 6	29.8	19.3	38.5	**97.9**
Japan	90 / 90	258.7	136.7	273.5	**105.3**
Kazakhstan	20 / 21	68.4	30.4	60.8	**39.8**
Kosovo	0 / 2	0.0	0.0	0.0	**0.0**
Kyrgyzstan	1 / 1	4.6	1.6	3.2	**2.8**
Laos	0 / 1	0.0	0.0	0.0	**0.0**
Madagascar	1 / 1	0.6	0.3	0.5	**0.3**
Malaysia	7 / 8	55.2	32.0	64.1	**35.1**
Mauritius	3 / 3	1.0	0.4	0.8	**0.6**
Mexico	3 / 3	27.4	13.0	26.0	**21.1**
Mongolia	5 / 5	5.7	2.1	4.1	**3.6**
Montenegro	0 / 1	0.0	0.0	0.0	**0.0**
Morocco	4 / 4	19.8	8.9	17.8	**12.3**
Myanmar	3 / 3	0.9	0.4	0.8	**0.5**
Namibia	1 / 1	0.8	0.3	0.7	**0.7**

Country	Number of coal plants profitably switchable **profitable / all**	Annual CO2 emissions saved by switching **Mt/yr**	Invest-ments Into WSB farms **US$bn**	Regular profits At 5–6% IRR, approx., not compounded **US$bn**	Addi-tional Profits from switch-ing over 30 years **US$bn**
Netherlands	4 / 4	16.5	9.8	19.5	**53.8**
New Zealand	1 / 1	3.0	1.1	2.3	**1.6**
Nigeria	3 / 3	1.7	0.8	1.6	**0.7**
North Korea	4 / 7	7.3	3.3	6.6	**3.1**
N. Macedonia	0 / 2	0.0	0.0	0.0	**0.0**
Pakistan	12 / 16	26.0	11.7	23.4	**16.7**
Panama	1 / 1	1.4	0.9	1.7	**0.7**
Philippines	24 / 26	58.5	27.1	54.2	**33.8**
Poland	43 / 43	157.6	87.4	174.8	**490.6**
Romania	8 / 8	17.2	9.5	18.9	**46.0**
Russia	0 / 73	0.0	0.0	0.0	**0.0**
Senegal	2 / 2	0.8	0.3	0.7	**0.5**
Serbia	0 / 4	0.0	0.0	0.0	**0.0**
Slovakia	4 / 4	4.5	2.6	5.1	**13.2**
Slovenia	2 / 2	5.2	2.7	5.3	**14.2**
South Africa	16 / 16	221.4	99.0	198.0	**174.7**
South Korea	25 / 25	180.3	91.4	182.8	**86.5**
Spain	6 / 6	11.9	7.2	14.4	**37.7**

Country	Number of coal plants profitably switchable **profitable / all**	Annual CO2 emissions saved by switching **Mt/yr**	Invest-ments Into WSB farms **US$bn**	Regular profits At 5–6% IRR, approx., not compounded **US$bn**	Addi-tional Profits from switch-ing over 30 years **US$bn**
Sri Lanka	1 / 1	4.3	1.8	3.6	**2.5**
Taiwan	20 / 20	90.9	48.0	95.9	**44.6**
Tajikistan	1 / 1	1.8	0.8	1.5	**0.8**
Thailand	9 / 10	16.9	9.0	18.1	**8.6**
Türkiye	10 / 34	35.2	19.9	39.8	**13.0**
Ukraine	14 / 14	55.6	21.7	43.5	**13.2**
United King-dom	3 / 3	21.2	10.0	20.0	**8.8**
United States	202 / 216	1004.7	475.1	950.1	**553.7**
Uzbekistan	0 / 2	0.0	0.0	0.0	**0.0**
Vietnam	27 / 28	131.2	70.6	141.2	**49.7**
Zambia	2 / 2	1.5	0.6	1.2	**1.0**
Zimbabwe	3 / 3	10.2	4.6	9.3	**8.2**
Global (sum)	2318 / 2515	9833	4917	9834	**6172**

These values can be used by delegates at COP28 to

(1) **pledge** additional coal plant retirements
(2) **Find investments** at COP28 to switch from coal to renewables
(3) **Use billions of dollars in profits** to catalyze the local implementation at home

Study approach

This study determines the solar radiation and wind speeds in the vicinity of around 2500 coal-fired power plant sites that are in operation or under construction worldwide. Based on this data, the study estimates the cost of solar and wind electricity nearby these locations.

Furthermore, it proposes for each location the optimal mix of solar, wind and battery capacities to be installed to replace the coal power supply as close as possible over each day and the seasons. Finally, it estimates the total amount of capital investments required, the total operating costs of the combined wind-solar-battery plant compared to the coal plant, and the resulting additional profits or losses.

A physical and an economic model have been developed.

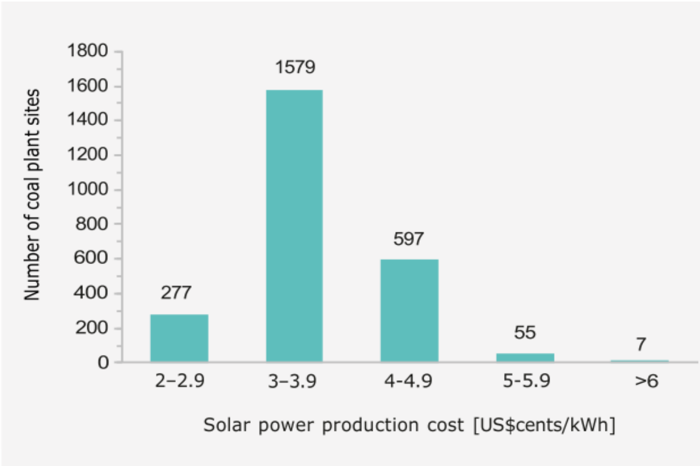
- Using the physical model, we calculate the required size of the wind, solar, and battery components so that enough renewable electricity can be reliably generated near the same location as each coal plant.
- Using the economic model, we assess the investments in the renewable system. To estimate the additional profits due to the lower operating costs compared to coal power, we use data from 2021, assuming that last year's price increase is temporary.

Sunshine and wind

The greater the amount of sunshine over the year, the cheaper solar electricity is. On top of this, there are, of course, variations we can find among countries, such as tax rates.[2] We found that most coal plant sites are in sunny places, where solar energy is cheap (about 3–4 US$ct per kWh of electricity), see Figure 3a.

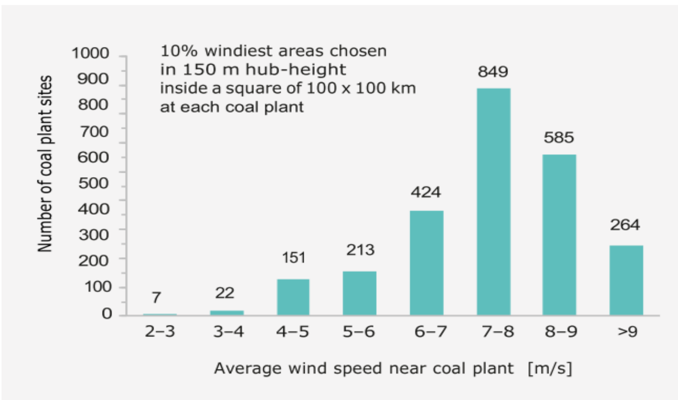
In addition, the windier it is, the cheaper the electricity from wind. Interestingly, most coal plants are also in areas with sufficient wind to warrant wind power at competitive energy prices (6–9 m/s average wind speed), see Figure 3b. However, the resulting electricity costs from wind farms depend on the local conditions, such as accessibility for transporting the blades, which must be considered on a case-by-case basis.[2]

Figure 3a: For the majority of coal plant sites, solar electricity costs are cheap (4 US$ct/kWh)



Source: SwitchCoal, 2023

Figure 3b: For the majority of coal plant sites, average wind speed is sufficiently high (6 m/s or higher)

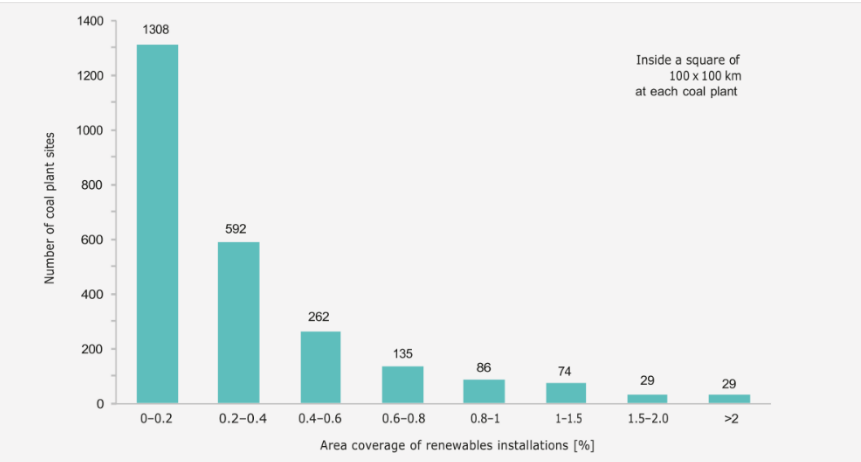


Source: SwitchCoal, 2023

Local surroundings

In our study, we generally choose the position of the solar and wind farms within a square of 100 by 100 km around existing coal plant sites. In this way, the new power sources can be fed into the existing grid at the location of the coal plant. This minimizes interconnection planning, which takes several years in many countries. It also avoids costly and lengthy network upgrades.

Figure 4:
For the majority of coal plant sites, less than 0.2% of the surrounding 100x100km area would be covered by the new solar, wind and battery installations



Source: SwitchCoal, 2023

The choice of a 100 x 100 km square also considers the possible local variations in wind speed.

Coal-fired power plants are often located in valleys, while good wind conditions prevail on hills and ridges. We have therefore selected the 10% windiest areas within this square. This approach also allows for flexibility when areas close to the plant cannot be used for solar or wind farms, such as built-up areas, nature reserves, water bodies, etc. In half of all the existing coal plant sites, solar, wind and battery power installations would cover less than 0.2% of the surrounding area of 100 x 100 km, see Fig. 4.

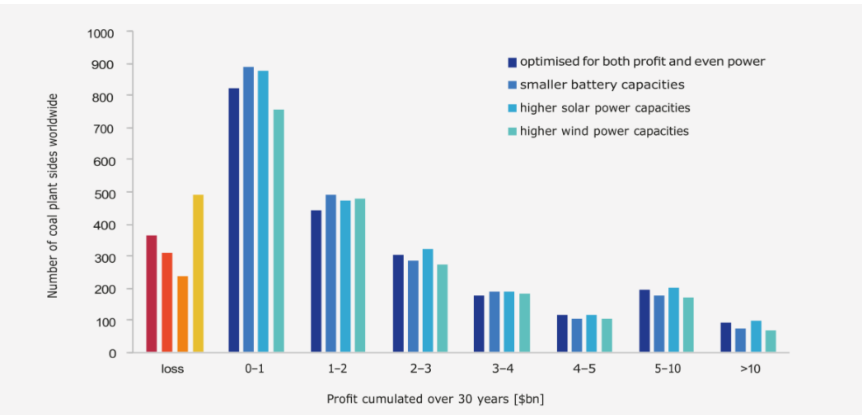
Sensitivity analysis of additional profits

On top of the regular project return on investment for the wind, solar and battery installations, including full return of capital and some 5–6% Internal Rate of Return (IRR), which are included in the power prices, additional profits arise from the much lower operating costs of renewable energies compared to coal.

Among other factors, these additional profits depend on the coal plant's operating costs as well as on the ratio between installed solar, wind and battery capacities. This ratio determines how evenly renewable electricity generation is distributed throughout the year.[9] For the operating costs of coal plants, we use regional averages given by the International Energy Agency (IEA).[3] It is important to note that the studied variations of wind-solar-battery capacities have no significant impact on the distribution of calculated additional profits across global coal power plants. In other words, the economic model is robust, see Figure 5.

Figure 5:

Robustness of the economic model, in terms of sensitivity to different ratios of installed solar, wind and battery capacities. The optimum is calculated for both profits and for evenly distributed power over the seasons.



Source: SwitchCoal, 2023

Of course, the exact additional profits need to be investigated in more detailed local assessments depending on local conditions. The robustness shown in Figure 5 is strengthened by the fact that we chose conservative estimates for fossil fuel prices by using low coal power cost data from 2021, prior to the price spikes in 2022.

It might be surprising that the additional profits are not substantially influenced by the amount of batteries, but large-scale batteries have become much cheaper. Our aim is to match the output of the renewable energy plant as closely as possible to the existing coal-fired power plant over the whole year, so that CO_2 emissions are truly avoided and not transferred to other types of fossil-fueled power plants that would have to compensate for lacking power. To match daily variations, we choose 8 hours of battery power per day – 4 hours in the evening when the sun goes down and 4 hours in the early morning when people get up before the sun rises. In summary, the physical and economic models are based on technologically and economically sound boundaries.

Amortization times

The resulting amortization times of the initial investments by the reduction of operating costs are 5–6 years at most sites in Spain, Poland and other European countries and for example, 15 years at many sites in India.

The very short amortization rates in Europe are due to the EU Emission Trading System (EU ETS) and the annually increasing prices per ton of CO_2 emission. Overall, an amortization period of 10 to 15 years is short and makes the switch from coal to renewables economically attractive.

Employment

Also, the social perspective of switching from coal to renewable energy can be made positive, as employees of the coal plants can continue to be employed at least for some time. Planning and installing solar power takes about two years. After short retraining, plant employees can assemble the solar modules in local assembly lines and install them. This gives time for a smooth transition of employment and local economic structures.

The same can be done for the employees in coal mines. Generally, renewable energies are a strong job generator, creating one million new employments just in 2022.[2]

CO_2 emissions

The investigated 2500 operating coal plant sites emitted approximately 11 Gt of CO_2 in 2021.[4] With about 90% of the coal plants switched profitably to renewable plants, nearly 10 Gt of CO_2 can be avoided per annum. This is about one quarter of all global CO_2 emissions.[4] Please note that this amount of CO_2 emissions can only be avoided

if the renewables and battery capacities are installed in such a way that the output of the renewables matches the output of the coal plant throughout the day and the year. Otherwise, other (fossil) power plants will make up for the missing output. We therefore try to match the renewable power as closely as possible to the coal-fired power by choosing batteries and an optimal ratio of solar and wind farms.

Background[22]

At the World Climate Summit COP28 in the United Arab Emirates (UAE), countries are expected to communicate the status of their carbon emission reductions since the Paris agreement, called the Global Stock Take.

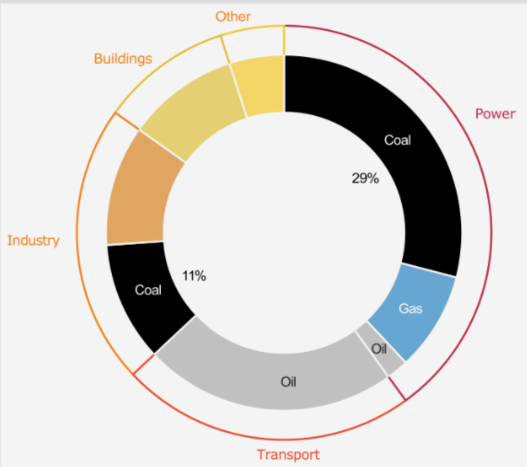
COP28 president Dr. Sultan Al Jaber has recently stated that at COP28, “we are going after the Gigatons” with a goal to “reduce 22 Gigatons by 2030”.

Coal-fired power plants are the easiest way to reduce carbon emissions and account for a staggering 11 gigatons of carbon emissions.[4]

Renewable energy has seen great cost reductions over the past decade and reached an economic tipping point in 2017 (Germany) and 2019 (India and China), with now being even cheaper than running existing coal plants, according to Bloomberg.[1]

Figure 6:
Global CO_2 emission by sector

- 29% comes from coal-fired power plants,
- another 11% from industrial use of coal[1,4]



Source: International Energy Agency[3]

Therefore, we have evaluated whether the world’s 2500 coal plant sites can be profitably switched to wind-solar-battery systems, including 8 hours of battery power, replacing coal plants on-site, on purely economic grounds.

Carbonbrief has published data on the world’s coal plants that are larger than 30 MW.[11]

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[22] REMARK from the PUBLISHER: Understanding the Framing “COP28”:
This part of the document is the original pre-release and has been written in the context of the International Congress of People (COP28) in Dubai 2023.

A comprehensive study of 145 countries accounting for 99.6% of the world's emissions has recently shown that it takes US$62 trillion for the global economy to transition to renewable energy systems, including 8 hours of battery power, with a payback time of only 5 years on purely economic grounds.[10]

The study uses these data, in conjunction with the World Bank’s global solar[12] and global wind[13] atlas, to evaluate the renewable resources at each coal plant site.

Economics for wind and solar energy production at the coal plant sites were calculated based on economic data from the International Energy Agency (IEA).[3]

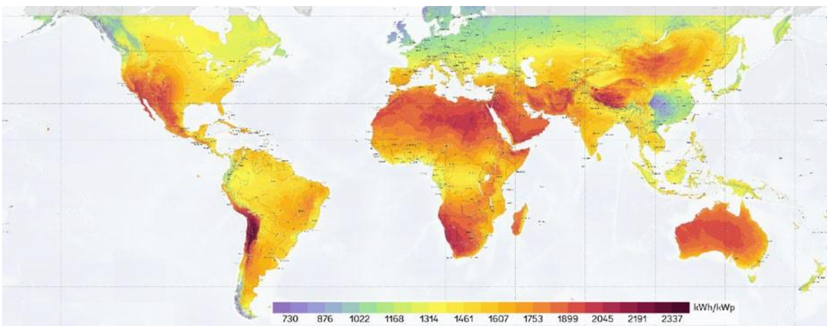
2500 coal plant sites cause 30% of global emissions

According to the IEA, coal-fired power plants (coal plants) are responsible for 29% of the energy-related global greenhouse gas emissions, as depicted in Figure 6.[3]

Solar potential for all coal plant sites

Figure 7:

World Bank's global solar atlas[12] In all regions colored light green, yellow, orange or red, solar energy is produced at 4 US$ct per kWh or less.



Solar potential at the 2500 coal plant sites

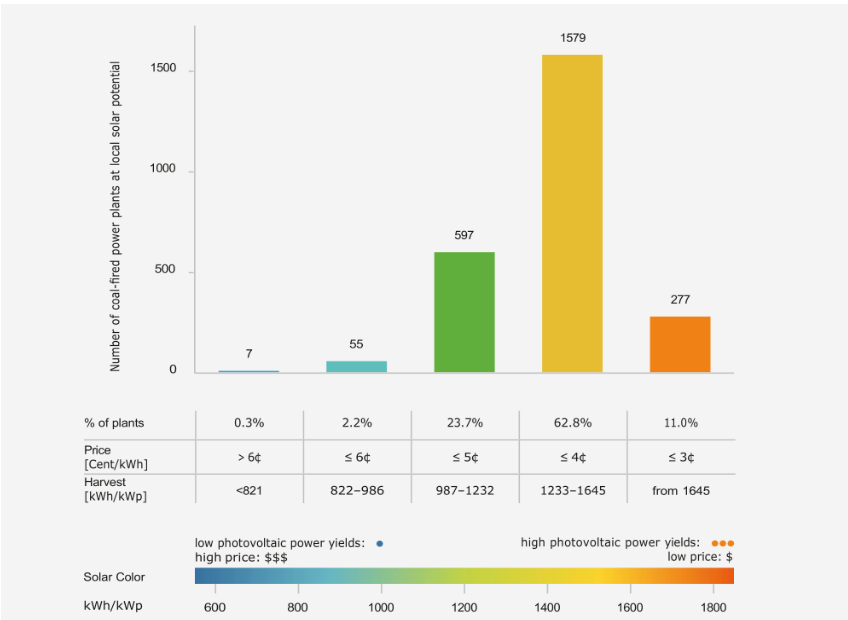
The World Bank has published a global solar atlas[12] for yearly photovoltaic power yields, shown in Figure 7.

To assess the solar potential, an algorithm was developed to automatically extract solar resources from the World Solar Atlas at each coal plant site.

The results depicted below show that about 74% of the coal plants have a solar potential with an annual production of more than 1233 kWh for each kWp installed (light green in the map), which is equivalent to solar energy production costs of 4 cents or less per kilowatt-hour (US$ct/kWh).

Figure 8:

World Bank's global solar atlas.[12] Solar potential at the world's 2500 coal plant sites (annual kWh/kWp). About three-quarters of sites produce solar energy at 4 US$cents or less.



Source: SwitchCoal, 2023

Calculations of the solar potential at the coal plant sites

We developed an algorithm to automatically extract the "specific photovoltaic power output", which is kWh of electric power produced per kWp of installed solar panels over an average year (kWh/ kWp), from the World Bank's global solar atlas[12] within an area spanning 100 km x 100 km around a coal plant.

The area needed for a large 500 MW solar farm is about 2.3 km x 2.3 km (500 hectares = 1235 acres). Because not all the terrain might be suitable for solar, a larger 100 km x 100 km area was chosen. Note: The solar irradiation is quite uniform in such an area.

Figure 9:

The solar potential[12] which is kWh of electric power produced per kWp of installed solar panels over an average year.

It varies only slightly within 100 km² in most geographies

Source: World Bank[13] and SwitchCoal, 2023

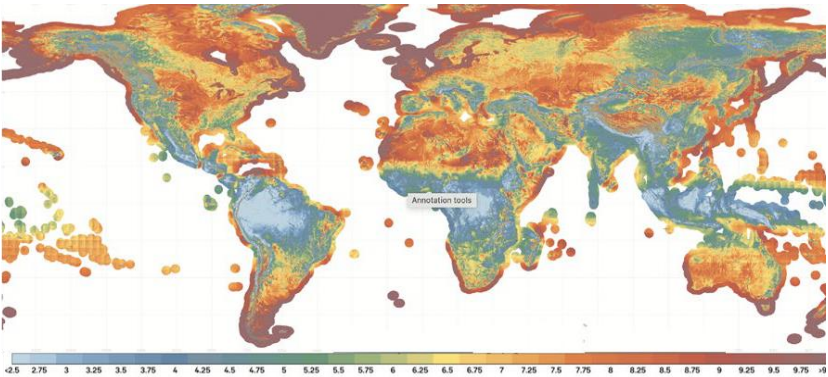
See https://globalsolaratlas.info

Wind potential at the 2500 coal plant sites

Figure 10:
The World Bank's global wind atlas.[13]

Most of the regions colored orange, red or purple have a sufficiently high average wind speed to produce wind energy

for US$4 cents per kWh or less



Source: GlobalWindAtlas.info (funded by World Bank)

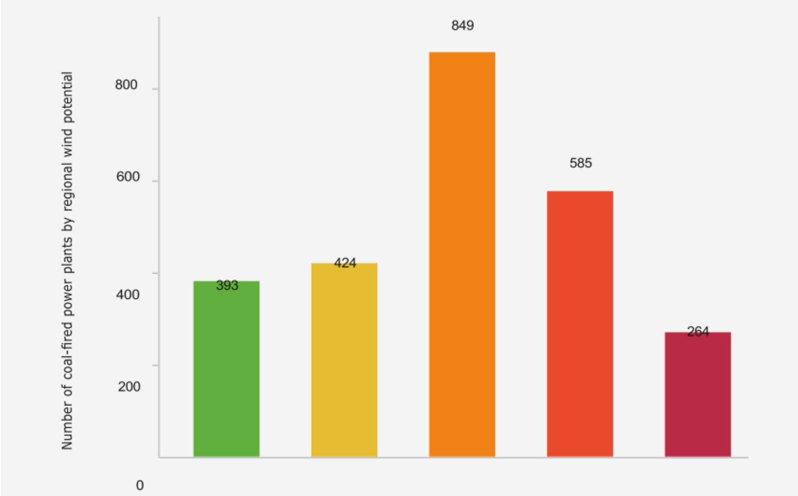
To assess the wind potential, we developed an algorithm to automatically extract the wind resources from the World Bank's global wind atlas[13] at each coal plant site.

The results depicted in Figure 10 show that 68% of the coal plant sites have a wind potential that exceeds an average wind speed of 7 m/s (orange in the map).

This is equivalent to wind energy production costs of about 4 cents or less per kilowatt-hour (US$ct/kWh) in many countries (a main exception is the EU with 5.13 US$ct/kWh).

Figure 11:
Wind potential at the world's 2500 coal plant sites (annual kWh/kWp). About 68% of sites with 7m/s or more produce wind energy at 4 cents or less.

The derivation of the cost (US$ct/kWh) is described in the section "Wind and Solar Energy production costs" below.



% of plants	15.6%	16.9%	33.8%	23.3%	10.5%
Price for US: [Cent/kWh]	> 5.28¢	≤ 5.28¢	≤ 4.27¢	≤ 3.74¢	≤ 3.44¢
Price for EU: [Cent/kWh]	> 6.24¢	≤ 6.24¢	≤ 5.13¢	≤ 4.53¢	≤ 4.2¢
Price for China: [Cent/kWh]	> 4.69¢	≤ 4.69¢	≤ 3.94¢	≤ 3.54¢	≤ 3.32¢
Price for India: [Cent/kWh]	> 4.72¢	≤ 4.72¢	≤ 3.84¢	≤ 3.38¢	≤ 3.12¢
Price for RoW: [Cent/kWh]	> 5.02¢	≤ 5.02¢	≤ 4.07¢	≤ 3.57¢	≤ 3.29¢
10% windiest area [m/s]	< 6	≥ 6	≥ 7	≥ 8	≥ 9

Source: SwitchCoal, 2023, using data from World Bank[13]

Calculations of the wind potential at the coal plant sites

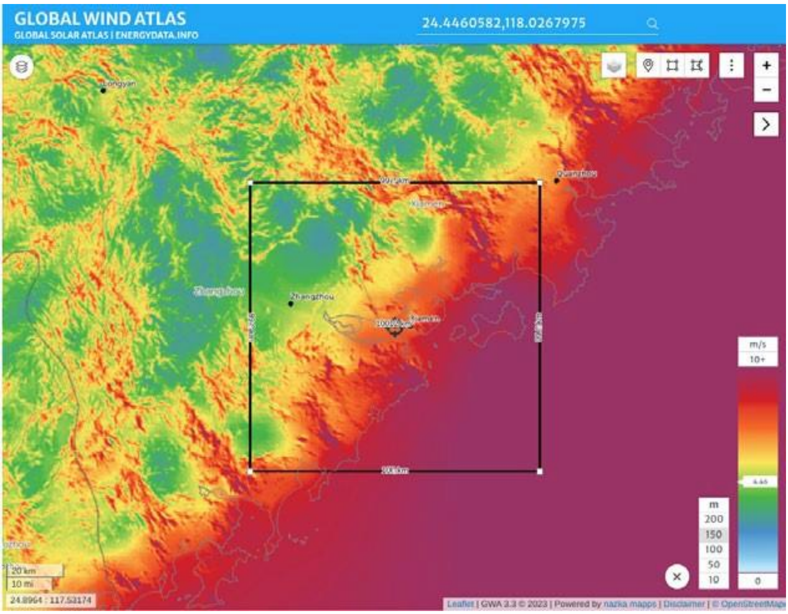
An algorithm was developed to automatically extract the average wind speed (m/s) from the World Bank's global wind atlas[13] of the best 10% area within a 100 km x 100 km area around the coal plant, see Figure 12.

The area needed for a large **500 MW** wind farm is calculated as follows:

- Wind turbine rated capacity: **6.8 MW**
- No. of wind turbines needed: 500 MW / 6.8 MW = **74**
- Diameter of wind turbine rotor: **D=175m**

Spacing between wind turbines: 3D x 10D (525m x 1750m)

Figure 12:
An area of 100 x 100 km around a coal plant
in the World Bank's global wind atlas



Source: World Bank[13] and SwitchCoal, 2023

Note: To Figure 12:

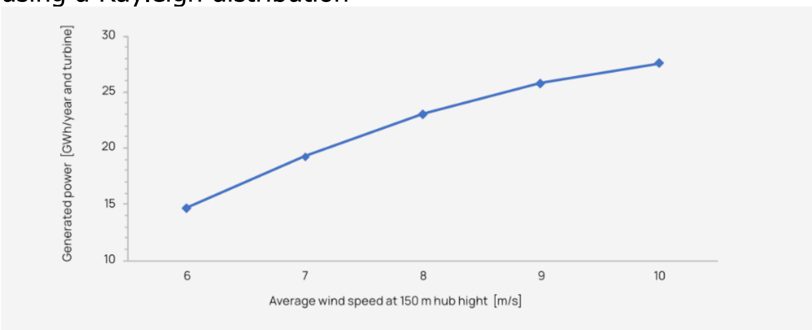
This spacing assumes strong average wind speeds exceeding 8 m/s from a predominant wind direction. For lower wind speeds, a less spread-out 3D x 5D spacing may be sufficient.

Area needed for 74 wind turbines: 10.5 km x 6.5 km

Wind speeds were assessed at 150 m hub height for wind turbines. Current developments with up to 199 m hub heights were not considered.

For the calculation of wind energy production from average wind speeds, a Raleigh distribution is used, averaging out local wind profile variations to estimate the wind energy production:

Figure 13:
Example of wind energy production estimating, using a Rayleigh distribution



Source: SwitchCoal, 2023

Optimization of the wind-to-solar ratio

In order to optimize the wind-to-solar ratio economically, the capital and operational expenditures (CAPEX and OPEX) for the installation and energy production for wind-solar-battery systems were assessed and compared to the operational costs (OPEX) of existing coal plants. The questions were a) how many coal plants can be profitably replaced with wind-solar-battery systems, and b) how profitable would it be to replace each of the world's 2500 coal plants?

Wind and Solar Energy production costs

Production costs were estimated based on 2021 economic data from the World Energy Outlook[3] from the International Energy Agency (IEA).[14]

A simplified unleveraged financial model was used to calculate internal rates of return (IRR) as deducted from the IEA economic data. Keeping these returns constant, production costs for wind and solar energy were calculated for the local wind and solar resources at each coal plant site. The results were already shown above in Figures 8 and 11.

Conclusions

- 68% of the coal plant sites with wind speeds of 7 m/s (orange in the wind map) or more, produce wind energy at 4 cents or less in many countries.
- 74% of the coal plant sites with solar resources of 1233 kWh/kWp (light green in the solar map) produce solar energy at 4 cents or less in most countries.

Economic input data of wind energy

The IEA provides economic data[3] for four geographic regions: the US, EU, India and China. Especially for wind farms, investment costs reflect many more parameters than for relatively simple solar farm constructions. For example, upgrading roads for the transport of long and heavy loads often adds to the investment costs.

For the purpose of our study, these IEA data were used, and a 5th region was defined as “Rest of World”, averaging out the somewhat similar economic parameters between the US, China and India. EU data were excluded because of high renewable energy installation costs, but also because of high operating costs (OPEX) for coal plants in the EU, both of which are not representative of countries outside the EU.

The IEA furthermore provides economic data for 2021, with often much lower cost estimates for 2030 and beyond. Despite the study scope focused on short-term installations from 2024–2030, we used only the rather conservative 2021 data to estimate wind energy production costs for each of the five regions.

Economic input data of solar energy

The IEA provides economic data[3] for 2021 for four geographic regions: The US, the EU, India and China. However, solar utility construction is relatively simple. The CAPEX consists mainly of solar panels, a racking system, inverters, electrical items, dirt roads and planning costs. With global markets for all items, there is no technical reason for higher costs, except for labor and political reasons like permission costs, trade barriers and so on.

The IEA furthermore forecasts lower CAPEX costs for 2030, possibly reflecting such global market adjustments.

According to the IEA, international tenders often result in CAPEX costs of $0,65 cents/Wp or less, for which reason a CAPEX of 0.65 US$ct/Wp is assumed for all countries in the current study.

Operating costs are based on experiences in the US with 200 MW solar farms, where operating expenses (OPEX) were assumed to be 9% of the revenues. Larger solar farms tend to have lower costs. However, we do not assume any cost degression for the large solar projects in this study.

Unleveraged financial model of the wind farm

We developed a simple unleveraged financial model (FM) to calculate the internal rate of return (IRR) for the IEA base case economic data.[2]

The IRR was calculated over 30 years.

Example for the US:

Investment (CAPEX):	1380$/kW
Average Capacity factor:	28%
Operating expenses (OPEX):	$10/MWh
LCOE production costs:	$45/MWh

The IRR was calculated, based on these input data, resulting in the base case internal rate of return.

Single input parameter changes were used to calculate different capacity factors, based on different wind speeds, resulting in a variation of the output, i.e. LCOE production costs.

These input/output data pairs were used to develop a trendline, which was used to calculate the production costs for each wind farm at each of the coal plant sites in a region.

OPEX costs for coal plants – examples

The graphics below show the US and India coal fleets with operating expenses (renewable energy generation costs, IRENA 2020).

According to the IEA, India's operating costs are on average 4 ct/kWh. According to Lazard, operating costs in the US are 5.2 ct/kWh.

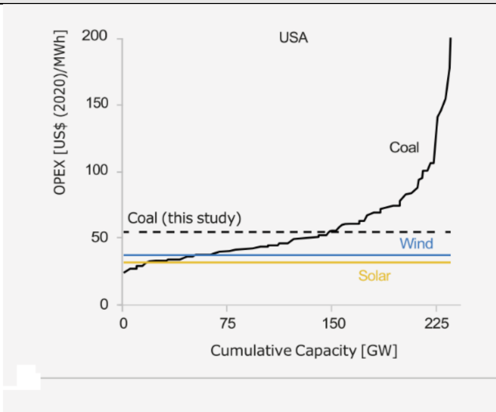


Figure 14a:
Operating expenditure of coal plants in the USA

The dashed lines represent purchase agreements (PPAs) of solar and onshore wind[2]

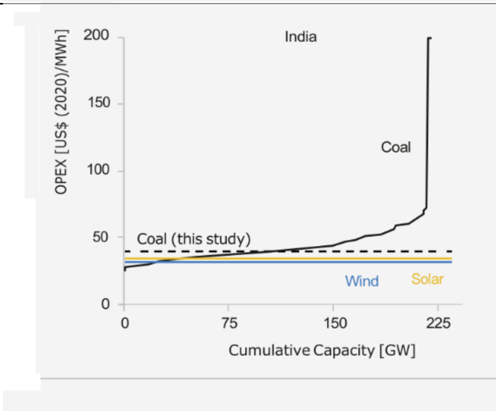


Figure 14b:
Operating expenditure of coal plants in India.

The sashed lines represent purchase agreements (PPAs) of solar and onshore wind[2]

Coal plant operating costs (OPEX)

The operating expenses for coal plants were taken from the World Energy Outlook (IEA)[3] with adjustments and extrapolations for regions not covered, as listed below. Furthermore, adjustments were made for lignite plants (see below).

Operating expenses for existing coal plants.

Region	US$ct/kWh	Reference
India	4.0	[A]
Indonesia	4.0	[B]
China	5.5	[C]
US	5.2	[D]
EU	13.8	[A]
Rest of the world	5.2	[D]

[A] IEA World Energy Outlook 2022, except lignite
[B] Assumed similar to India [A], except lignite
[C] IEA World Energy Outlook 2023, not 2022, because it is lower.
[D] Lazard 2023

Lignite power plants

Based on IEA data (World Energy Outlook 2022, p. 412), peat and lignite coal represent 5% of the overall coal production:

year	2010	2021
	[Mt]	[Mt]
World coal production	5235	5825
Steam coal	4069	4560
Coking coal	866	1030
Peat and lignite	300	235

The Carbon Brief data on coal plants used in this study identify 264 lignite power plants.

The following assumptions are made for the study:

OPEX	US$ct/kWh	
China	4.0ct	reflecting carbon pricing
US	1.5ct	reflecting clean air standards
EU	no corrections made, because of high carbon pricing	
Rest of world	1.0ct	with no carbon pricing

Additionally, we found that half of all coal plants have a remaining lifetime shorter than 25 years, and a quarter of plants have a remaining lifetime shorter than 5 years.

The depreciation time is usually much shorter than the plant life.

Please note: A minor number of coal plants also supply heat to heating networks. Once the coal plant is converted to renewable energies, the heat can be generated by heat pumps (or other sources), which require around 10% more electricity. This is not considered in this study, as the heating market is different from the electricity market.

Wind-solar-battery system
– optimization for wind and solar –

With regards to the ratio of wind to solar energy, we chose two different approaches:

1. **A physics-based optimization model** for even power generation over the seasons.9
2. **An economic optimization model**, which seeks to install cheaper renewable power than is optimum in the first model.

The **first approach** can be seen in Germany, with both renewables being complementary, especially with wind at night, with no sunlight.

There is also a seasonal component in Germany, with much more wind in winter and much more sun in summer.

In this case, the energy produced by a coal plant could be substituted with about 50% wind energy and about 50% solar energy, i.e. same amount of annual kWh produced.

Germany runs separate auctions for wind and solar energy to take advantage of both complementary renewable energy sources.

The **second approach** is to optimize for the cheapest renewable energy in a region. For example, in India, many coal plant sites only have marginal wind resources, but a high solar potential. In this case, a coal plant could be substituted by 90% solar energy and 10% wind energy (conceptually for the night / Note: The power grid usually provides backup power in power grids with renewables contributing less than 50% of the energy, with no need for batteries). This is probably the most common reality in the world: the cheapest renewable energy wins.

In the **second approach** (cheapest renewable energy), the wind-solar-battery system was optimized as follows:

1. A pricing coefficient "solar energy" divided by "wind energy" was calculated for each coal plant site, and the result
   <1: reflects solar energy being cheaper
   >1: reflects wind energy being cheaper
   =1: reflects same pricing for both, wind and solar
2. If the pricing coefficient is between 0.9 – 1.1,
   wind and solar energy were both taken into consideration on a 1:1 energy basis.
3. If the pricing coefficient is <0.9,
   solar energy was added in for 90% of the energy,
   wind energy was taken for 10%.
4. If the pricing coefficient is >1.1,
   wind energy was added in for 90% of the energy,
   and solar energy was taken for 10%.

With respect to the existing coal plants at 2500 sites, the average capacity factor is 53% according to Carbon Brief,[11] i.e., they are only running at half their capacity. For the purpose of this study, the energy produced by each coal plant was derived from the carbon emission data and has been completely replaced with wind and solar energy in the study.

Note: base load is becoming less relevant due to larger energy grids, storage capacities and the fact that wind and solar energy often balance each other well in higher latitudes.

Wind-solar-battery system
– optimization of batteries –

While wind and solar energy provide cheap renewable energy, batteries can fill in the gaps. The question is how much. The study distinguishes 3 scenarios.

Standard "Load following" scenario

The first scenario is a standard "load following" scenario, which reflects historic power markets whereby load simply follows demand, which requires large amounts of batteries to back up renewables, with up to 100% of the system peak capacity.

An example is the power market in California. 4h batteries are used to discharge for 4h in the late afternoon, typically from 5–9 pm, when the sun goes down, and people go home to cook and power use. Similarly, power is also needed in the morning before the sun rises. Therefore, this study assumes 8h of battery backup.

The amount of battery backup in this study was reduced to 50% because of significant flexible loads coming on in the future with EVs and heat pumps, and because of a renewable energy penetration in most countries of much less than 100%.

"Flexible use" scenario

The second scenario is a "flexible use" scenario, reflecting future power market designs with high renewable penetration, whereby a "renewable pricing signal" indicates the abundance of cheap renewable energy ("green light"), or its scarcity ("red light"), functioning like a traffic light. 80% of the future energy consumption is expected to be flexible (EVs, heat pumps, smart fridges, laptops, etc.). Studies have shown that the amount of backup power is greatly reduced in such a future electricity market design, to only about 10% of the installed peak capacity for "flexible use" markets.[15] Therefore, the study assumes a 10% battery backup in this case.

"Low renewable energy" scenario

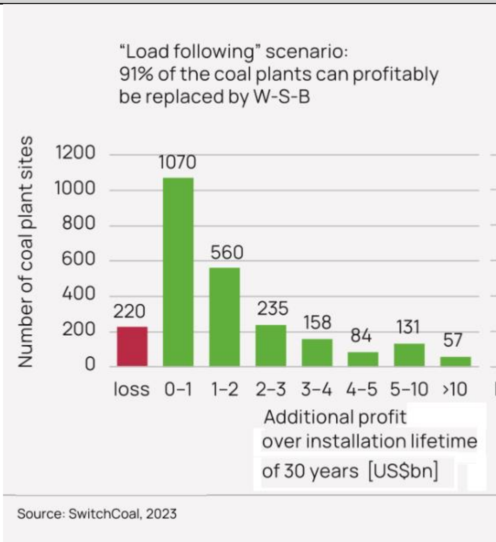
A third scenario reflects "zero batteries". Countries with low overall renewable energy installations may not need to back up renewables with batteries at all.

All three scenarios were calculated to determine the number of coal plants that can profitably be switched to wind-solar-battery systems. The results are depicted below.

The observation that all three scenarios hardly differ in the results underpins the robustness and validity of our approach. In summary, the battery size (50% or 10% or 0% of the system peak capacity) does only marginally affect the number of coal plants that can be profitably switched to wind-solar-battery systems.

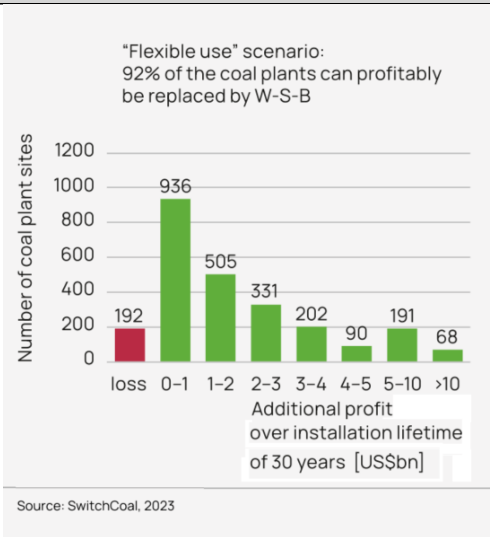
The results of the 1st approach, the physics-based optimization model, are listed below the executive summary (Table 1 on pages 25 to 29). The detailed physical-economic model will be published in a scientific journal.

Figure 15:
About 90% of the coal plants can be profitably switched to wind-solar-battery systems regardless of the battery capacities installed.

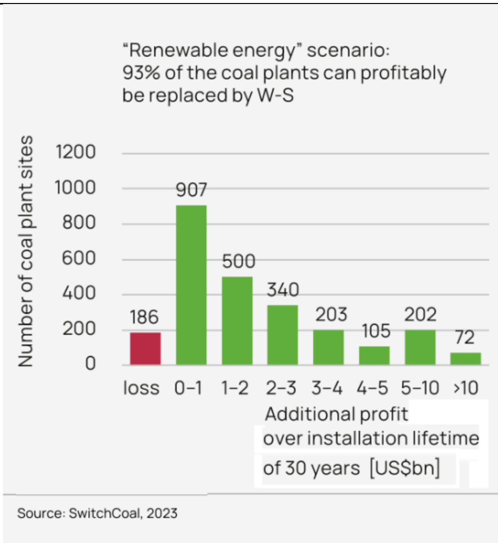


The "load following" scenario [...] reflects historic power markets [...] with up to 100% of the system peak capacity.

An example is the power market in California. 4h batteries are used for 4h in the late afternoon, in the morning before the sun rises. Therefore, this study assumes 8h of battery backup.



In the "flexible use" scenario, a 10% battery backup is assumed to reflect future power market designs with high renewable penetration, whereby a "renewable pricing signal" indicates the abundance of cheap renewable energy ("green light"), or its scarcity ("red light"), functioning like a traffic light. 80% of the future energy consumption is expected to be flexible.



A "Low renewable energy" scenario reflects "zero batteries".

Countries with low overall renewable energy installations may not need to back up renewables with batteries at all.

Battery cost assumption

The battery system is charged twice per day: during the day for 4 hours in the evening, and by wind energy during the night for 4 hours in the morning before sunrise. If less than 10% wind is installed optimally, the batteries are charged during the day for a whole of 8 hours.

Investment costs into utility-scale batteries are assumed to be $285/kWh for a 4-hour battery, according to the IEA (2021 data). Battery costs are assumed to decline to $185/kWh by 2030; however, such future cost degressions have not been considered in the study. With manufacturers warranties from 10 – 20 years, a 15-year lifespan was assumed for the battery.

Please note: Several car manufacturers have announced to introduce sodium salt batteries to the market, in up to every 4th of its battery cells at only $40/kWh. With common (sodium) salt costs in the $800 range per ton, compared to $40,000 – 80,000 for Lithium, costs may drop sharply in the future for such utility-scale cheap sodium salt batteries. Such cost drops have not been considered in the study.

Please note: Batteries are the only storage technology considered in this study. There are other proven storage technologies, such as pumped hydropower, electricity-heat sector coupling, and others.

The results of the 2nd approach, the economically optimized for the cheapest wind-solar-battery systems, are listed in the table in the appendix (Table 2 on pages 60 to 64).

This approach reflects market realities with mostly low renewable energy penetration and the cheapest renewable energy prevailing.

This simple model yields similar results to our first approach. This shows that the simple model is also accurate enough to support our arguments.

Feasibility by 2030

We next evaluated the feasibility of the switch from coal power plants to renewables by 2030. Experience shows that planning large-scale wind-solar-battery projects requires years, with the grid connection studies often taking up most of the time. Results show that planning times can be reduced to 2–3 years if the existing grid connection of the coal plant can be used.

Furthermore, we evaluated the global wind and solar manufacturing capabilities to see if the coal plants at the 2500 sites can be switched to renewables before 2030, given global manufacturing capacities. The results show that manufacturing capacities are already sufficiently large (and growing fast) to install the necessary wind and solar farms by 2030,

Annual global PV manufacturing capacity

2021	168 GW
2022	239 GW
2023	790 GW

Annual global wind turbine additions

2021	94 GW
2022	78 GW
2023	117 GW

Note: Doubling the wind power capacity is possible by switching from the current 3-4 MW class of wind turbines to the new 6-7 MW class, which is expected to happen.

SwitchCoal

Wind	capacity needed:	1.5 TW
Solar PV	capacity needed:	4.8 TW

Considering that production capacities for wind and solar energy grow, both are sufficient to replace all coal-fired power plants prior to 2030, with production capacities still available for other applications.

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Appendix

Results of the physics-based optimization model

According to Carbon Brief[11], there are about 2500 coal plant sites in the world with a capacity greater than 30 MW. The Carbon Brief's country-specific values of plant total capacity, carbon emissions from these coal plants and their share in electricity-related emissions are given in these tables. The main question for replacing coal power is the optimal ratio of wind capacity to solar capacity. The seasonal weighting of "Kapicia" values was normalized to derive the optimal mixture closed to the maximum yield of local renewables. The solar, wind and battery capacities necessary for the switch are the results of this model.[9] The results for the expected investment, the return on investment and the additional profits from the switch (over the 30-year service life of the renewable system with a battery replacement after 15 years) are shown in Table 1 (on pages 25 to 29).

Table 2: Physics-based Optimization Model

Country	Capa-city of all coal-plants	Number of coal plants profitably switch-able	Annual CO_2 Emission saved by switching	Share in electr. related CO_2 emissions	Solar power capacity required for switching	Wind power capacity Required for switching	Battery capacity
	GW	profitable / all	Mt / y	%	GWp	GWp	GW
Argentina	0.6	2 / 2	3.2	1.7	0.6	0.7	0.1
Australia	24.0	16 / 19	98.6	26.8	40.3	13.4	1.9
Bangladesh	8.6	7 / 7	34.6	32.4	19.1	3.2	0.6
Bos Herz	2.1	0 / 5	0.0	0.0	0.0	0.0	0.0
Botswana	0.7	2 / 2	3.6	51.4	1.9	0.2	0.1
Brazil	3.2	7 / 7	15.7	3.2	7.5	1.6	0.4
Brunei	0.2	1 / 1	1.2	16.6	0.8	0.0	0.0
Bulgaria	4.7	10 / 10	28.3	64.8	7.6	6.1	0.5

Country	Capa-city of all coal-plants	Number of coal plants profitably switch-able	Annual CO_2 Emission saved by switching	Share in electr. related CO_2 emissions	Solar power capacity required for switching	Wind power capacity Required for switching	Battery capacity
	GW	profitable / all	Mt / y	%	GWp	GWp	GW
Cambodia	1.7	5 / 5	8.0	47.2	4.7	0.7	0.2
Canada	4.7	10 / 10	25.3	4.5	4.0	5.9	0.5
Chile	4.3	8 / 8	22.6	26.4	10.0	3.1	0.5
China	1208.4	1162 / 1187	5284.5	42.4	2546.6	770.0	107.4
Colombia	1.6	5 / 5	8.8	11.3	6.0	0.1	0.3
Croatia	0.2	1 / 1	1.2	6.7	0.4	0.2	0.0
Czech Rep	7.4	25 / 25	43.6	44.6	8.6	9.7	0.8
Denmark	1.6	4 / 4	8.0	29.3	0.8	2.1	0.2
Dominican R.	1.1	3 / 3	5.2	18.8	2.7	0.2	0.1
Finland	1.5	7 / 7	8.0	20.5	1.5	2.5	0.2
France	2.5	6 / 6	13.1	4.3	3.7	2.9	0.3
Germany	40.5	58 / 58	204.7	30.7	37.0	48.9	3.9
Greece	2.9	4 / 4	15.0	28.1	5.2	2.4	0.3
Guadeloupe	0.1	1 / 1	0.4	22.2	0.2	0.0	0.0
Guatemala	1.2	12 / 12	5.7	28.2	3.5	0.1	0.2
Honduras	0.1	1 / 1	0.6	6.2	0.3	0.1	0.0
Hong Kong	6.1	2 / 2	32.0	96.4	14.1	6.9	0.7
Hungary	0.9	2 / 2	5.8	11.4	1.4	1.4	0.1

Country	Capacity of all coal-plants	Number of coal plants profitably switch-able	Annual CO_2 Emission saved by switching	Share in electr. related CO_2 emissions	Solar power capacity required for switching	Wind power capacity Required for switching	Battery capacity
	GW	profitable / all	Mt / y	%	GWp	GWp	GW
India	266.3	274/291	1148.6	43.4	653.8	102.9	24.4
Indonesia	59.5	88 / 99	260.1	43.2	176.0	1.1	9.2
Iran	0.7	1 / 1	2.8	0.4	1.2	0.2	0.0
Ireland	0.9	1 / 1	5.1	14.6	0.6	1.2	0.1
Israel	4.3	2 / 2	21.9	36.8	8.8	4.1	0.5
Italy	6.2	6 / 6	29.8	9.3	11.1	7.1	0.6
Japan	55.4	90 / 90	258.7	23.9	109.6	51.5	5.1
Kazakhstan	13.1	20 / 21	68.4	32.4	14.4	16.8	1.4
Kosovo	1.3	0 / 2	0.0	n.a.	0.0	0.0	0.0
Kyrgyzstan	0.8	1 / 1	4.6	42.7	0.9	0.8	0.1
Laos	1.9	0 / 1	0.0	0.0	0.0	0.0	0.0
Madagascar	0.1	1 / 1	0.6	11.3	0.3	0.1	0.0
Malaysia	13.3	7 / 8	55.2	21.9	45.3	0.0	2.3
Mauritius	0.2	3 / 3	1.0	24.2	0.4	0.1	0.0
Mexico	5.4	3 / 3	27.4	6.5	14.9	2.0	0.9
Mongolia	1.0	5 / 5	5.7	22.8	1.7	0.7	0.1
Montenegro	0.2	0 / 1	0.0	n.a.	0.0	0.0	0.0
Morocco	4.3	4 / 4	19.8	26.9	8.4	2.6	0.4

Country	Capacity of all coal-plants	Number of coal plants profitably switch-able	Annual CO_2 Emission saved by switching	Share in electr. related CO_2 emissions	Solar power capacity required for switching	Wind power capacity Required for switching	Battery capacity
	GW	profitable / all	Mt / y	%	GWp	GWp	GW
Myanmar	0.2	3 / 3	0.9	2.2	0.5	0.1	0.0
Namibia	0.1	1 / 1	0.8	19.7	0.4	0.0	0.0
Netherlands	4.2	4 / 4	16.5	11.2	2.7	4.8	0.3
New Zealand	0.5	1 / 1	3.0	9.2	0.7	0.5	0.1
Nigeria	0.3	3 / 3	1.7	1.3	0.9	0.2	0.0
North Korea	3.3	4 / 7	7.3	11.7	3.1	1.0	0.1
N. Macedonia	0.8	0 / 2	0.0	0.0	0.0	0.0	0.0
Pakistan	8.4	12 / 16	26.0	11.8	15.1	0.8	0.9
Panama	0.3	1 / 1	1.4	11.2	1.2	0.0	0.1
Philippines	12.6	24 / 26	58.5	39.5	31.7	4.4	1.2
Poland	29.2	43 / 43	157.6	49.1	30.0	40.5	3.1
Romania	3.0	8 / 8	17.2	21.8	5.1	3.6	0.3
Russia	40.0	0 / 73	0.0	0.0	0.0	0.0	0.0
Senegal	0.2	2 / 2	0.8	6.7	0.4	0.0	0.0
Serbia	4.8	0 / 4	0.0	0.0	0.0	0.0	0.0
Slovakia	0.8	4 / 4	4.5	12.0	1.1	1.1	0.1
Slovenia	1.1	2 / 2	5.2	36.7	1.7	0.9	0.1
South Africa	45.2	16 / 16	221.4	50.8	119.6	13.9	4.6

Country	Capacity of all coal-plants	Number of coal plants profitably switch-able	Annual CO_2 Emission saved by switching	Share in electr. related CO_2 emissions	Solar power capacity required for switching	Wind power capacity Required for switching	Battery capacity
	GW	profitable / all	Mt / y	%	GWp	GWp	GW
South Korea	42.3	25 / 25	180.3	28.8	78.4	31.4	3.6
Spain	2.2	6 / 6	11.9	5.1	4.8	2.4	0.2
Sri Lanka	0.9	1 / 1	4.3	18.0	2.2	0.2	0.1
Taiwan	19.2	20 / 20	90.9	31.5	49.0	11.9	2.1
Tajikistan	0.4	1 / 1	1.8	17.8	0.6	0.3	0.0
Thailand	6.1	9 / 10	16.9	6.3	11.0	1.3	0.3
Türkiye	20.2	10 / 34	35.2	7.8	15.2	8.0	0.7
Ukraine	9.3	14 / 14	55.6	30	8.6	13.0	1.0
United Kingdom	4.1	3 / 3	21.2	6.3	2.9	4.8	0.4
USA	212.0	202/216	1,004.7	21.1	312.1	181.1	19.6
Uzbekistan	2.5	0 / 2	0.0	0.0	0.0	0.0	0.0
Vietnam	30.8	27 / 28	131.2	40.8	69.0	19.8	2.5
Zambia	0.3	2 / 2	1.5	21.4	0.8	0.0	0.1
Zimbabwe	1.9	3 / 3	10.2	83	6.1	0.2	0.4
Global	**2273**	**2318 / 2515**	**9876**	**29.4**	**4551**	**1420**	**206**

Sources: Carbon Brief (2023), except for the required solar and wind capacities.

Results of the economic optimization model

According to Carbon Brief[11], there are about 2500 coal plant sites in the world with a capacity greater than 30 MW. The solar, wind and battery capacities necessary for the switch are the results of this study, using the economic

optimization model, which seeks to install cheaper renewable power than is optimum for even power generation over the seasons. This model reflects the economic reality when the annual penetration of renewable energies in the electricity grid is below 50 %, where the fluctuations in renewable energies can be supplemented with the remaining fossil-fueled power plants. Above

a renewable penetration of about 50%, sufficient energy storage must shift renewable power from day to night (mostly batteries). About 10% of renewable power must be shifted to periods of no sun and no wind only if renewable penetration exceeds about 80% (by hydro, pumped hydro, renewable gas, electricity-heat sector coupling, and other possibilities). A renewable penetration of 80% is usually not reached by switching coal plants alone.

Table 3: Economic Optimization Model

Country	Invest-ment	Regular profits	Addi-tional profits	Solar power capacity	Wind power capacity	Battery capacity
	in wind-solar-battery farm	at 5–6% IRR approx., not compounded	from switch-ing, over 30 years	required for switching	required for switching	Battery capacity
	US$bn	US$bn	US$bn	GWp	GWp	GW
Argentina	1.2	2.5	1.8	1.2	0.5	0.2
Australia	43.7	87.4	48.7	49.9	8.8	5.5
Bangladesh	17.4	34.9	13.1	20.6	2.9	1.9
Bosn and Herz	0.0	0.0	0.0	0.0	0.0	0.0
Botswana	1.5	3.0	2.1	1.8	0.2	0.2

Country	Invest-ment	Regular profits	Addi-tional profits	Solar power capacity	Wind power capacity	Battery capacity
	in wind-solar-battery farm	at 5–6% IRR approx., not compounded	from switch-ing, over 30 years	required for switching	required for switching	Battery capacity
	US$bn	US$bn	US$bn	GWp	GWp	GW
Brazil	7.2	14.5	**7.0**	8.1	1.7	0.9
Brunei	0.6	1.1	**0.6**	0.8	0.0	0.1
Bulgaria	15.1	30.1	**77.3**	18.0	1.9	1.6
Cambodia	4.2	8.5	**2.5**	5.1	0.7	0.4
Canada	11.1	22.2	**9.8**	8.0	7.5	1.4
Chile	9.9	19.7	**12.2**	11.5	1.7	1.3
China	2549.5	5099.0	**2074.5**	1950.6	1633.8	293.0
Colombia	4.2	8.4	**3.7**	4.6	1.1	0.5
Croatia	0.6	1.3	**3.3**	0.8	0.1	0.1
Czech Rep	24.8	49.7	**110.0**	19.3	12.0	2.4
Denmark	3.7	7.4	**21.5**	0.8	3.4	0.4
Dominican Rep	2.2	4.3	**3.0**	2.6	0.3	0.3
Finland	4.9	9.8	**19.5**	3.7	2.5	0.4
France	7.1	14.2	**34.4**	5.9	3.1	0.7
Germany	111.3	222.5	**521.7**	69.4	66.9	11.3
Greece	7.5	15.0	**42.1**	8.8	1.0	0.8
Guadeloupe	0.2	0.3	**0.2**	0.2	0.0	0.0
Guatemala	2.5	5.0	**3.0**	2.9	0.4	0.3
Honduras	0.3	0.6	**0.2**	0.3	0.1	0.0
Hong Kong	16.4	32.9	**10.9**	12.3	11.1	1.8

Country	Investment	Regular profits	Additional profits	Solar power capacity	Wind power capacity	Battery capacity
	in wind-solar-battery farm	at 5–6% IRR approx., not compounded	from switching, over 30 years	required for switching	required for switching	Battery capacity
	US$bn	US$bn	US$bn	GWp	GWp	GW
Hungary	3.4	6.7	**15.2**	4.1	0.4	0.3
India	536.8	1073.6	**94.9**	628.7	121.6	62.8
Indonesia	117.7	235.5	**15.6**	151.1	7.6	13.2
Iran	1.2	2.3	**1.6**	1.4	0.2	0.2
Ireland	2.2	4.5	**13.8**	0.5	2.0	0.3
Israel	9.5	18.9	**11.9**	10.9	1.7	1.2
Italy	15.0	30.0	**83.7**	17.3	2.4	1.7
Japan	129.1	258.3	**76.2**	113.8	67.1	14.3
Kazakhstan	27.4	54.8	**27.1**	8.7	30.1	3.8
Kosovo	0.0	0.0	**0.0**	0.0	0.0	0.0
Kyrgyzstan	1.6	3.2	**2.3**	0.3	1.9	0.3
Laos	0.0	0.0	**0.0**	0.0	0.0	0.0
Madagascar	0.3	0.6	**0.3**	0.3	0.0	0.0
Malaysia	28.2	56.4	**21.0**	38.1	0.0	3.1
Mauritius	0.4	0.9	**0.5**	0.4	0.2	0.1
Mexico	11.9	23.8	**14.8**	14.9	0.8	1.5
Mongolia	2.4	4.8	**3.2**	2.9	0.3	0.3
Montenegro	0.0	0.0	**0.0**	0.0	0.0	0.0
Morocco	8.5	17.1	**10.7**	10.0	1.4	1.1
Myanmar	0.4	0.9	**0.4**	0.5	0.1	0.0

Country	Investment	Regular profits	Additional profits	Solar power capacity	Wind power capacity	Battery capacity
	in wind-solar-battery farm	at 5–6% IRR approx., not compounded	from switching, over 30 years	required for switching	required for switching	Battery capacity
	US$bn	US$bn	US$bn	GWp	GWp	GW
Namibia	0.3	0.6	**0.5**	0.4	0.0	0.0
Netherlands	9.6	19.3	**41.1**	7.5	4.7	0.9
New Zealand	1.1	2.2	**1.3**	0.2	1.4	0.2
Nigeria	0.9	1.7	**0.6**	1.0	0.1	0.1
North Korea	3.6	7.2	**2.8**	4.2	0.7	0.4
N. Macedonia	0.0	0.0	**0.0**	0.0	0.0	0.0
Pakistan	11.8	23.5	**12.9**	13.7	2.1	1.4
Panama	0.7	1.4	**0.4**	0.5	0.5	0.1
Philippines	27.0	53.9	**25.2**	28.5	8.2	3.2
Poland	90.0	180.0	**396.4**	67.8	45.3	8.7
Romania	9.5	18.9	**46.3**	11.4	1.2	1.0
Russia	0.0	0.0	**0.0**	0.0	0.0	0.0
Senegal	0.3	0.7	**0.4**	0.4	0.1	0.0
Serbia	0.0	0.0	**0.0**	0.0	0.0	0.0
Slovakia	2.6	5.2	**11.7**	2.8	0.6	0.2
Slovenia	3.0	5.9	**13.7**	3.5	0.5	0.3
South Africa	92.1	184.1	**127.1**	107.2	14.5	12.3
South Korea	87.4	174.9	**67.1**	93.5	26.4	10.0
Spain	6.4	12.8	**32.1**	7.1	1.3	0.7
Sri Lanka	1.9	3.9	**2.1**	2.3	0.2	0.2

Country	Invest-ment	Regular profits	Addi-tional profits	Solar power capacity	Wind power capacity	Battery capacity
	in wind-solar-battery farm	at 5–6% IRR approx., not compounded	from switch-ing, over 30 years	required for switching	required for switching	Battery capacity
	US$bn	US$bn	US$bn	GWp	GWp	GW
Taiwan	46.2	92.2	**31.2**	54.0	9.3	5.0
Tajikistan	0.8	1.7	**0.8**	1.0	0.1	0.1
Thailand	8.5	17.0	**6.4**	10.0	1.7	0.9
Türkiye	17.7	35.4	**12.9**	19.7	4.6	2.0
Ukraine	27.2	54.4	**8.9**	23.2	14.9	3.1
United Kingdom	9.4	18.8	**5.9**	2.1	8.4	1.2
United States	467.6	935.2	**419.5**	410.5	199.0	55.7
Uzbekistan	0.0	0.0	**0.0**	0.0	0.0	0.0
Vietnam	67.9	135.9	**36.1**	65.8	29.2	7.3
Zambia	0.6	1.3	**0.8**	0.7	0.1	0.1
Zimbabwe	4.3	8.6	**5.7**	4.9	0.9	0.6
Global	**4742**	**9438**	**4726**	**4155**	**2376**	**545**

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The World Bank's global solar atlas:

We acknowledge the use of the Global Solar Atlas 2.0, a free, web-based application, developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalsolaratlas.info
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The World Bank's global wind atlas:

We acknowledge the use of the Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 was released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info
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Zero Emission Think Tank

For the present solutions study, **SwitchCoal**, ZETT brings together experts from science, technology, business and economics. ZETT greatly appreciates the support and the work on key climate solutions by Amory Lovins, Mark Jacobson, Tony Seba, Dan Kammen, Christian Breyer, Hans-Josef Fell, the late Hermann Scheer, and others.
(www.ZeroEmissionThinkTank.com)

Carbonbrief / Global Energy Monitor:

The data is applied in this study from this source: "Global Coal Plant Tracker, Global Energy Monitor, July 2023 release" - complying with the license relevant here: Creative Commons Attribution 4.0 International Public License (https://globalenergymonitor.org/creative-commons-public-license/)

Disclaiming: No fitness of data for the creation of energy plants

There is especially no Liability to use the SwitchCoal results as the bare input for financial commitments or any similar cases like implementation or planning of (likewise wind or solar-) power plants.

The project's resource databases explicitly deny the fitness of their data for the purpose of projection of renewable energy installation at the database locations.

In order to plan and/or build wind-&solar energy plant projects, explicit engineering and measuring of regional/local real, physical environmental conditions is required and inevitable.

Erratum (2023)

- ✓ A few typos have been corrected.
- ✓ And a few minor adjustments for better clarity.
- ✓ Chapter Employment : fixed missing comma after "Also". *"Also, the social perspective of switching from coal."*
- ✓ Chapter References: fix of faulty hyperlink address in reference [3] IEA, "World Energy Outlook 2022" IEA (2022), showing data from 2021, e.g., page 469. https://www.iea.org/reports/world-energy-outlook-2022
- ✓ Chapter References: reference [16] was added (see Terms of Use), Neil N. Davis, Jake Badger, et.al. "The Global Wind Atlas: A high-resolution dataset of climatologies and associated web-based application"; Bulletin of the American Meteorological Society,….

SwitchCoal

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Addendum (2025/26)

Epilogue (by Thomas Ladwig, for Quality Assurance)

The authors of the SwitchCoal initiative would like to outline what has not been revised or documented yet and what has, in general, not been in scope. The content of this chapter shall be regarded as an announcement resp. appeal for further work or as a helpful clarification.

1) The core part of this SwitchCoal study is from 2023 and is kept unchanged. It has been extended by prefaces, forewords and this epilogue in 2025-2026. The start of the 2023 study core part is marked with an extra page.
2) Since 2023, a long time has passed in the dynamic energy markets. While the fundamental wind and solar data of each coal-plant-site may have stayed mostly the same, the coal plant sites key-data[23] of many coal plant sites might have changed. An update of that data would be useful and is planned.
3) After scrutinizing our system model, there are hints that the considered storage capacities are too small by default. Fortunately, relevant battery costs have remarkably fallen recently; thus, there is a good chance that both effects compensate each other roughly[24].
4) In the same vein, the costs of capital may be evaluated a bit too optimistically or coarsely meshed so far. However, those costs are quite dynamic and fluctuating generally[25], so it is difficult to pinpoint them once and for all (as any study or report is outdated a bit in this regard already when issued). We will strive for a future, finer-grained model soon. It is planned to document and to disclose the system and financial models of SwitchCoal in more detail in the near future, too.

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[23] Coal plant's key data likewise the Tons of CO_2 and produced electric power in GW.

[24] See e.g. https://nzero.com/blog/the-falling-cost-of-battery-storage-and-its-impact-on-renewables/ and specifically for China (by far the most important coal-country): https://reneweconomy.com.au/watershed-moment-big-battery-storage-prices-hit-record-low-in-huge-china-auction/

[25] See e.g. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Jul/IRENA_TEC_RPGC_in_2024_2025.pdf (look in particular for costs of capital) and https://www.weforum.org/stories/2023/03/tracking-changes-cost-of-capital-accelerate-investment-low-carbon-energy/

5) Deeply rooted in tradition and history, coal is still widely regarded as a backbone for the supply of electric power. The energy sector has to rethink its business model towards the use of SwitchCoal. It is not easy to tackle and overcome such psychological caveats, especially in some of the most important coal countries (India and China[26]).

6) Peak load safeguarding and grid stabilization are obstacles for SwitchCoal, as it raises the importance in proliferate transformation to renewable energies[27]. A comprehensive solution for this issue is necessary and can hopefully be achieved with the rapid evolution of battery-storage price and means. (This is not in the scope of "SwitchCoal 2025/26").

7) A fixable weakness of SwitchCoal occurs during a seldom-weather phenomenon called "dark doldrum" (in Germany called "DunkelFlaute").

   In case of a several-day-long weather period without wind or sunshine, a complete drop out of renewable energy production arises. For this case, the SwitchCoal principle fails in the affected region. The SwitchCoal initiatives have to face a problem of complete drop-out of enough available electric power in a certain region. This may be exacerbated by being particular cold or hot as well, summarized termed here a "cold dark doldrum".

   a) As a consequence, additional electric power is required in the region(s) hit by the "cold-dark doldrum" weather.

   b) A solution lies in the fact that the "electric-power grids-connections" are geographically wider than the regional critical weather phenomenon. If such a dark doldrum appears (likewise in Bavaria (South-Germany) in most cases, adjacent regions (e.g., North-Germany) are not affected and still can produce renewable energy. The geographical size of the power grid levels out the regional power shortages. This solution requires wide-range, high-capacity electrical power grids.

[26] See e.g. https://www.downtoearth.org.in/energy/india-and-china-drive-87-of-new-coal-power-proposals-in-2025-report-finds?utm_source=chatgpt.com

[27] See e.g. https://www.carbonbrief.org/guest-post-china-and-india-account-for-87-of-new-coal-power-capacity-so-far-in-2025/?utm_source=chatgpt.com and https://arxiv.org/abs/2207.02151?utm_source=chatgpt.com

c) Thanks to the weather forecast, such a problematic period can be predicted several days ahead. In the short term, a solution may be to transform a few coal plants via SwitchCoal in order to keep their coal-firing power-generation facilities. Especially during such dark doldrums, these coal plants can be ramped up and step in to fill the lack of electric-power generation.

d) Yet, for long-term mitigation, more comprehensive transformations seem to be more economical. In particular, the option to convert such coal plants to thermal storage plants allows storing electricity generated by solar and wind, this way, for longer periods.[28]

e) It is important to keep in mind that "dark doldrums" are happening in limited regions only for some days per year. In most regions, they happen not at all. (E.g. In Germany, dark doldrums have a duration in the range of about 5-8 days.[29])

8) Coal lobby's influence is an important opponent against phasing out Coal-fired power generation rapidly. This comprises fewer coal plant owners themselves, but the entire coal industry (incl. mining, transportation) has often local or regional interest[30]. It seems not easy to break or mitigate such headwind, maybe at best with a hint to superordinate interests, yet again, this has still to be analyzed deeper and elaborated.

9) Mid- or long-term contractual liabilities with coal suppliers may also be a considerable obstacle, with contracts often binding for 10 or more years[31]. Even worse affected by fossil dependencies are sites where coal mines and coal plants are vertically integrated or operate in a mine-mouth-cooperation; fortunately, this is the case at relatively few locations.

How to overcome such quasi-captive constraints? Here politics can enter the game – where there is political will to overcome these issues, there is a chance to do so in a sustainable and profitable way.

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[28] See https://www.researchgate.net/publication/358076896_Conversion_of_Existing_Coal_Plants_Into_Thermal_Storage_Plants

[29] See DE-Wikipedia: https://de.wikipedia.org/wiki/Dunkelflaute#Definition

[30] See Global Energy Monitor: „When coal won't step aside: The challenge of scaling clean energy in China"

[31] See https://wires.onlinelibrary.wiley.com/doi/10.1002/wcc.918

Western Germany is a good example how this might work: there the coal phase-out (end of operation for lignite fired coal plants) was initially not planned at all, then intended for 2050, next 2038, and finally preponed for 2030[32]. So investors or plant owners might address politics to apply that proceeding as a blueprint.

Alternatively also coal-mine owners could be addressed - in trying to convince them to take part in joint investments, shared extra-profits can be generated even faster, meanwhile the potential for that appears limited.

Note: despite of the fact, that Renewables energies are already cheaper than burning coal, actually market prices do not state the entire truth. Taking all negative effects (like the overall health costs, resulting by climate change and/ or the Nationally Determined Contributions (NDC) to be paid for each and every kg of CO_2 emission caused by the burning coal into account, those prices would have to be much more higher. That's why carbon pricing (in the EU ETS) is a good means to tackle that[33].

10) Finally, perhaps the most severe obstacle is:
    a) The rapidly developing economies of large Coal countries like China, Indonesia, and especially India (often with close to +7% GDP growth p.a.!) demand more and huge amounts of power supply steadily.
    b) E.g. in India, renewable energies expand rapidly while fossil fuels are not phased out. This appears as an economic advantage for the short term, since both renewables and fossils supply more electric power compared to renewables and a drop in fossil energy production[34].

    To resolve this predicament appears difficult.

Perhaps a hint to the impending, potentially uninhabitable large areas of a lot of coal countries, most strikingly India and southeast China, owing to the unabated climate crisis in the medium term, may be helpful – this is not just a dent of economic growth and wealth but the end of everything.

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[32] See https://www.cleanenergywire.org/factsheets/spelling-out-coal-phase-out-germanys-exit-law-draft

[33] See https://climate.ec.europa.eu/document/download/5dee0b48-a38f-4d10-bf1a-14d0c1d6febd_en?filename=factsheet_ets_en.pdf

[34] See „Why India is rebuffing a coal-to-clean deal with rich nations“

Outlook – how to implement SwitchCoal (T. Schmidt)

Development and Empowerment of the Stakeholders

The best way to empower the Stakeholders for many cases, is maybe like this:

i) **Develop** layout for Wind and Solar farms (desktop)
ii) **Secure** land (onsite)
iii) **Enviro studies** (desktop + onsite) = Project @permitting ready
iv) Politics/Investors help for Joint Venture (JV with coal plant **owner** utility)
a.) use existing Interconnect b.) obtain permits c.) obtain offtake (PPA)
v) Politics/Investors help with **financing** Joint Venture
vi) Politics/Investors help with **manufacturing** Joint Venture:
- solar panel assembly line gives like 150 jobs, located at the plant site,
- coal plant employees to transition 1:1 into solar jobs.

Financing and risk management (with Joined Ventures)

Detailed project planning costs an average of around €500,000 per coal-fired power station site (although actual costs can vary significantly, as the size of individual sites varies greatly). To ensure that investors or power plant operators can manage these costs, and given that corruption can be a problem in some countries, we propose three options to mitigate the risks for specific projects:

1. Establishment of a trust or foundation to cover the initial planning costs – once the planning is complete, there is a better chance of obtaining approval for the entire wind-solar-battery project; furthermore, following this preparatory work, the power plant operator is more likely to join the project than before.
2. Engage professional wind and solar developers for each site, who initially cover the planning costs and, in return, secure the right to 30–50% of the investment, which is then resold in exchange for a commission.
3. Initiate/introduce a targeted foreign energy policy (TCFP) in wealthy countries that promotes joint ventures with power plant operators in other countries and reduces financing risks.

Resolve financing issues in developing countries

An IRR of 6% is high enough in developed markets to secure commercial financing (from private investors), partly because government bonds, yielding around 4%, are not as lucrative as SwitchCoal's "business case". In emerging markets, however, long-term bond yields can reach 6–8% , and they are less risky than SwitchCoal.
Therefore in a certain amount of cases financing is difficult without risk mitigation,

i.e., without, for example, public-sector guarantees. Solutions for these cases include, for example following strategies: providing first-loss guarantees, granting low-interest, subsidized loans (Bridgetown proposal), or waiving a share of the profits (in favor of the power plant operator).

Contract and constraint management

On the upside existing PPAs may be reused, revised or replaced by new ones, so easing and securing the sales of the generated electricity. That there are PPAs in place already often here is a considerable advantage. So it is always worthwhile to check out what is possible in a concrete case.
On the other hand mid-or even long-term contractual liabilities with coal suppliers may be a larger issue. The key player to resolve this is politics (as exemplified for instance in Western Germany with their Coal phase-out schedule). So if an issue in a concrete case it is advisable to reach out to the government in charge, at least to figure out what can be expected or in best case changed there.

Collaboration instead of Competition (with plant owners)

Ultimately, a short sketch of how this may work from an investor's perspective:

“What if I told you coal plants could become the heroes of renewable energy? Introducing SwitchCoal, we **don't compete with coal plant owners, we offer a unique chance for collaboration with profitable, renewable business**.”[35]


(36)


(37)

Renewable energy investors and coal plant owners **both cash in on the additional profits, proving that clean energy is a smart investment**. Let's make the shift to renewable energy faster, smarter and more profitable. Turning coal plant owners into green energy pioneers - from coal to clean, **the power of partnership**.

Welcome to a future with Climate Impact Investments like SwitchCoal!

[35] See Video “SwitchCoal: Transforming Coal Plants into Renewable Powerhouses” (https://www.youtube.com/watch?v=s6XORtYW3jY)
[36] Screenshot from AI-generated Video (https://www.youtube.com/watch?v=s6XORtYW3jY)
[37] Screenshot from AI-generated Video (https://www.youtube.com/watch?v=s6XORtYW3jY)

Engage Joint Ventures and cash in additional profits

Try to take plant owners and operators on board. With their local expertise and influence on authorities and politics. **Reusing their existing grid connection saves 2-3 years in project realization times**, compared with conventional renewable projects.

In addition, this preserves contractual value, reduces costs and risks, eases regulatory approval, and ultimately accelerates renewable deployment.

Note: a comparable study from IEEFA, published in June 2024 – Accelerating the coal-to-clean transition – shows similar results[38])

Unique Selling Points

- **Cooperation with coal plant owners**
  (instead of competition to the Renewables)
- **Re-use of existing grid connections**
  (instead of need to apply and wait for a permit)
- **Re-use of existing PPA...**
  (for the newly build assets)

Possible ways to kick off

1. **Buy the coal plant**, and force the transition yourself, and cash in all profits
2. **Empower the coal plant owner** (by motivation, direct invests, partnership...)
3. **Empower developer companies** for the renewables, which are operating in that area; trusting in their local experience and **focusing on Joint Ventures** with the coal plant owner **right after creating own assets** to put into negotiation: – by driving land protection / lease agreements,
   – environmental studies etc.

[38] See "Key Findings" (https://ieefa.org/resources/accelerating-coal-clean-transition)

References

There are several webpages referencing SwitchCoal, here is a good choice:

- EduClimate Website (with projects for a transition toward an environmentally and socially sustainable society): https://educlimate.org/
- SwitchCoal Website: (Pre-Evaluation-"Resources"): https://www.switchcoal.org/en/resources
- Jochen Wehrmuth, "Business Case for CO_2 reduction": https://www.switchcoal.org/en/insights/business-case
- Tom's Creative Lab: "Multi-billionaires around the world - call to Cut 26% CO_2 #SwitchCoal" https://www.youtube.com/watch?v=xc48yUBCbss
- Tom's Creative Lab: "SwitchCoal: Transforming Coal Plants into Renewable Powerhouses" https://www.youtube.com/watch?v=s6XORtYW3jY
- House of Communication: https://www.house-of-communication.com/de/de/cases/switchcoal-from-coal-to-clean.html
- ZETT Website (with SwitchCoal Solutions Study): https://zeroemissionthinktank.com/switch-coal-renewables/ note: the ZETT organization is currently planned to be restructured, and a new website is intended for the future.

These have been inserted 2025 to credit the Global-Wind-Atlas publication:

- Neil N. Davis, Jake Badger, Andrea N. Hahmann, Brian O. Hansen, Niels G. Mortensen, Mark Kelly, Xiaoli G. Larsén, Bjarke T. Olsen, Rogier Floors, Gil Lizcano, Pau Casso, Oriol Lacave, Albert Bosch, Ides Bauwens, Oliver James Knight, Albertine Potter van Loon, Rachel Fox, Tigran Parvanyan, Søren Bo Krohn Hansen, Duncan Heathfield, Marko Onninen, Ray Drummond; *"The Global Wind Atlas: A high-resolution dataset of climatologies and associated web-based application"*;
- Bulletin of the American Meteorological Society, Volume 104: Issue 8, Pages E1507-E1525, August 2023, DOI: https://doi.org/10.1175/BAMS-D-21-0075.1"

Electricity for 6.3 cents – Germany's future lies in energy prices

A guest contribution by Dr. Paul Grunow and Jochen Wermuth[39]

Germany is at a turning point: the energy crisis has painfully demonstrated how dependent and vulnerable our economic model has become. At the same time, the key to the solution has long been on the table – or rather, on our roofs, fields, and in our research institutes.

With innovative technologies that are now virtually ready for the market, we could generate electricity at 6.3 cents per kilowatt-hour. This would not only be a milestone for climate protection but also a massive competitive advantage for Germany in the global marketplace.

“**The technologies for affordable, green electricity are here – we just need to use them properly.**”

In recent statements, the current Minister of Economics, Katherina Reiche, has predicted a future electricity price of around 25 cents. At first glance, this sounds plausible: renewable energies such as wind and solar provide electricity for around five cents per kilowatt-hour, but the costs of grid expansion and storage for so-called dark doldrums drive up the overall bill for the system by 10 cents/kWh in each case. Green hydrogen is also often mentioned as a solution, but at 35 cents per kilowatt-hour from today's perspective, it hardly seems competitive. This has given rise to the idea of building gas-fired power plants again, which supply electricity from LNG at 10 cents/kWh, but save the 10 cents for dark doldrums storage.

This would put the price below €0.25/kWh, but at €0.20/kWh it would still be hopelessly lost – e.g., compared to Dubai, where base load electricity from solar and batteries already costs only 3.3 cents/kWh today.

“**It's not electricity that's expensive – it's the system behind it.**”

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[39] Dr. Paul Grunow (founder of Q CELLS GmbH – https://www.q-cells.de/impressum) and Jochen Wermuth (climate impact investor – see chapter [Authors])

This calculation is therefore backward thinking. And new approaches show how system costs can also be dramatically reduced within Germany. Take hydrogen, for example: Swedish company Plagazi is set to produce green hydrogen from waste for just 3 € per kilogram – a third of the usual electrolysis costs. Converted back into electricity, this corresponds to around 12 cents per kilowatt-hour, which is on a par with coal-fired electricity in Germany.

It becomes even more efficient when existing infrastructure is used intelligently. Historically, Germany's gas network was designed for city gas with high hydrogen content.

Instead of investing 700 billion euros in new power lines, the gas network could be upgraded for around 30 billion, a fraction of the cost. That amounts to 0.5 ct/kWh for the gas network upgrade instead of 10 ct/kWh for an electricity grid expansion. Storage for annual dark doldrums can also be realized much more cost-effectively with green hydrogen than with batteries designed for daily use, adding another 0.5 ct instead of 10 ct per kWh.

Combining these approaches results in a new calculation: renewable energies supply the majority of electricity for five cents per kilowatt-hour. Hydrogen steps in during periods of low wind and low sunlight – at 12 cents. Because this only covers around 15 percent of annual demand, the average electricity production cost would be around 5.15 cents/kWh, and after gas network and gas storage upgrades to hydrogen and operating costs, an average price of 6.3 cents would be realistic. A completely climate-neutral, stable, and affordable electricity system is thus becoming a reality.

"**At 6.3 cents per kilowatt-hour, the future of the German economy begins.**"

The consequences would be enormous. Cheap, green electricity not only means security of supply, but also fuel for a new economic miracle. McKinsey expects the climate-neutral economy and artificial intelligence to each reach a global volume of €15 trillion by 2030. If Germany regains ten percent of the global market thanks to breakthrough innovations in the climate-neutral economy, Germany's gross domestic product will rise from 4 to 5.5 trillion euros! **With such a prospect**, the energy transition would not only be an ecological necessity **but also an economic quantum leap**.

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- (GSA) Global Solar Atlas (SOLAR-Potential data) https://globalsolaratlas.info/support/terms-of-use, **Solargis s.r.o**. and **World Bank Group**
- (GWA) Global Wind Atlas (WIND-Potential data) https://globalwindatlas.info/en/about/TermsOfUse, the **Technical University of Denmark (DTU)**

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At the time, we had been thinking about what we could tackle first that would have a rapid global impact, and we agreed to explore the issue of coal-fired power plants. For this study, he contributed to concept development, programming, solution finding, QA and writing the report.

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SwitchCoal Team (2023- 2026)

SwitchCoal is playing big tennis

SwitchCoal had been initiated by THOMAS LADWIG and the "KLIMA-PAZIFIST" THOMAS SCHMIDT, they analysed what CO_2-reduction lever is available at all and decided to go for coal. The "GERMAN PHYSIKER" FRANK HAFERKORN joined soon, while the ZERO-EMISSION-THINK-TANK (ZETT) steered the core team with extremely important technical and strategic wisdom.

The 3 Person **SWITCHCOAL CORE-TEAM** has been working completely "pro-bono" since early 2023 up to publication date 2026. They solved all problems, stones and hurdles on their way from early 2023 to their first publication.

They already served on COP28 in Dubai 2023 and on COP29 in Baku 2024. Sadly, the voice of the Team had no chance to get heard at all.

(at COP28, in Dubai: Jochen W. with Tafadzwa Kurotwi and Solvejg N.)

(at COP29, in Baku: Thomas Schmidt with Dianah Mugalizi)

This is not surprising, as a t every COP "felt" ten-thousands of NGOs and hundreds of lobbyist groups are trying to hit at the same spot, and try to catch attention. As a result, the SwitchCoal Team failed to get the right attention. Bringing the idea into the world was no success up to Dec. 2025.

In 2026 the things should run different:

2026-02	Jochen Wermuth and Paul Grunow gave a quest contribution.
2026-03	Pao-Yu Oei granted us a Foreword.
2026-04	Frank Ossenbrink supported us with the following Backmatter.
2026-05	add. chapter Abstract / relevance for human-being (Thomas S.)

Backmatter about dis-balancing (Frank Ossenbrink)

Dr. and CEO of „media group berlin GmbH Verlag", Berlin/Helsinki

Imagine a regional newsroom in a small town whose streets have been shaped for decades by coal mining: the lives of miners, children with respiratory problems, and looming municipal investment decisions. These local realities provide a tangible entry point to a global question that is felt in a very concrete way here: how can global CO_2 emissions be reduced without destroying the livelihoods of entire regions? This is precisely the task facing media in lower-income countries: to translate the abstract idea of a coal phase-out into locally intelligible, practicable terms.

The guiding principles are straightforward but have important implications for reporting. "Think local, explain global" means that international climate policy must be translated into its effects on towns, regions, and households. Tonnage of CO_2 matters scientifically, but it rarely persuades on its own; observable benefits — better health outcomes, lower household expenditures on medicine and energy, new income opportunities, and reduced operational risks — are the narratives that people can relate to. Trust is built when newsrooms do more than transmit information: they open spaces for dialogue, surface questions and locally held concerns, and transparently follow decision-making processes.

Operationalizing this approach requires concrete formats. Human stories, not just statistics, should anchor reporting: profiles of miners, clinical accounts of pollution-related illness, or features on entrepreneurs running solar facilities make both harms and opportunities emotionally and cognitively accessible. Simple visual comparisons cost and emissions per kWh, infographics linking particulate matter to disease burden, and before-and-after scenarios for regions that have hosted renewables projects support comprehension and verification. In many low-income settings, radio and smartphones are the primary channels; short radio segments, podcasts in local languages, and brief video clips distributed via messaging apps reach broad audiences. Complementary local fact-checking services can systematically rebut misinformation about supposed economic collapse or imminent power shortages using locally relevant data and plausible scenarios.

Substantive reporting must be technically and politically robust. Cost accounting that internalizes environmental and health externalities often demonstrates that solar plus storage is economically competitive. Analyses of employment pathways — current coal job counts, existing retraining programs, and documented examples of successful workforce transitions — are crucial for credibility.

Energy security explanations that detail grid stability measures, demand flexibility, storage solutions, and regional grid integration can reduce fears of blackouts. Clear exposition of financing mechanisms — from microcredit and grants to guarantees and multilateral funds — helps stakeholders understand how transitions are funded. Finally, people need transparency about governance: reporting on planning processes, compensation schemes, and participation mechanisms is essential for legitimacy.

Communicators should avoid predictable pitfalls: alarmist rhetoric alienates, understatement undermines urgency, polarizing “us versus them” frames inhibit collaboration, and unrealistic promises about wholesale job replacement by renewables erode trust. A realistic, empathetic tone grounded in evidence is more effective.

Practically, newsrooms should develop internal expertise — one or two journalists trained in energy economics, data literacy, and technical basics — form partnerships with research institutions and NGOs for reliable data, and create a practical toolbox of interview templates, validation checklists, and locally adaptable graphics. Sustained coverage — serial reporting rather than one-off pieces — builds institutional trust. Cross-platform strategies that combine print, radio, social media, and community events will reach different demographic groups.

Organizations such as SwitchCoal can accelerate this shift by supplying localized case studies, supporting the initiation of investigative reporting and training stipends, inspiring editorial exchange networks, and providing data kits and editable maps that newsrooms can adapt quickly. Media that adopt these methods become bridges between global climate science and local lived realities, and thus vital actors in pursuing a socially just, technically grounded global reduction of CO_2 emissions.

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[40] ***Carbon-Brief Global Energy Monitor*** (https://globalenergymonitor.org/ *2023*)

Thanks…

from the SwitchCoal Core-Team TO:

All the Ladies and Gents… (and everybody else)
…of all ages (from 1-year-olds to 142-years-olds)

All those who think they know what to do…
…and the rest of Our Planet Earth 🌎 🌍 🌏

(41)

"It is Over, when it is Over"…

- J Henry Fair[42] (Contemporary Photographer)

[41] Cartoon Archive by Johann Mayr, see: https://johannmayr.de/carchiv/indexa.html
[42] American photographer, co-founder and director of the Wolf Conservation Center, see his (latest) photographies on his website: https://www.jhenryfair.com/

What if one of **the biggest climate solutions is also one of the smartest business opportunities**?

The **SwitchCoal** experts and scientists elaborated a solution to reduce the worldwide emissions of Carbon-Dioxide **shortly** by 10 Gigatons per year. This reduction is about 25% of all human-made Greenhouse gas emissions.

For almost each other fossil energy sectors (buildings / industry / mobility / ...), rapid reductions of CO_2 emissions are very hard to achieve. Therefore, SwitchCoal addresses only the subsector of coal-based power-production (with 29% of all energy-related CO_2 emissions).

SwitchCoal calculated

- for which of the (worldwide) about 2.500 Coal-Plant-Sites
- it is feasible and profitable (within a short amotization time)
- to replace coal-fired electrical power generation
    - by renewable energies (solar- and wind-parks)
    - combined with battery storage solutions
- in the regional vicinity of each coal plant site.

The results of various implementation scenarios are impressive:
This *transformation towards renewable energy* production pays off for about 90% of all worldwide coal plant sites.

In order to roll out SwitchCoal worldwide,
literally thousands of US$ billions of capital are required,
but each Dollar is a profitable investment.

Beyond that a successful kick off may become even a trigger for more...

SwitchCoal is a **worldwide solution**
to drastically reduce Carbon-Dioxide Emissions
with a high
RoRI = Return of Renewable Investment.

SwitchCoal is more than a climate argument, SwitchCoal is a business case:
https://www.switchcoal.org/en/insights/business-case

So there is no excuse for mankind no more...

Let us UNLEASH the ECONOMIC FORCES and SAVE OUR PLANET!

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