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Limits to Efficiency: Rethinking Current Perspectives on Climate Action

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ABSTRACT

Climate change and economic development are emotive subjects that are closely related: yet one is caused by the other. People's lives are increasingly getting affected by the negative side-effects of climate change, particularly in developing countries which, at the same time, face enormous challenges to their aspirations for economic growth. Leading scientists agree that global warming is a reality and greenhouse gas (GHG) emissions are required to be reduced as quickly as possible. The Nationally Determined Contributions (NDCs) declared in Paris will not be sufficient. Instead, the imperative is absolute reductions. The conflict, therefore, between environmental and economic goals is steadily increasing. Investment in higher efficiency is often proffered as an appropriate solution to drive economies and reduce GHG emissions at the same time. This paper explains why a focus on (energy) efficiency is self-limiting, prevents innovation, and is often economically unattractive or even impossible for emerging economies. India's push for renewable sources of energy, in contrast, may be the more effective approach in an environment of exponentially growing economies. To understand why and how India might have found the "magic formula" to reconciling economy and environment, requires the rediscovery of a result-oriented paradigm where effectiveness comes first, and efficiency, second.

INTRODUCTION

Scientists and experts have established enough evidence to prove that not only is climate change anthropogenic, but the operating range to keep tabs on the phenomenon is diminishing. With the rise of the environmental movement in the late 1960s and the publication in 1971 of "Limits to Growth",[1] the once unintended consequences of industrialisation became condoned. Yet, the international community is not moving fast enough to tackle climate change effectively. Questioning current practices is seen as a threat to current lifestyles. In a sense, little has changed since the environmental enlightenment of the '70s, even as the world today is supposed to know better.

Global carbon emissions continue to rise due to fossil-fueled economic growth. As renewable energy sources provide less than four percent of global energy consumption, prosperity and misery remain correlated. Global industrial production, trade and international division of labour – or simply, globalisation – have, on one hand, improved the lives of billions. On the other hand, it has caused massive social and environmental damage, especially among the poor countries that have had to suffer the export of "dirty" manufacturing of goods from the industrialised to emerging markets.[2] In these countries, the environmental standards are pulled down to incentivise investment and increase both, national GDP and employment. However, it is true that any economic model, technology, or system is the result of human decisions. This is why human behaviour is both, cause *and* solution to the climate crisis.

This paper attempts to shed light on the dimensions of climate strategies that need to be tackled by the global community, including necessary reductions in future emissions of greenhouse gases. Indeed, the industrialised world's development was fueled by fossil fuel; today, these countries continue to generate the highest per-capita carbon emissions. Developing countries, in contrast, stand to be most severely affected by climate change, a phenomenon that they have hardly caused. The Global Climate Risk Index 2018, analysing the extent of impacts by weather-related loss events, ranks India sixth after Haiti, Zimbabwe, Fiji, Sri Lanka, and Vietnam.[3] The paper argues that as Asia and Africa pursue their own economic rise, a reduction in total carbon emissions cannot be realised by an improvement in efficiency as long as the source of energy continues to be fossil fuel.

This paper does not venture into unchartered scientific terrain, nor plays the blame game. Rather, it seeks to offer a more nuanced and general perspective on the matter of effective climate action. The paper will argue that the concept of 'efficiency' might not be the solution but rather the opposite: the cause for stagnation, and part of the reason for losing the war against climate change.

The first section of this paper examines the historic development of carbon emissions in four regions to highlight a powerful dynamic that seems to be widely ignored in current discussions: the exponential economic growth of the global economy. The subsequent section will explain the difference between 'efficiency' and 'effectiveness' and why current environmental policies require a re-assessment; and why the focus on efficiency is more an economic principle than an environmental strategy. The last part examines the price drops in renewable sources of energy, and points out why India's push for these alternatives could serve as a role model for an ongoing and inevitable energy transition—or the "third energy revolution".

I. EMISSIONS: DEVELOPMENTS AND DRIVERS

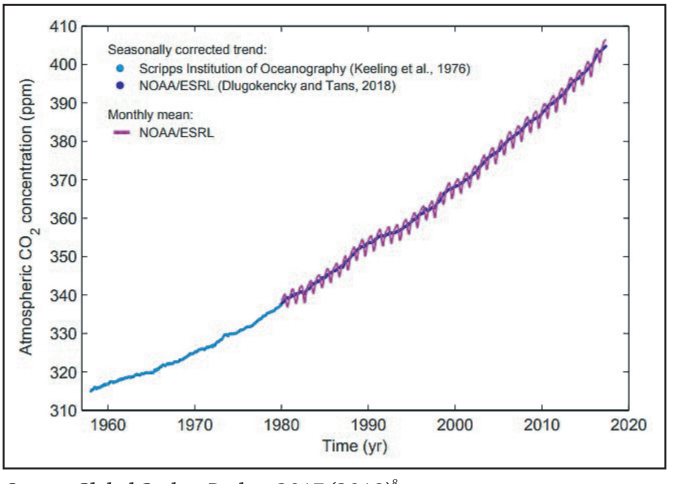
1.1 Fossil Fuel

"In 2015, carbon dioxide levels hit 400 parts per million (ppm). The last time levels were this high was more than a million years ago. Humans are pumping carbon into the atmosphere at a rate higher than any point in the last 66 million years - and the effects are being felt."

— Tim Jackson, Robin Webster–University of Melbourne (2016)[4]

It is now widely accepted that climate change is anthropogenic. The drastically increasing amounts of accumulated carbon dioxide (CO_2) in the atmosphere have had, and will continue to have, a massive impact on the anthroposphere.[5] In the 1920s, fossil fuels became the dominant source of emissions and added to the natural carbon cycle.[6] Today, fossil fuels and industry generate around 90 percent of all CO_2 emissions caused by human activities.[7] The origin is undeniable and the trend continues, despite significant improvements in technologies and, in particular, their efficiency.

Figure 1. Average atmospheric CO_2 concentration (ppm)



Source: Global Carbon Budget 2017 (2018)[8]

The Paris Agreement, signed in 2015, was historic as 195 countries made sweeping pledges for the environment, including the reduction of net carbon emissions to climate-neutral levels before the end of the century.[9] The Nationally Determined Contributions (NDCs) submitted by the signatories strengthened those commitments, even as the stated pledges are insufficient to reach the two degree climate goal. A modeling project of the Massachusetts Institute of Technology (MIT) predicted a minor difference in temperature above pre-industrial levels of 3.7 (applied NDCs) versus 3.9 degrees Celsius (without NDCs).[10] However, the NDCs initiated a dynamic that allowed the installation costs of renewable energy sources to increase exponentially – pushed by India's active engagement. The implementation also demonstrated the co-benefits like decreased air pollution, better public health, and a new employment sector. Most importantly, Paris represented progress from the time the climate talks were stalled for decades because of discussions on burden-sharing.

The crude figures, however, are discouraging. Under the premise of current and planned policies (NDCs included), world-wide energy-related carbon emissions will increase year on year until 2040, before dipping slightly by 2050 to remain roughly at today's levels.[11] Between 2000 and 2016, primary energy consumption and CO_2 emissions from fossil fuel increased by around 40 percent.[12] Eighty percent of the added primary energy *supply* was based on new oil, coal, and natural gas production.[13] Between 1990 and 2016, the global primary energy *demand* (=consumption) grew by 53.35 percent, while fossil fuel demand grew by even 58.27 percent in the same period.

Table 1 Global Primary Energy Consumption by Source (TWh), 1990 / 2016

	1990	2016	1990-2016 (change in percent)	
Solar	0.4	333.1	86057.45%	
Wind	3.6	959.5	26315.34%	
Other RE	116.4	561.7	382.37%	
Hydro	2154.4	4022.9	86.73%	
Natural gas	**20555.4**	**37264.2**	**81.29%**	
Coal	**26125.7**	**43403.1**	**66.13%**	**58.27 %** (Natural gas, Coal, Crude oil)
Crude oil	**36754.1**	**51384.2**	**39.81%**	
Nuclear	2001.8	2616.5	30.71%	
Traditional	11111.1	11003.2	-0.97%	
TOTAL	**98823.0**	**151548.5**	**53.35%**	

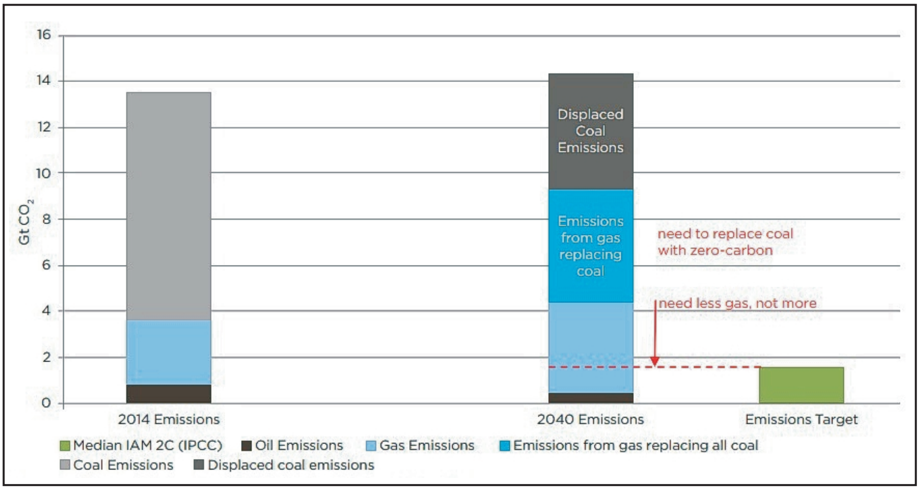
Source: Author's calculations based on data from Our World in Data.[14]

Two examples help explain why the share of fossil fuels have been rising despite additionally installed renewable sources of power:

1. The US' production of natural gas has been skyrocketing by around one-third since 2006[15] and prices have been plummeting accordingly, due to the shale revolution (horizontal drilling, hydraulic fracking). Since 2009, the US has been the world's top gas producer and since 2013, the world's top petroleum hydrocarbons producer.[16] Gas became not only a competitive source of energy, it became cheaper than coal. Since 2005, energy-related carbon emissions have been reduced by 14 percent[17] as both, coal and petroleum are more carbon-intensive fuels than gas.[18] One fossil fuel has only been replaced by another. Indeed, gas power plants are able to ramp-up energy supply quickly and natural gas therefore is often

discussed as a back-up solution together with fluctuant renewable energy sources. As the power sector requires to be decarbonised by 2050, natural gas could hardly be used as a "bridge fuel" of the energy transition as it does not provide enough CO_2 emissions reduction to reach even the 2040 targets.[19]

Figure 2. Global Power Sector Emissions – 2014 and Projected 2040 – Compared with Median IPCC 2040 Power Sector Emissions for 2°C (assuming all coal is displaced by gas)

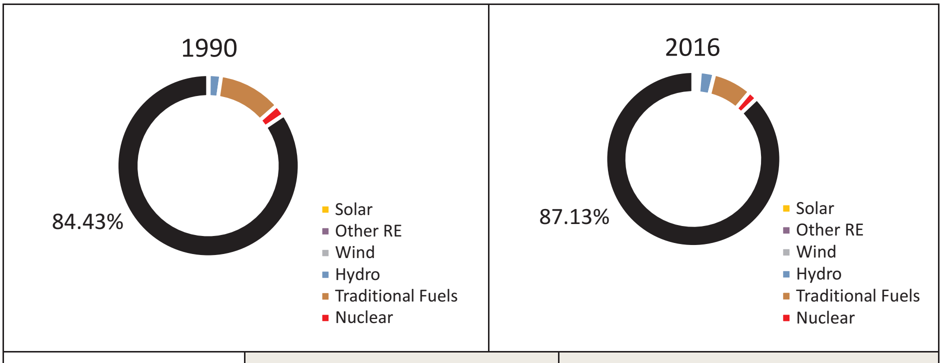


Source: Oil Change International *analysis, using data and projections from IEA and IPCC (2018)*[20]

2. Although, China added 53 GW (+75 percent) of new solar and 16 GW (+26 percent) of wind generation capacity in 2017 only, the growth of total clean energy production fell from 10.5 percent to 9.6 percent while fossil fuel power generation grew by 5.2 percent (46 GW). Total carbon emissions could not been stabilised but – again – increased (+1.4 percent).[21] A closer look at the energy sources reveals that coal remains as the main energy source for China, accounting for 60.4 percent of the country's total energy consumption in 2017. This figure is the lowest in modern times, but still dominates China's CO_2 emissions, comprising 78 percent of total emissions from fossil fuels.[22]

As energy capacity is more of a theoretical figure, energy demand (or consumption) gives a more accurate picture of what sources actually provide energy. Due to availability and rising demand, the global fossil fuel share in the power mix increased from 84.4 percent to 87.1 percent in the same period. Despite global-record-setting installations of renewable energy sources, and the demand these low carbon energy sources covered (1990-2016: +158 percent), their share in the energy mix is still marginal: Renewables only covered 3.9 percent of total primary energy consumption in 2016 (1990: 2.3 percent) and have only been added but have not replaced fossil fuels to satisfy a globally rising energy demand. Projections – depending on the scenario – are not promising, either.[23]

Figure 3. Global primary energy consumption by source (share), measured in terawatt-hours (TWh), 1990 and 2016



	1990		2016	
Solar	0.00%		0.22%	
Other RE	0.12%	2.3 %	0.37%	3.9 %
Wind	0.00%		0.63%	
Hydro	2.18%		2.65%	
Traditional Fuels	11.24%		7.26%	
Nuclear	2.03%		1.73%	
Fossil Fuels	84.43%		87.13%	

Source: Author's calculations based on data from Our World in Data.[24]

The growing share of fossil fuel in the energy mix is often used as proof that renewables are unable to replace fossil fuel. However, as fossil fuel capacities continue to be added in even higher rates than renewables, the question becomes more about choice rather than the limitations of renewable technologies. In this context, it is important to draw the line connecting the world's rising energy demand to its cause: exponential economic growth. It is worth examining its dynamic force, which has simply outpaced the development of renewables.

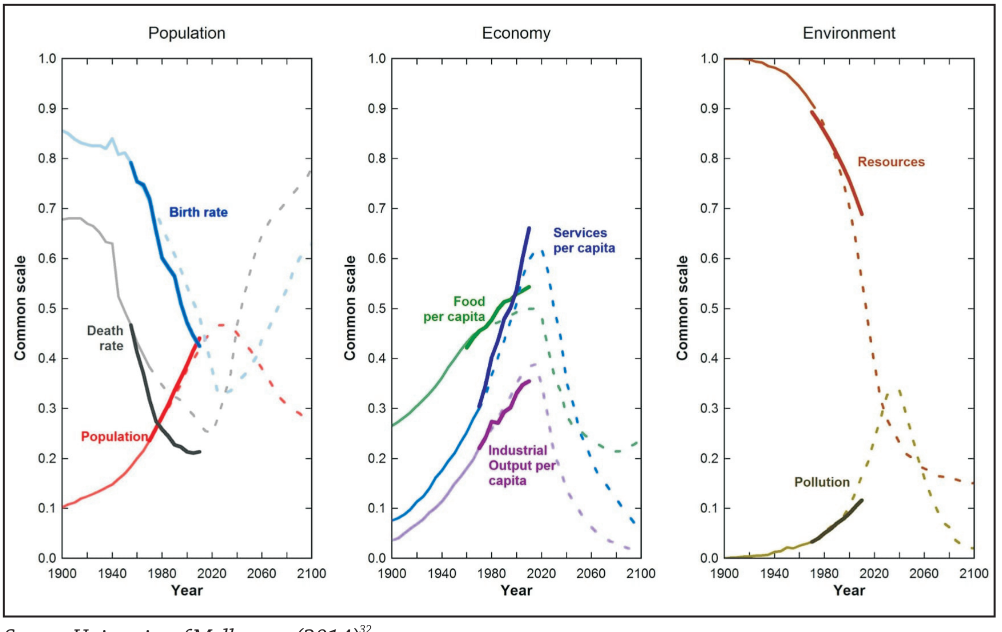
1.2 Exponential Growth

> *"Exponential growth—the process of doubling and redoubling and redoubling again—is surprising, because it produces such huge numbers so quickly. Exponentially growing quantities fool us because most of us think of growth as a linear process."*[25]
>
> — *Club of Rome (2004)*

World economic growth is not only fossil-fueled, it is also exponentially increasing—a fact that most discourses about environmental policies seem to ignore. As early as in 1971, the Club of Rome – a group of about 30 thinkers, diplomats, academics and civil society leaders from 10 countries – had acknowledged that the practiced principles of exponential growth collide with a finite frame called 'earth'. Unfortunately, the core message and rational approach was mostly misunderstood and seen through the ideological prism. In the seminal publication, *Limits to Growth* (LtG),[26] the authors did not warn about the economic growth itself but the effects they called "human ecological footprint" which would "overshoot" the capacity of the world to absorb due to delays in decision-making and exponentially rising input (resources) and output (emissions, waste).[27] In particular, five major trends were investigated in different scenarios: "accelerating industrialization, rapid population growth, widespread malnutrition, depletion of nonrenewable resources, and a deteriorating environment."[28] A peak would be reached between 2020 and 2030, assuming a business as usual (BAU) scenario. The exponential growth of population and consumption could not be stemmed only by technological progress, but also a change in behaviour. Immediately after its publication, "the report began to attract heavy criticism - often by economists and business people."[29] The reaction was hysteria on one hand, ridicule and denial on the other—"most people saw it as a threat to the cherished ways of the present."[30]

In 2009, academic and climate-change sceptic Bjørn Lomborg sought to throw LtG into the "dustbin of history."[31] Five years later, however, when the calculations from 1972 were compared with current figures, the criticisms toned down. The actual data followed the "standard-run" (business-as-usual) scenario. After 42 years, the model presented by LtG proved disturbingly close to reality.

Figure 4. Predictions of "Limits of Growth" compared with real-world Data (2014)



Source: University of Melbourne (2014)[32]

In August 2018, the thesis of an "overshoot" was echoed in an essay published by leading scientists. Here, the authors argue about a "domino effect", which could push the world into a "hothouse" state where single climate change effects would drive and accelerate each other. The ability to stop this development would have been lost past this point.[33] Time, and effective carbon reduction become the crucial factors.

Exponential economic growth, a principle that emerged with the industrial revolution of the 19th century, is driven by the inherent economic principle of growth, rising world populations, and urbanisation. All these drivers lead to a steady increase in consumption.[34] Today these dynamics can particularly be observed in Asia. With its high economic growth rates, the region is increasingly becoming the main driver for global economic growth (and, also, its side-effects), and Africa is slowly following in Asia's footsteps.

> *"By 2050 it is projected that around two thirds of the human population will live in urban areas. Over 90 per cent of the growth in urban populations between now and 2050 will take place in Asia and Africa."*
>
> — *United Nations (2018)*[35]

India's population is expected to surpass that of China after 2024, when both countries are accommodating roughly 1.44 billion citizens each. Six years hence, India's population is projected to reach 1.5 billion and will peak at 1.66 billion in 2050. This will make India one out of ten countries that will account for more than half of the world's projected population increase over the period from 2017 to 2050 (+24 percent).

Table 2 Total Population by Country (in millions, rounded-off)

	1990	2010	2014	2017	2030	2050	2100
World	5 331	6 958	7 298	7,550	8,551	9,772	11,184
EU	477	502	507	512	524	529	653
United States	253	309	318	324	355	390	447
China	1 172	1 360	1 390	1,410	1,441	(1,364)	(1,021)
India	870	1 231	1 294	1,339	1,513	1,659	(1,517)

Sources: United Nations, 2017[36], Eurostat[37], EEA[38] (figures in brackets: decline)

Further, it is projected that world population would peak earliest in 2070[39] or – according to the United Nations – not before 2100. As a consequence, the gross world product (GWP)[40] – the figure which represents global consumption – will head to new heights over the years. Even though average annual global growth rates decreased over time, economic growth continued to increase every year in some regions, between 3.87 percent (EU) and 11.99 percent (China). (See Table 3.)

Table 3. GDP, PPP (in trillions, current US$) and average annual growth rate of GDP (in percent)

	GDP, PPP (absolute)					average annual growth rates of GDP (percent)			
	1990	2010	2014	2016	2023 *estimated*	1990-2010	1990-2014	1990-2016	2016-2023 *estimated*
World	27,283	89,346	110,342	120,367	178,018	6.11%	5.99%	5.87%	5.75%
EU	7,476	16,885	18,789	20,082	26,408	4.16%	3.91%	**3.87%**	3.99%
US	5,980	14,964	17,428	18,624	24,537	4.69%	4.56%	4.47%	4.02%
China	1,120	12,406	18,229	21,290	37,067	12.78%	12.33%	**11.99%**	8.24%
India	987	5,312	7,340	8,705	16,785	8.78%	8.72%	8.73%	9.83%

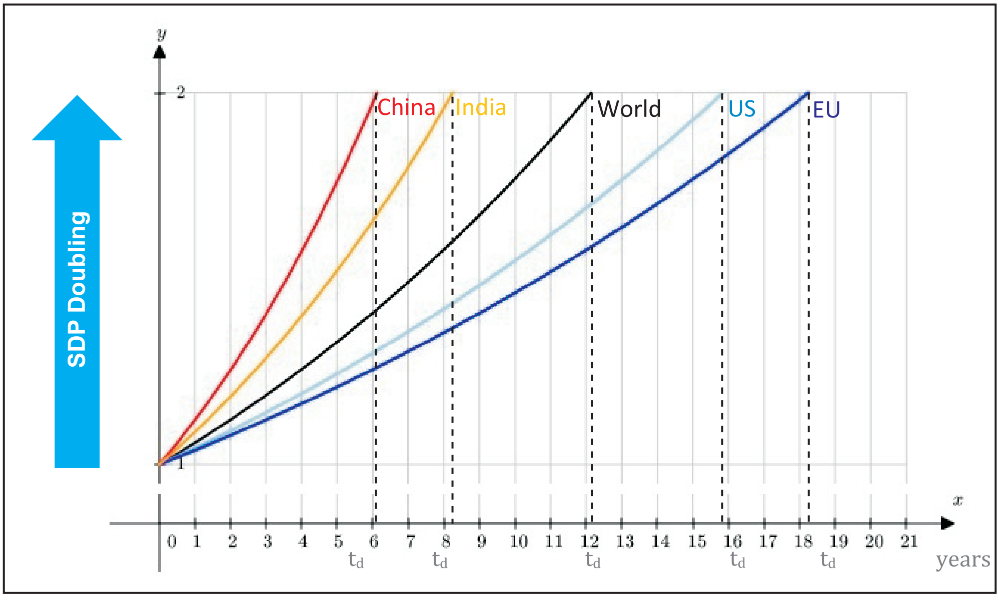
Source: Author's calculations based on data from IMF (2018).[41]

It is necessary to understand the concrete aftermath and magnitude of constant positive annual growth rates (exponential growth).

Mathematics becomes a helpful tool to understand the dynamics accompanied by exponential growth and to explain why environmental initiatives often fail to have an absolute effect as they settle only for a relative effect.

In the West, it required 16 years (for the US) and 18 years (EU) to double economic output between 1990 and 2016. Meanwhile, in the East, it took China only six years and India eight, to double their GDP, or quadruple it in 12 years or 16 years, respectively.

Figure 5. Doubling of GDP in years, based on 26 years of GDP, PPP in current international $ (1990 – 2016)



Source: Author's calculations and design, based on World Bank data (2018)[42]

Exponential growth, compared to linear growth, is rising not with constant but with incrementally and infinitely rising amounts. It becomes obvious, why the questions raised by the Club of Rome are indeed legitimate. Infinite growth fueled by finite resources cannot be a viable long-term strategy.

Relatively saturated, high-income societies such as the US or the EU need more time to double their economic output. Here, the times of high economic growth are over while average welfare, consumption, and emissions have been stabilised along high levels. Additional energy capacities are easier to be satisfied. Side-effects on environment (emissions, waste, and pollution, among them) and on public health or on societal and economic structures are easier to be stabilised or even partially reduced. In countries like India and China, the time for introducing policies and reacting on developments become more of a crucial factor as circumstances (energy demand, population, and consumption, among them) increase significantly faster. In other words: (High) economic growth rates do not only increase national income and wealth exponentially, but challenge society and politics with exponentially rising (energy) requirements and negative side-effects, as well. A particular indicator might be helpful to understand the dimensions of the required reduction of carbon emissions in the context of (exponential) economic growth.

1.3 Reduction Requirements: Theoretical Gains and a Suitable Indicator

High growth markets such as India are expected to emerge with an average growth rate close to 10 percent between 2016 and 2023 (see Table 3). Only to stabilise total carbon emissions, a reduction of 50 percent in carbon emissions would be required in the period when GDP is doubling. Taking India's expected average annual growth rate of 9.83 percent between 2016 and 2023 as an example (see Table 3), carbon emissions would require a reduction of 50 percent within only 7.4 years.[43] Even then, total (absolute) carbon emissions would not have been reduced. To reduce total carbon emissions, the annual retrenchment would require an absolute carbon reduction with a *higher* decrease rate than the GDP growth rate.

The indicator, which includes both, emissions and GDP, is called emissions intensity or – as used in this paper – carbon intensity (CI). It describes how many tonnes of carbon are emitted per units of GDP produced.

$$Carbon\ Intensity\ (CI) = \frac{carbon\ emissions\ (tCO_2)}{economic\ output\ (\$m\ GDP)}$$

The comparison of actual changes in total emissions in reference to economic growth is hereby enabled. CI describes how carbon-efficient an economy is, while the change rate of CI illustrates the actual success or failure of emissions reduction measures as it illustrates the actual reduction or rise of CO_2 (carbon-effective) from one period to the other. The reciprocal value of the economic growth (GDP) rate represents the necessary CI decrease rate to stabilise total emissions ($CI_{equilibrium}$). Assuming the priority to be that of reducing total emissions, the CI decrease rate has to be higher than the reciprocal value of the GDP growth rate. Otherwise, emissions keep growing exponentially.

Equation 1: GDP growth and necessary CI decrease for an equilibrium in annual carbon emissions

X: total emissions
C: emissions per GDP unit (carbon intensity)
G: GDP
g: GDP growth factor: g = 1 + (annual change of GDP in percent)/100
d: CI growth factor: d = 1 + (annual change of CI in percent)/100

$$G(t) = G(0) \cdot g^t \quad (1)$$

$$C(t) = C(0) \cdot d^t \quad (2)$$

$$X(t) = G(t) \cdot C(t) = G(0) \cdot C(0) \cdot g^t \cdot d^t = G(0) \cdot C(0) \cdot (g \cdot d)^t = X(0) \cdot (g \cdot d)^t \quad (3)$$

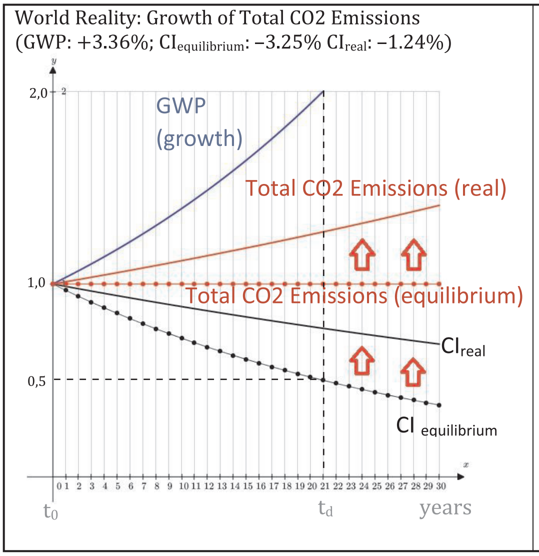
X (total emissions) grows and decreases by $(g \cdot d)$

- $g = \frac{1}{d}$ => equilibrium (between emissions and reduction) because $1^t = 1$
- $g \cdot d > 1$: X (total emissions) is growing exponentially by factor $g \cdot d$
- $g \cdot d < 1$: X is decreasing exponentially by factor $g \cdot d$

Source: Author's calculations

Referring to the global development of the average annual economic growth rate of Gross World Product (GWP) of 3.36 percent between 1990 and 2010 (see Table 4), a CI decrease rate of 3.25 percent (1/1.0336-1 = - 0.0325) would have been necessary to *stabilise* total emissions ($CI_{equilibrium}$). Instead, the actual real CI decrease rate was only - 1.24 percent (CI_{real}), which led to the exponential rise of total emissions. In other words: The actual CI (CI_{real}) was insufficient to compensate for the emissions generated by the economic growth in the same period.

Figure 6. Scenarios of growth and Carbon Intensity decrease (in percent) and Total CO_2 Emissions (1990-2010)



<u>Scenario of *stabilised* carbon emissions:</u>

GWP (blue solid graph) increased with an average growth rate of 3.36 percent, which leads to a doubled economic output (from 1 to 2 on y-axis) after around 21 years (t_d). To stabilize carbon emissions (red dotted graph) in the same period the emissions per unit of GWP ($CI_{equilibrium}$) needs to decrease accordingly (black dotted graph).

<u>Reality of *increasing* carbon emissions:</u>

Even though the emissions per unit of GWP (CI_{real}) decreased (black solid line). Total carbon emissions grew (red solid line) as economic growth was too high for the gains made by an increased efficiency/emissions (negative growth) per unit of GDP.

Source: Author's calculations, using data from Table 4

A closer view of the historic development of emissions, economic performance (GWP/GDP), and CI offers a more practical understanding and application of the indicator. Between 2010 and 2014, global emissions grew by an average annual rate of 1.93 percent. Compared to the period between 1990 and 2010 (2.09 percent) the annual emissions growth rate was marginally reduced by only 0.16 percent. While the GDP and CO_2 emissions grew on a global scale (absolute), the EU and the US have obviously been able to reduce their total emissions over time.

Table 4. Average Annual Change of GDP (PPP, constant 2011 international Dollar), CI, and total CO_2 emissions, 1990-2010 / 2010-2014

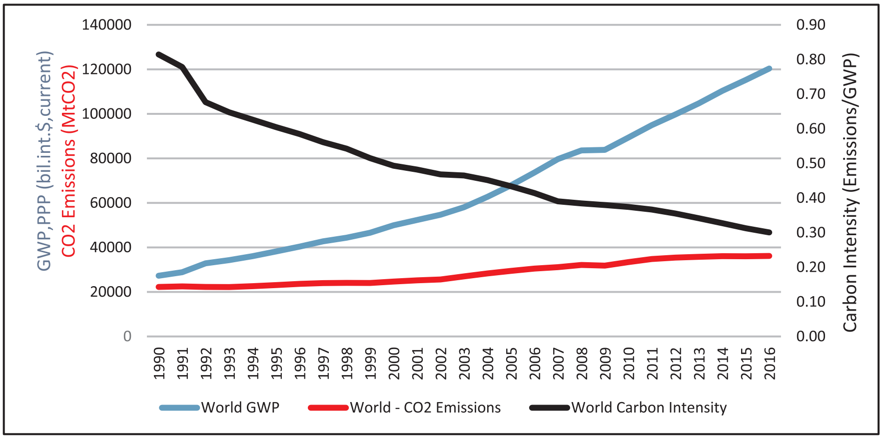
	1990-2010			2010-2014			2014-2016		
	average change in **GDP**	average annual change in **CI**	average annual change in **total CO2 emissions**	average change in **GDP**	average annual change in **CI**	average annual change in **total CO2 emissions**	average change in **GDP**	average annual change in **CI**	average annual change in **total CO2 emissions**
World	3.36%	-1.24%	2.09%	3.57%	-1.58%	1.93%	4.44%	-4.12%	0.14%
EU	1.86%	-2.32%	-0.50%	0.84%	-4.12%	-3.31%	3.38%	-2.89%	0.39%
US	2.54%	-1.93%	0.56%	2.02%	-2.63%	-0.66%	3.38%	-5.50%	-2.31%
China	10.49%	-3.52%	6.60%	8.11%	-3.74%	4.06%	8.07%	-8.07%	-0.65%
India	6.54%	-1.22%	5.24%	6.49%	0.30%	6.81%	8.90%	-4.27%	4.25%

Source: Author's calculations, based on World Bank data (2018)[44]

The highest decrease in CI was realised between 2010 and 2014 by the EU (-4.12 percent) followed by China (-3.74 percent) and the US (-2.63 percent). It is important to acknowledge that the absolute reduction of emissions in the EU and the US between 2010 and 2014 was accomplished with relative low annual GDP growth rates (0.84-2.02 percent). Emissions reductions were higher than economic growth. This explains why even China's accomplishments in reducing emissions were once again overcompensated by growth in 2017: Total carbon emissions could not been stabilised but – again – increased (+1.4 percent) due to higher economic growth.[45] It may therefore not be surprising that a recent IMF Discussion Paper comes to the conclusion that China is far from a decoupling growth from emissions.[46] As observed earlier, the primarily fossil fueled economic growth was stronger and caused more emissions than efficiency improvements and additional installation of renewable energy were able to compensate.

The dependency between Gross World Product (GWP), CI, and emissions shows that total emissions keep rising as GWP is growing faster than CI is decreasing.

Figure 7. Development GWP, PPP (current, bil. int. \$), CO_2 Emissions ($MtCO_2$), Carbon Intensity ($MtCO_2$/GWP), 1990-2016



Source: Author's calculations, based on data from Global Carbon Atlas (2018)[47], IMF (2018)[48]

Thus CI illustrates whether emission reductions – including the economic growth effect – have been achieved or need to be achieved to meet emission targets. A closer look into the future gives a more realistic idea about the dimensions of the required emissions reduction. Today, the EU already has one of the most rigorous emission regulations and has reached one of the highest levels of carbon-efficiency globally.[49] Therefore, the EU serves as a suitable arithmetic example to show the sheer magnitude of required emissions reduction of a highly developed economy with a population of around 510 million consumers.

The EU official long-term target is an 80-95 percent reduction of CO_2 emissions (compared to 1990 levels) by 2050.[50] Choosing the lowest target of an 80 percent reduction and assuming a low average annual GDP growth rate of moderate two percent by 2050 (Scenario A, see Table 5), would require a reduction of 97.5 percent emissions of 2016 levels to 89 $MtCO_2$ total emissions or a continuous reduction to 98.7 percent of CI (gains in emissions reduction). This would translate to a required average annual emissions reduction of 10.2 percent or 12 percent average annual decrease of CI.

Table 5. Scenarios for the EU with 2 percent average GDP growth rate/ 80 percent emissions reduction; GDP, PPP(bill.int.$); Emissions ($MtCO_2$), CI (Emissions/GDP)

Scenario A										
					Absolute change			Average annual change		
	1990	**2014**	**2016**	**2050**	**1990-2014**	**2014-2016**	**2016-2050**	**1990-2014**	**2014-2016**	**2016-2050**
GDP	7,476	18,789	20,082	39,374	151.3%	6.9%	96.1%	3.9%	3.4%	**2.0%**
CO2	4,461	3,472	3,499	**89**	-22.2%	0.8%	**-97.5%**	-1.0%	0.4%	**-10.2%**
CI	0.233	0.185	0.174	0.002	-20.7%	-5.7%	**-98.7%**	-1.0%	-2.9%	**-12.0%**

Source: Author's calculations, based on data from Global Carbon Atlas (2018)[51], IMF (2018)[52]

Even more drastic reductions become necessary (see Table 6) if the reduction target is 95 percent (22 $MtCO_2$) until 2050. In this case, the required emission reductions between 2016 and 2050 are 99.4 percent. Reaching this target requires a CO_2 emission reduction of 13.8 percent or an CI decrease of 15.5 percent, both annually.

Table 6. Scenario B for the EU with 2 percent average GDP growth rate/ 95 percent emissions reduction; GDP, PPP (bill.int.$); Emissions ($MtCO_2$), CI (Emissions/GDP)

Scenario B										
					Absolute change			Average annual change		
	1990	**2014**	**2016**	**2050**	**1990-2014**	**2014-2016**	**2016-2050**	**1990-2014**	**2014-2016**	**2016-2050**
GDP	7,476	18,789	20,082	39,374	151.3%	6.9%	96.1%	3.9%	3.4%	**2.0%**
CO2	4,461	3,472	3,499	**22**	-22.2%	0.8%	**-99.4%**	-1.0%	0.4%	**-13.8%**
CI	0.233	0.185	0.174	0.001	-20.7%	-5.7%	-99.7%	-1.0%	**-2.9%**	**-15.5%**

Source: Author's calculations, based on data from Global Carbon Atlas (2018)[53], IMF (2018)[54]

The historical data (1990, 2014, 2016) help to bring this into context. Compared with the highest achieved annual decrease rate of CI by 2.9 percent between 2010 and 2014, the required annual CI decrease rates between -12 percent and -15.5 percent (see Tables 5 and 6) seem hardly realistic. In other words: The EU's emission targets require by far more drastic measures than already achieved until today. As countries such as India are on the economic rise, both past and projected figures should encourage deeper thinking about the key aspects of globally applied climate policies and their focus. The dependencies and required reductions of carbon emissions illustrated in the preceding analysis question the effectiveness of environmental policies worldwide.

A popular claim is to increase efficiency. Indeed, there is no discourse about climate change that fails to discuss the "imperative" of improving efficiency. But what about effectiveness? What differentiates an *efficient* from an *effective* policy, process, or technology?

Summary

1. Economies are still (and in the predicted future) fueled mainly by fossil fuel.
2. Economic growth and therefore energy demand is exponential.
3. A fossil fueled economic growth leads to rising instead of decreasing global CO_2 emissions.
4. Carbon Intensity (CI) represents the carbon-efficiency of an economy; its change represents the effective (total) carbon emission reduction or growth.
5. Previous climate policies and agreements have obviously failed to reduce global carbon emissions and require a new approach.

II. EFFECTIVENESS AND EFFICIENCY

> *"It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth."*
>
> — *William Stanley Jevons (1865)*[55]

Since the 19th century, industrialisation has been driven by a continuous increase in efficiency and is dependent on the cost-benefit ratio. Efficiency measures follow the economic principle of "maximum result" or "minimum effort". In this sense, "efficient" and "economic" share the same meaning. The goal is to achieve as much as possible (output) with minimal use of resources (input). It is every industry's and business inherent interest to reduce costs and increase profits. If profits are the desired result (effect), an improved efficiency is the natural approach to reach it.

If a coal power plant is more efficient than the other, it can generate the same amount of energy with less fuel and thereby save on fuel costs. This is why efficiency is called the "5th source of power" or simply "the cheapest of all".[56] It is cheaper to improve the existing technology than develop and prepare a new technology for the market. This is why a higher efficiency is – superficially – attractive for both, businesses (cost-effect) and environment (emission-effect). However, as described in the preceding section of this paper, the world economy is growing exponentially, even as emissions keep rising instead of decreasing. Indeed, a higher efficiency reduces relative emissions (per unit). If more units are consumed, though, the gains made by a higher efficiency are diminished. While the effect of cost-reduction might be achieved, the effect of an absolute emissions reduction is not. Higher efficiency cannot compensate for a lack of effectiveness (total emissions reduction). Every technology, process, and strategy is (or should be) based on a desired result before it is implemented (effective) to reach this result with the lowest possible resources (efficient). Without the first, there is little sense in pursuing the latter. Table 7 gives an overview about the difference between effectiveness and efficiency.

Table 7. Efficiency vs. Effectiveness

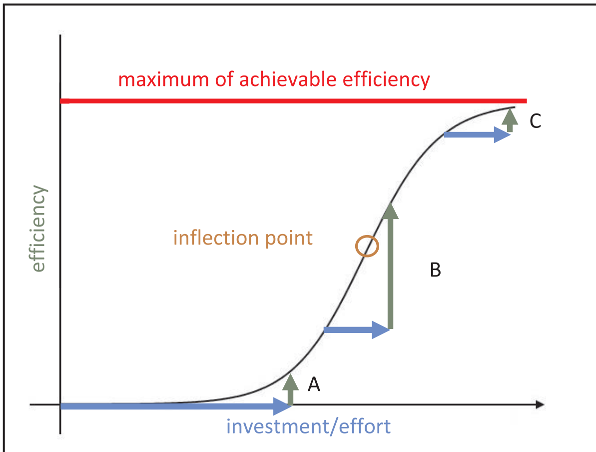
	Effectiveness	**Efficiency**
Motto	Doing the right things	Doing things right
Approach	Result-oriented	Yield-oriented
Purpose	Strategy Formulation	Strategy Implementation
Meaning	The level of nearness to the actual results as originally planned	Ability to produce maximum output with limited resources
Ascertainment	Strategies	Operations
Time Horizon	Long-run perspective	Short-run perspective

It becomes obvious which of the two is required first, if climate action is to succeed. The preceding section has illustrated that "doing things right" cannot replace or ignore the question of whether "the things" themselves are "right". Or in other words, climate policies are not result-oriented (not effective) if they do not serve the reduction of total GHG emissions (within the given time frame). Nevertheless, it is often argued that efficiency only has to be further increased. Technologies and processes, however, that are built or rely on fossil fuels emit carbon emissions by nature; efficiency measures are limited due to technical, physical, and economic reasons.

2.1 Limitations

The improvement of efficiency is always restricted by the framing parameters. The maximum achievable efficiency of every technology is defined by the affected physical laws. In the case of thermal power, combustion or steam engines, which transform heat energy into mechanical energy, the highest possible efficiency is limited by the laws of thermodynamics. Carnot's Efficiency is "the difference in temperature between the hot working fluid — such as the steam in a power plant — and its cooled-off temperature as it leaves the engine, divided by the temperature in degrees Kelvin [...] of the hot fluid."[57] It is the maximum efficiency that these machines can theoretically reach (51 percent).[58] Furthermore, efforts and expenditures required for an improvement in efficiency are rising over time, while gains per investment are progressively dropping and costs are – at some point – economically not further justified. It means, in a competitive market scenario, the end of a technology's life-cycle as it is most likely replaced by a new technology (innovation).

Figure 8. The Principle of Efficiency: Self-limiting logistic growth / S-Curve of a Technology



Every technology is limited by a maximum of efficiency, which can be achieved by improvements.

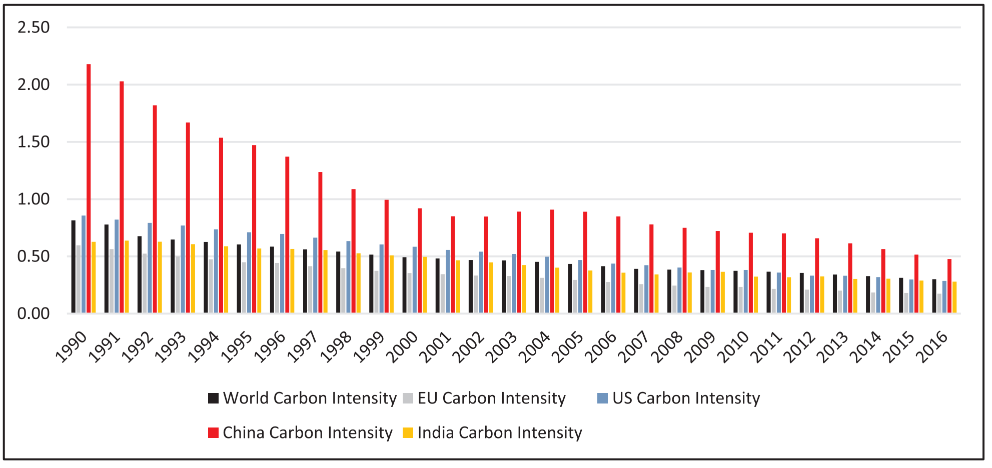
While in the first (research & development) phase the investment is high but the efficiency gains are still relatively low (A), later in the life cycle these gains are relatively high but draw to the limit (maximal achievable efficiency) with decreasing efficiency gains per investment/effort (C). Efficiency peters out.

Investments before the inflection point offer rising gains by efficiency per investment, while after the inflection point the gains per investment decrease and draw to zero.

Source: Author's own design

This is another reason why fossil-fueled economies, although they may theoretically become more efficient, will not be efficient enough to be *effective* (in regards to an absolute carbon emissions reduction). The investment in higher efficiency (of the current technology) is often more economical than an investment in a new technology. A new technology requires significantly higher initial investment before the gains in efficiency are enough to become competitive. However, efficiency gained per investment begins to decrease after the inflection point (green arrow, Figure 8). This natural limitation can be observed in the historical development of Carbon Intensity (CI), which represents an economy's carbon efficiency.[59] Figure 9 illustrates steadily decreasing CI values but also decreasing CI rates. The gains (reduction of emissions per GDP) clearly deteriorate every year.

Figure 9. Carbon Intensity ($GtCO_2$ per GDP, PPP), 1990-2016



	1990	2000	2010	**2016**
World	0.81	0.49	0.37	0.30
EU	0.60	0.35	0.23	0.17
US	0.86	0.58	0.38	0.29
China	2.18	0.92	0.71	0.48
India	0.63	0.50	0.32	0.28

Source: Author's calculations, based on data from Global Carbon Atlas (2018)[60]*, IMF (2018)*[61]

Today, Europe has the most efficient industry as its CI is the lowest compared to all other countries (0.17 $GtCO_2$/GDP). As a consequence, further gains in efficiency are expected to decrease as longer-term policies focus on higher efficiency. It is becoming obvious that even if India or China – in this comparison the lowest carbon-efficient economy – would reach current European levels, the reductions in global carbon emissions would not be sufficient enough to comply with the climate targets. As calculated earlier (see Tables 5 and 6), the GDP may be generated with nearly zero emissions (0.002 $GtCO_2$/GDP) until 2050. In other words: It is not possible to reach the climate goals with a fossil-fueled economy, even the most *efficient* one.

2.2 Price Effects

Policies – in the name of sustainability – often aim for a higher efficiency to reduce emissions by increasing emission standards and/or taxes on energy or carbon emissions. At first sight, the idea seems to be simple and convincing at least from the environmental perspective: As more CO_2 is emitted, the more costly it gets for the emitter. As a response, the emitter (or energy consumer) invests in higher efficiency to reduce or compensate these tax expenses. However, besides growth effect and the limits explained earlier, such government-initiated stimulation may even have counterproductive effects for a successful climate action.

First, it is important to acknowledge that the fossil fuel energy market is shaped by a supply-side oligopoly and therefore characterised by a high dependency. Second, competition is limited by significant entry barriers set by the required infrastructure (pipelines, refineries, gas stations, among them). Third, to provide affordable energy—a pillar of economic prosperity—most governments subsidise fossil fuel in some form. Often mentioned in the context of renewable energy, subsidies for fossil fuels are far more excessive and estimated to range in OECD countries between US$ 373 billion and US$ 617 billion between 2010 and 2016.[62] The dependency on fossil fuel as the prerequisite for economic growth and prosperity has led not only to direct, but also indirect subsidies. Past and current fossil fuel prices do not represent real prices but are below the natural level.

India, like most countries in the world, runs its economy on fossil fuels and has introduced subsidies to provide low energy prices and drive economic growth; therefore, it is not an outstanding example for a fossil-fuel-focused energy policy. In possession of significant hard coal resources, India once identified coal as a base fuel for its economic development – like Poland did about hard coal or Germany, lignite. Even though there is a change in awareness, subsidies or social and environmental costs remain excluded in the calculation of fossil fuel price — not only in India. On the other hand, policies levy taxes on energy (indirect) or emissions (direct) to reduce emissions. But what are the consequences?

A *moderate* increase in taxes on fossil fuel (or on carbon emissions) raises energy (or emission) costs for consumers but most likely will lead to investments in an improved efficiency if the savings at least compensate for invested capital.[63] The decision is based on an economic principle of maximising profits/minimising costs and is done by a standard cost-benefit assessment. As a result, the demand for more efficient technologies grows. Investments in research and development (R&D) for more efficient (improved and existing) products/processes increase. A higher demand creates supply for more efficient products, which cuts prices by economies of scale. Lower or stable prices for more efficient products – often accompanied together with a rising income – lead to a higher demand, a higher economic output, and higher carbon emissions. Products become economically more attractive and affordable (e.g. lower running costs). Even though science does not provide a clear answer about the magnitude of this so-called "rebound effect",[64] capital savings will most likely be reallocated to other forms of consumption or investment.[65]

Example: India's increased income, demand, and efficiency of ACs

Over the last 10-15 years room air conditioner (AC) sales have been growing at a CAGR of more than 10 and are expected to continue to rise with the same growth rate due to increase in incomes, urbanization, falling end-consumer prices and lower operational costs/higher efficiency. Today air conditioning accounts for 40-60 percent of summer peak load in large Indian cities such as Delhi and expected to add 140 gigawatts (GW) or 30 percent to peak demand in 2030 (equivalent to about 300 power plant units of 500 MW each). Already in the past India's policies improved the average efficiency of ACs by about 35% (2006-2016; 3 percent per year). Growth outnumbered efficiency improvements.

Total room AC consumption in TWh/year (BAU scenario, 2015-2030)

2015	2020	2025	2030
60	81	126	197

Source: Lawrence Berkeley National Laboratory (2017)[66]

The other effect of a moderate increase in energy prices (or tax on emissions) and resulting investments in efficiency is the classic crowding-out. When energy prices increase moderately – at a pace that a higher efficiency can presumably both, overcompensate the investment costs and deliver the necessary cost-benefit ratio for the required R&D – the investments to improve current technologies oust investments in alternative and fundamental new, non-fossil fuel-related technologies. It is economically more viable to maintain current technologies and improve their efficiency rather than drive a technological revolution or true innovations. The classic example for this phenomenon is the car industry.

Excurse: The (German) Car Industry – Investments and Emission Effects

"Among German combustion engine patents, we find that over two-thirds of all inventions focus on making engines more fuel-efficient."

Ifo-Institute (2017)

From the **business perspective** it obviously does make little sense to change the drive train from ICE to electric vehicle (EV), hybrid or fuel cell, very soon.

The German car industry is leading with the most patents for ICE related technologies. However there is a significant lack of battery technology related patents. It is therefore not surprising that the interest in a quick transition towards e-mobility is moderate. The focus of research and development on ICE becomes obvious when taking a closer look on the figures. While the share regarding EV, hybrid, or fuel cells are high and provide the impression that innovation in these alternative technologies (34 percent of all registered patents, 2010-2015), is nearly equal to ICE (40 percent of all registered patents, 2010-2015), the absolute numbers of patents related to EVs (1,355) compared to ICE (3,394) illustrate the unilateral innovation focus. This is in fact valid for the whole industry. The number of all registered patents worldwide (rounded) show a strong growth in both technologies but still more than twice as many patents on ICE:

Period	total number of patents / EV	total number of patents / ICE
1995 – 1999	100	1972
2000 – 2004	226	3972
2005 – 2009	1289	6033
2010 – 2015	3954	8409

From the **climate perspective** it might make more sense to take the accumulated emissions into account, instead.

Germany's transport sector is dominated by road transportation. Even though efficiency of vehicles with internal combustion engines (ICE) was improved between 1995 and 2014 (buses: +6 percent; passenger cars: +11 percent; trucks: +25 percent), total CO2 Emissions caused by road transportation increased even by 7 percent (1995-2014). The gains by efficiency were outnumbered by growth of traffic. Indeed, there was a reduction of CO2 emissions by a higher efficiency per unit (relative reduction). Indeed, the total CO2 emissions would have been higher without an improved efficiency. But funds for research and development of more efficient ICE a) did actually not serve the goal to reduce total emissions (absolute reduction) and b) were not invested in new technologies, comparably.

Sources: Ifo-Institute[67], German Environment Agency[68]

Both, rebound and crowding-out effects refer not only to business but also to private end-consumers, who have less to spend for other consumer goods or investments. Due to lower capital stock, the price sensitivity for price changes as well as the absolute price level is higher in low-income countries. Taking electricity in an emerging market like India as an example, the key objective for economic and social development besides availability, accessibility or reliability, is the aspect of affordability.

In India and other developing countries, high risk as well as low income, cash flow, and funds are the main limiting factors. Here, an even more cautious cost-benefit assessment is crucial. Micro, small and medium enterprises (MSME) in India contribute 28.77 percent of GDP. The micro sector, with an estimated 63 million (630.52 lakh) enterprises, employs 107.6 million (1076.19 lakh) people, which accounts for around 97 percent of total employment in the sector.[69] The available funds particular in this sector are limited. Here, higher energy prices eliminate economic activity rather than stimulate investments.

The tension between environmental and economic goals becomes more obvious here than in other sectors or industrialised countries – a significant aspect to identify and to develop applicable policy strategies. Higher efficiency requires investment but – as illustrated – cannot reduce total CO_2 emissions.

It is important to emphasise again, that a lack of effectiveness (here: net-zero carbon economy) can never be compensated by improved efficiency and even could bind available capital for the wrong (ineffective) cause. The solution is to be found at the beginning—at the source of the emissions, not at the end. That said, an increase in efficiency is not "wrong", *per se*. However, being a natural economic goal (cost reduction), the question is whether an improvement in efficiency in the name of the environment has to be stimulated by government regulation. Rather, it might make sense to do a case-to-case evaluation, if investments in clean sources of energy (research and development; installation) should have a higher priority as they might be more effective for both, costs and emissions. Economic interests are a powerful force, more so when they share environmental aspects.

Summary:

1. Every effective strategy, policy, process or technology follows a desired result (effectiveness) before it is improved (efficiency).
2. Efficiency is bound and limited to current/existing technologies and processes.
3. Higher efficiency cannot substitute effectiveness of a technology, process or strategy.
4. A successful push for higher efficiency is dependent on the cost-benefit assessment.

5. Government stimulated investments in a higher efficiency crowd-out investments in new technologies and hereby delay or even prevent major innovations.
6. Developing countries have another social situation, emphases and main tasks than developed countries. Concrete economic challenges rule out/compete with environmental interests here even more. Costs for a higher efficiency are often seen as an existential threat.
7. Improving efficiency is rather an economic principle to reduce costs or increase profits than it is an effective environmental policy or strategy.
8. Replacing fossil fuel with clean /low-carbon energy sources might be more carbon- and cost-effective than improving the efficiency of existing fossil fueled processes and technologies.

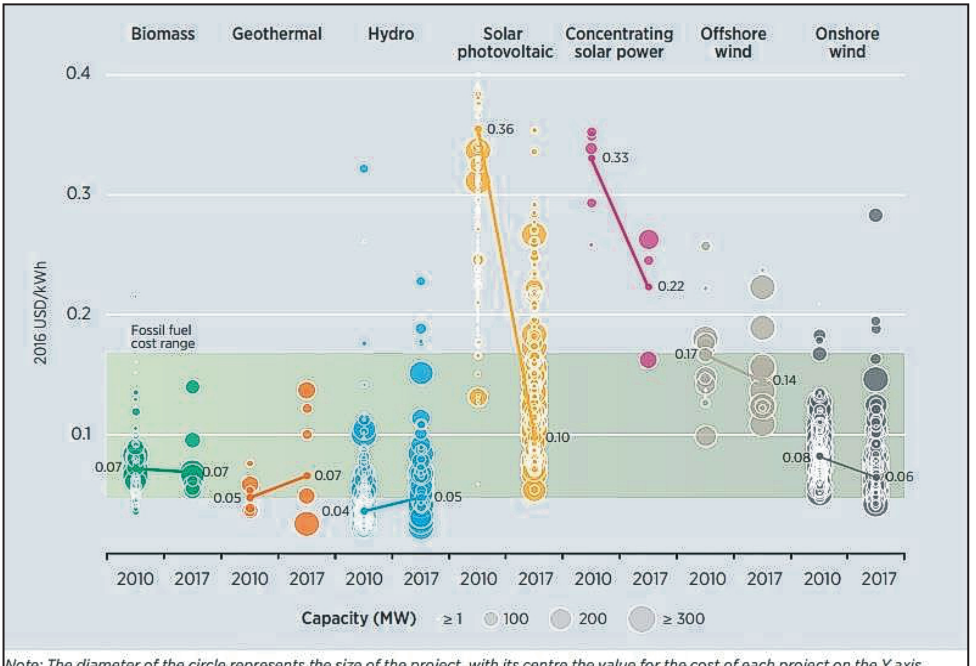
III. GAME CHANGER

As already highlighted, India is not an outstanding example for a fossil fuel-dependent economy with corresponding energy policies. Its sheer size and growth potential, together with initiatives like the International Solar Alliance (ISA) or the renewable power targets, however, attract global attention. According to the extraordinary push for renewables on the one hand, and the shelving of coal power projects, on the other, the Indian government has proved that it has understood the necessary imperative of de-carbonisation. During the last few years the parameters have been changing dramatically and initiated a global dynamic in renewables. The latest developments might help to evaluate the economic potential of renewable energy as a competitive and cost-effective alternative to fossil fuel energy. As time is crucial, it is more important than ever for governments to question current policies, identify effective strategies, and find out how they might be both, socially and economically viable.

3.1 Price Drops

The German "Energiewende" initiated in 2000 was driven by significant financial incentives (feed-in tariff). This was necessary as long as installation costs for renewable power were by far higher than for conventional power – and possible as Germany was financially able to bear such an approach. It is the reason why until today, German consumers pay a high price for being the first movers in the energy transition towards a low-carbon economy. India's ambitious renewable energy targets declared in Paris 2015 did not only place the ball in the court of industrialised countries to tag along with comparable higher environmental targets, but most notably pushed renewables into break-even point owing to the sheer amount of installed capacity and financial

Figure 10. Global levelised cost of electricity from utility-scale renewable power generation technologies, 2010-2017



Note: The diameter of the circle represents the size of the project, with its centre the value for the cost of each project on the Y axis. The thick lines are the global weighted average LCOE value for plants commissioned in each year. Real weighted average cost of capital is 7.5% for OECD countries and China and 10% for the rest of the world. The band represents the fossil fuel-fired power generation cost range.

Source: IRENA (2018)[70]

tools such as reverse auctions. Higher installation costs—once an essential entry barrier for renewable energy—vanished. In 2017, solar photovoltaic installations hit the lowest tariff of 2.44 INR/kwh (~$0.037/kWh) in India.[71] Together with wind energy, solar is now playing in the same price league as conventional power.[72]

Due to the subsidised over-supply from China, the main producer of photovoltaic solar cells worldwide, the prices are expected to further drop in the future.[73] Bloomberg expects a decrease of 35 percent in 2018 and another 10 to 15 percent in 2019.[74]

> *"We are really observing a tipping point among the institutional investors on climate change […] Until recently, that question was not on their radar screen. It's changing, and it's changing super fast."*
>
> — *Frederic Samama, Amundi SA (2018)*[75]

The allure of renewables is simple enough: The fuel is free and the energy is the cleanest form – even over the whole life-cycle. Renewable energy today promises both, effectivity (power, low-carbon emissions) and efficiency (price).

Figure 11. Life cycle GHG emissions from power sources (gCO_2equivalent/kwh)

	Wind	Solar	Nuclear	Coal
Implementation	13.7	37.5	1.2	3.6
Operation	4.7	12.0	12.4	918.8
Decommissioning	0.6	0.5	0.4	52.2
TOTAL	**19.0**	**50.0**	**14.0**	**975.3**

Source: Ministry of New and Renewable Energy (MNRE)[76]

However, major challenges remain. Renewables provide fluctuating energy and require cost-efficient storage solutions to completely replace conventional power. Electricity grids have to be adjusted and build to both, manage the volatility and coordinate the dispatch. Furthermore, creative financial instruments and commitments of risk mitigation are required to attract necessary capital. There is no doubt that conventional power still has an active role in the current power mix to guarantee the necessary base load. Currently, 70GW coal capacity require 170GW of solar photovoltaic (PV) capacity to be replaced due to its volatile nature.[77] It is also important to acknowledge that solar PV is only one form of renewable energy. And even though several different storage technologies are not cost-efficient or market-ready yet, research and development investments are growing due to potential market and the necessity: Every existing and additionally installed renewable power plant is a potential client as it could be upgraded to a 24/7 stable power supply *ex post*. As the globalised market competition is increased, technologies and innovations become cheaper and spread faster. According to a report by McKinsey, price drops in storage technologies between 55 and 70 percent by 2025 are to be expected.[78] From the technological perspective of some experts, 100-percent renewable energy scenarios are not only feasible in the future, but already viable today.[79] Assuming that at one point in the near future bundles of variable renewable energy combined with energy storage solutions become economical and the whole grid reached the necessary flexibility, conventional sources of power will lose the investors' favour. Only the possibility of such a market scenario is essential to assess political options, particularly as it would correspond with climate goals.

3.2 Global Developments

The cost-effect can be seen as a major reason why several countries and states declared to exit coal by 2030,[80] or even earlier.[81] France, for example, is reducing its nuclear capacities from 75 to 50 percent by 2025 and is planning to double solar and wind by 2022.[82] Belgium, for its part, is replacing nuclear capacities with off-shore wind energy.[83] Britain, "the last surviving enthusiast for nuclear power in the West",[84] plans to switch from coal to nuclear, while Asia becomes the only remaining market for nuclear power plants.[85] Even though nuclear has the third lowest life-cycle carbon emissions,[86] it is (and always has been) the most expensive source of power[87] – which is not a promising argument for this technology, either. Instead, the trend shows in another direction and major global players adjusted their investment strategies (examples):

- Saudi Aramco, the biggest oil exporter in the world, shifts towards renewables.[88]
- Vanguard, the world's largest provider of mutual funds pushes major oil companies to invest in renewables.[89]
- Allianz, Europe's biggest insurance company, announced its retreat from coal related insurance policies.[90]
- Rio Tinto, the global mining giant, struck a deal to sell its last coal mine.[91]

A recent study says the risk of a "carbon bubble" is emerging. The underestimated dynamic of renewable energy technologies could generate a significantly high amount of stranded assets in the fossil fuel sector[92] – a sector which seems to steadily lose ground and trust. At least the symptoms of such an energy transition are more visible than ever before.

3.3 Accelerating Transition

India's declaration and actual push of renewables under Prime Minister Narendra Modi might become a role model for other countries. While the original renewable capacity target of 175GW by 2022, was quite ambitious, it has been raised twice since 2015: Power and New &

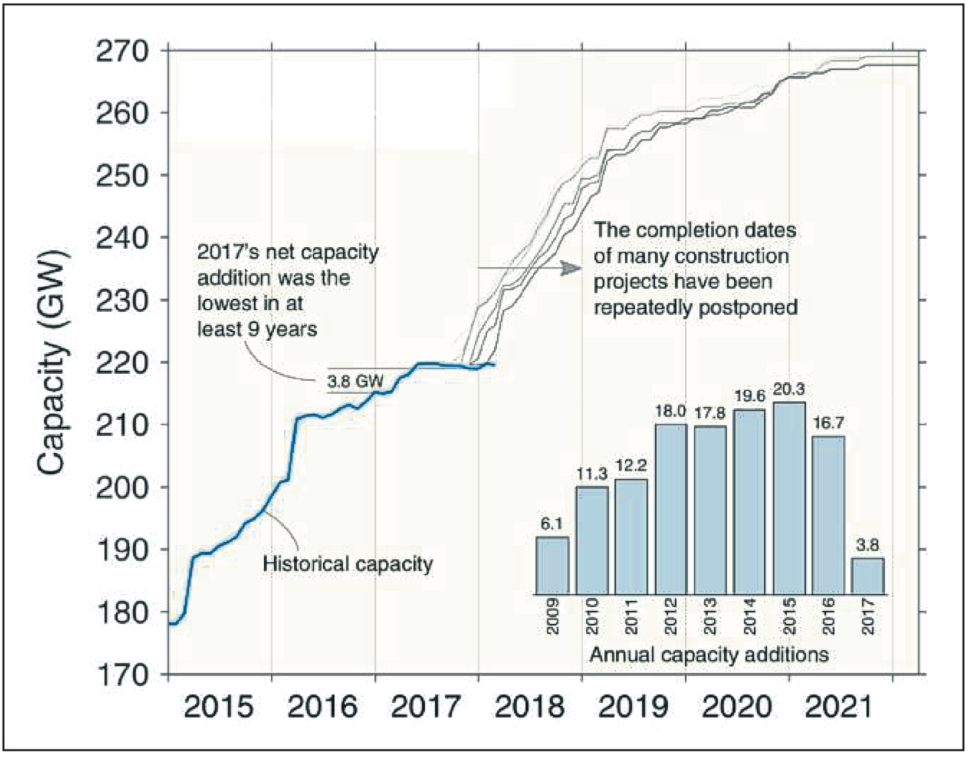
Renewable Energy Minister R K Singh increased it first in 2017 to 200 GW[93] and then again in June 2018 to 227GW.[94] In this context, the official approval of the world's largest solar power plant with a capacity of 5GW by the Gujarat Government in April[95] and, two months later, the announcement about the world's biggest tender for renewable energy (100GW) including energy storage, is only a consequent step to fulfill the ambitious targets.[96]

The vast amount of cheap renewables entering the market has led to lower wholesale prices of electricity, in particular on the short-term market. While renewables are offered for around INR 2.4 per kwh, coal-based power is sold for INR 3.7 per kwh – far below the break-even point of INR 5.[97] Distribution companies (DSICOMs) avoid long-term contracts with thermal power plants due to the higher price per kwh compared to renewables. Some 34 electricity projects worth INR 1.74 lakh crore are tied up as outstanding debt.[98] These developments might be one reason why NTCL, India's largest coal-based power generator, has decided to "back down from thermal power for more renewables."[99] India's power demand has risen slower while renewable energy has developed faster than expected. As a result, the workload of coal-fired power plants dropped from 77.5 percent in 2010 to 56.7 percent in 2016-2017. The currently scheduled additional 50 GW generated by new coal power plants will push down the average workload to around 50 percent as another 50GW are stranded.[100]

> *"The long-term outlook for coal is also far from heartening. Govt. policy directly and indirectly supports renewable capacity addition. With renewables achieving grid parity, there has been a reversal in the merit order for DISCOM. In addition, plants depend on imported coal are also at significant price risk [...]."*
>
> *— Boston Consulting Group (2018)*[101]

It is therefore no surprise that the completion dates of several coal projects have repeatedly been postponed. The financial risks become obvious and they materialise with the withdrawal of funds. While 84GW coal power plants are officially progressing, it might be more realistic if these projects are shelved or cancelled altogether.[102]

Figure 12. India's thermal electricity generation capacity (2015-2021) and annual capacity additions (2009-2017)



Source: CEA (2018)[103]

Another cost factor is the imported coal rising from 137 million tonnes in 2017 to an expected 145 million tonnes this year.[104] This neither fits with the often promised energy independence gained by national coal power nor does this reduce the coal energy prices in the long term. The import costs are expected to increase annually due to inflation (4 percent), shipping (2 percent), and the nominal coal price (1.5 percent).[105]

Another important but often ignored aspect for comprehensive cost calculations are the immediate consequences of climate change. While thermal power plants require freshwater for cooling, renewables like solar photovoltaic (PV) and wind are resilient against droughts. Today, 47 percent of the global thermal power plant capacity (coal, natural gas and nuclear) and 11 percent of hydroelectric capacity are located in highly water-stressed areas.[106] In India, 40 percent of thermal power is located in areas with water scarcity. This has already led to shutdowns in 14 of 20 largest thermal power plants between 2013 and 2016, resulting in additional costs of US$1.4 billion or a loss of 14 TWh of power (equal to Sri Lanka's annual electricity demand). The World Resources Institute (WRI) expects that by 2030, around 70 percent of India's thermal power plants are significantly affected, jeopardising a reliable power supply and resulting not only in higher costs for coal power plant operators but also increased electricity prices.[107]

Moreover, there is the nature of the fossil fuel market. While the fossil fuel market is led by producers, the renewable energy market is consumer-led.[108] Without the need for any fuel supply and the referring infrastructure power is shifted to the consumers, who become independent producers once the renewable energy has been installed (off-grid). Even if grid connection is an attractive incentive, it is not a requirement and therefore quickly enables stand-alone solutions and the electrification of rural areas.

3.4 Social Challenges

It is a brave claim to make that the only effective climate action is a fossil fuel exit, not increased efficiency in fossil-fueled technologies and processes. Even as the future is uncertain, the disruptive changes in the energy sector are undeniable. Given the inevitable technological development driven by both, economic and environmental interests, the real challenge of the transition from fossil fuel to renewable power is societal adaptation to significant structural changes. The high grade of complexity of social developments and humans' inherent character to resist hasty changes makes time an even more valuable resource. The tension is obvious between the necessity to reduce emissions quickly, on the one hand, and on the other, to act gradually and deliberately to facilitate a smooth and socially acceptable transition. Still, governments and the public, in general, seem to deny the sense of urgency. This, however, might change soon.

> *"Largely driven by a population which continues to choke on hazardous air, India is creating a blueprint for how to deliver clean energy at a fraction of the cost of fossil fuels, using less agricultural land, far less water and with a tiny fraction of the pollution and carbon emissions.[...] Coal will not be gone in a decade, but the era will end sooner than many expect."*
>
> — *Tim Buckley (2018)*[109]

In the case of India, the employment figures in the coal sector are significant and therefore highly relevant for every government. In 2014, just under half a million people were employed in coal extraction and transportation while there were more than one million jobs in different aspects of the construction and operation of coal-fired power plants.[110] A sudden coal exit would compromise millions of employees in this sector. Coal India (CIL), for instance – nationalised in 1973 – has around 310,016[111] employees and 500,000 retirees on their balance sheet.[112] Indeed, the latest push for privatisation in the coal sector[113] might help to drive its efficiency and to share risks with private investors. Nevertheless, it will neither transform the energy sector towards renewable energy nor secure an incremental shift of skills to foster the transition.

Closely linked with the disruptions in the energy sector, are transport and manufacturing—the other major industry sectors facing major challenges caused by the transition. In particular, the automotive sector, which seems not to be prepared for a transition, yet. In India, this sector contributes around US$93 billion or 7.1 percent of GDP and employs 29 million people (directly and indirectly).[114] Having focused long on efficiency, car manufacturers worldwide are currently trying to keep up with change or slowing down the process. In this sense, e-mobility could become for the car industry tomorrow, what renewables are for the conventional power industry, today. Electric vehicles generate zero emissions and require significantly fewer parts. This reduces production costs at some point but affects employment in production, assembly as well as the whole after-sales market with garages, parts, and maintenance services. It is not beside the point to assert that both, industry and politics in most countries either underestimate dynamic and consequences of the energy transition or tend to postpone necessary decisions over time.

The actual challenge for political decision-makers everywhere is to prepare society (employment), infrastructure (grid requirements and distribution of supply and demand), and industry (research and development) for the transition adequately. Jobs and skills have to be reduced at one side (fossil fuel) and upscaled on the other (renewables). In this sense it has to be acknowledged that the most effective climate action is a well-managed and energy transition—which is, in the end, a *social* transition.

Summary:

1. Latest since 2017 installation costs of renewables are competitive with conventional thermal power.
2. Rapid development of additional renewable energy let electricity wholesale prices drop in India and push conventional thermal power farther below break-even.

3. Cost-efficient storage technologies expected to emerge and make fossil fuel power obsolete.
4. The energy transition is a matter of time and is even accelerating due to economic interest.
5. The energy transition is less a technological than a social challenge (employment, skilling).
6. A roadmap, policy strategy and legal frame are necessary to provide reliability and a smooth transition towards a net-zero carbon emission world economy.

IV. CONCLUSION

Striving for higher efficiency to reduce costs is an economic aspiration. Yet, a process or technology might be more efficient than another but still less effective and, therefore, the wrong option. Translated into climate action and environmental policies, the purpose is clear: zero-carbon emissions – the earlier, the better, and as socially viable as possible. This is a goal that has been, and will continue to be impossible with improved efficiency, if fossil fuel remains the major source of energy. Even the most efficient fossil-fueled technology emits CO_2, while the two-degree climate target requires a *de facto* zero carbon emission economy. The difference between relative (per unit) and absolute (total) emissions reduction as well as the (exponential) growth of the global economy, however, seems to be widely ignored in political discourses.

Promoting higher efficiency to fight climate change is less of an environmental policy and more of a reflex, even an illusion. To do the "wrong" thing a bit better can even spur the opposite: Government-induced incentives for efficiency could oust investments in new technologies and jeopardise profits or economic growth in developing countries. A gradual replacement of current fossil fuel technologies and an investment in the energy transition towards renewables instead might not only be more carbon-effective but also cheaper than investments in higher efficiency of both, the energy demand and supply. This is because of the recent drop in the installation price for renewables.

Germany's "Energiewende" initiated the process in 2000, proving that an industrialised country with a high energy demand is willing and able to do such a step – even if it was inefficient (expensive). While this enthusiasm seems to be on the wane, India's bold approach and crucial role in the Paris Agreement in contrast helped accelerate the worldwide growth of renewables and the further price drops which came along with it. The induced rising demand for renewables and the related new industry sectors are continuously driving the economies of scale and further reducing prices. With its latest commitment to install even 227GW until 2022 and the practice of reverse auctions, India is leading the global transition to a low-carbon future by example and in the most effective way eliminating carbon emission. India is not only able to reduce its fuel dependency, it has also taken over the trophy of "soft power in climate change"[115] that Germany once possessed - an aspect not to be underestimated.

While the last energy revolution from coal to oil was a matter of solely rational choice, the upcoming revolution is driven by rational choice *and* the moral imperative. As the effects caused by climate change are expected to worsen in the coming decade, public awareness is increasing, too, along with the pressure on governments to respond. This takes on a singular urgency in countries with high economic growth rates like India, where social challenges and the impact on the environment appear even faster and significantly more people are affected by climate-induced disasters such as heat-waves, droughts, and floods. Every delay in providing the necessary legal framework for the transition will require drastic decisions at a latter point of time.

The globalised research and development is expected to offer cost-efficient storage technologies only due to economic interests. Technologies that enable a coordinated dispatch of fluctuant power are already available. Financial mechanisms, based on political decisions, might soon bundle renewable power assets and mitigate risks to attract necessary capital. At some point, fossil fuel power will be obsolete for electricity generation as well as for transportation. As economic interests are expected to drive the transition even faster than expected, societies and political leadership all over the world will be challenged more than ever before to balance environmental, social, and economic needs. Therefore, the question is not "if" an energy transition will take place, but "how" it can be done while minimising social and economic disruptions. This is the real and most pressing challenge for policy- and decision-makers all over the world. Preventing the energy transition from becoming a disruptive energy revolution requires effective policies for a smooth transition.

Understanding the difference between *efficiency* and *effectiveness*, as laid out in this paper, might be the first step to get the math right and save both, economies and climate.

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