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Upward-scaling tipping cascades to meet climate goals – plausible grounds for hope

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Abstract

Limiting global warming to well below 2°C requires a dramatic acceleration of decarbonisation to reduce net anthropogenic greenhouse gas emissions to zero by mid-century. In complex systems – including human societies – tipping points can occur, in which a small perturbation transforms a system. Crucially, activating one tipping point can increase the likelihood of triggering another at a larger scale, and so on. Here we show how such upward-scaling tipping cascades could accelerate progress in tackling climate change. We focus on two sectors – light road transport and power – where tipping points have already been triggered by policy interventions at individual nation scales. We show how positive-sum cooperation, between small coalitions of jurisdictions and their policymakers, could lead to global changes in the economy and emissions.

Keywords: climate policy; tipping points; technology transitions; diplomacy

JEL code: O33

Key policy insights:

- Tax and subsidy policies that bring clean technologies below the threshold of cost-parity with fossil fuel technologies can lead to disproportionately rapid decarbonisation.
- Small groups of countries working together can accelerate the activation of tipping points in the global economy, facilitating decarbonisation in all countries.
- The value of decarbonisation policies should be judged not just on their immediate effects, but also for their potential to contribute to upward-scaling tipping cascades.

Introduction

We have left it too late to tackle climate change incrementally. Limiting global warming to well below 2°C now requires transformational change, and a dramatic acceleration of progress (Geels *et al.* 2017; Farmer *et al*. 2019; Otto *et al*. 2020). The power sector needs to decarbonise four times faster than now (Pavarini and Mattion 2019). The pace of the transition to zero emission vehicles needs to double. Improvements in energy efficiency need to proceed two to three times as fast (IEA 2019a). Global zero carbon steel production needs to grow ten thousand fold over the next two decades (Victor, Geels and Sharpe 2019). Economy-wide decarbonisation needs to happen at a rate only previously seen in the collapse of the Soviet Union. The achievability of all this is increasingly questioned. But plausible grounds for hope lie in the way that tipping points can be activated to propagate rapid change through complex systems (Farmer *et al*. 2019; Otto *et al*. 2020; Lenton 2020).

Upward-scaling tipping cascades

In complex systems such as an ecosystem, a financial system, or the economy, tipping points can occur, when a small perturbation triggers a large response from a system, sending it into a qualitatively different future state (Lenton 2020). Sometimes, the activation of one tipping point can increase the likelihood of triggering another at a larger scale, and then another at a still larger scale. Such upward-scaling tipping cascades can cause rapid change on very large scales (Lenton 2020). The global financial crisis of 2008-9 followed this pattern: home-loan defaults triggered devaluation of collateralized debt obligations, which triggered bank and insurer insolvency, which led to a credit crunch, and wider consequences still felt today.

Equally, several past ‘socio-technical transitions’ started with disruptive technological innovations in niches that cascaded upwards through tipping points to society-wide change (Smith, Stirling and Berkhout 2005). For example, the invention and refinement of the steam engine triggered a massive expansion of coal mining and the creation of a rail transport network, propelling the industrial revolution in England. At the start of the twentieth century, the transition from horse-drawn carriages to fossil-fuelled cars happened in just over a decade in US cities. In fact, each historical transition in primary fuel supply – from wood through coal to oil and gas – was of this type (Smith, Stirling and Berkhout 2005).

Looking ahead, tipping cascades could conceivably be activated to meet climate change goals – which require rapid system transitions in power, transport, buildings, industry and agriculture (Rogelj *et al.* 2018). Whilst many factors – social, cultural, technological, economic and political – can influence a transition, policy can make a critical difference by redirecting support from incumbents to disruptors. From a policymaker’s perspective, an upward-scaling tipping cascade offers the maximum possible ‘bang for your buck’.

To identify the potential to trigger tipping points and cascades within these systems, methods developed for early warning of environmental tipping points could be deployed (Lenton 2020). These hinge on detecting a slowing recovery rate of an incumbent regime to perturbations. Equally, working by analogy should help – noticing where tipping points have been successfully activated, and aiming to replicate this in other sectors and geographies.

The connection of countries by flows of finance, knowledge, technology, trade and transport means the options for global decarbonisation are not limited to unilateral policy and multilateral agreements. Small groups of countries, coordinating their actions, may be able to catalyze change at the global scale (Victor, Geels and Sharpe 2019).

Light road transport

Electric vehicles (EVs) account for around 2-3% of new car sales globally. Growth in this share needs policy support to maintain, because EVs still cost more than conventional cars.

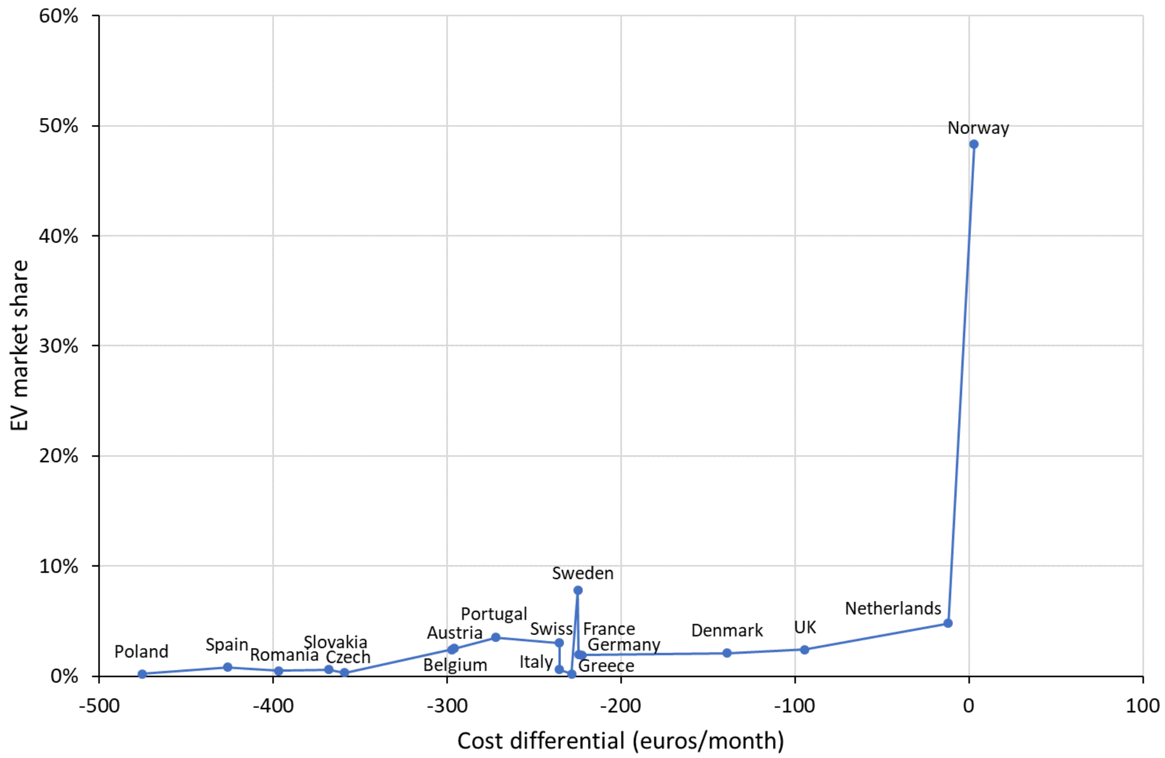


Fig. 1. Electric vehicle (EV) market share in a sample of 18 European countries as a function of cost differential expressed as average of equivalent petrol or diesel vehicle minus EV (monthly cost of ownership in euros).

The share of EVs in new car sales is higher in countries with stronger policies (IEA 2019b). Norway's EV share now stands at over 50%, over ten times higher than almost any other country (IEA 2019b). This is non-linearly related to the ownership cost differential between EVs and conventional vehicles (Fig. 1). Norway has many policies to support EV uptake, but one of them is unique. In the words of its government: "The progressive tax system makes most EV models cheaper to buy compared to a similar petrol model… This is the main reason why the Norwegian EV market is so successful compared to any other country." Norway has activated a tipping point, resulting in a world-leading pace of transition.

A second tipping point will occur when EVs reach cost parity with conventional cars without assistance from tax or subsidy. Beforehand, withdrawal of policy support could still see balancing feedbacks from market competition and incumbent industry power bring back the state of petrol and diesel dominance. Afterwards, policy support will be unnecessary, as the reinforcing feedback of increasing returns to scale will take over – with costs falling as production rises. As EVs become ever cheaper, consumers will increasingly prefer to buy them, manufacturers will prefer to make them, investors will be more willing to invest in charging infrastructure, and even governments that care nothing for climate change will want to support the transition in their own countries.

A small number of countries could accelerate the activation of this global tipping point. Ten countries account for three quarters of global car sales. Just three jurisdictions – the EU, China and California – account for around a half, and their interests are already aligned with the transition. The EU and California aim to achieve net zero economy-wide emissions by 2050 and 2045 respectively, and road transport is one of the easier sectors for early decarbonisation. China wants to reduce its oil imports, improve its air quality, and strengthen its competitiveness in auto manufacturing (much more achievable in the context of a transition to EVs).

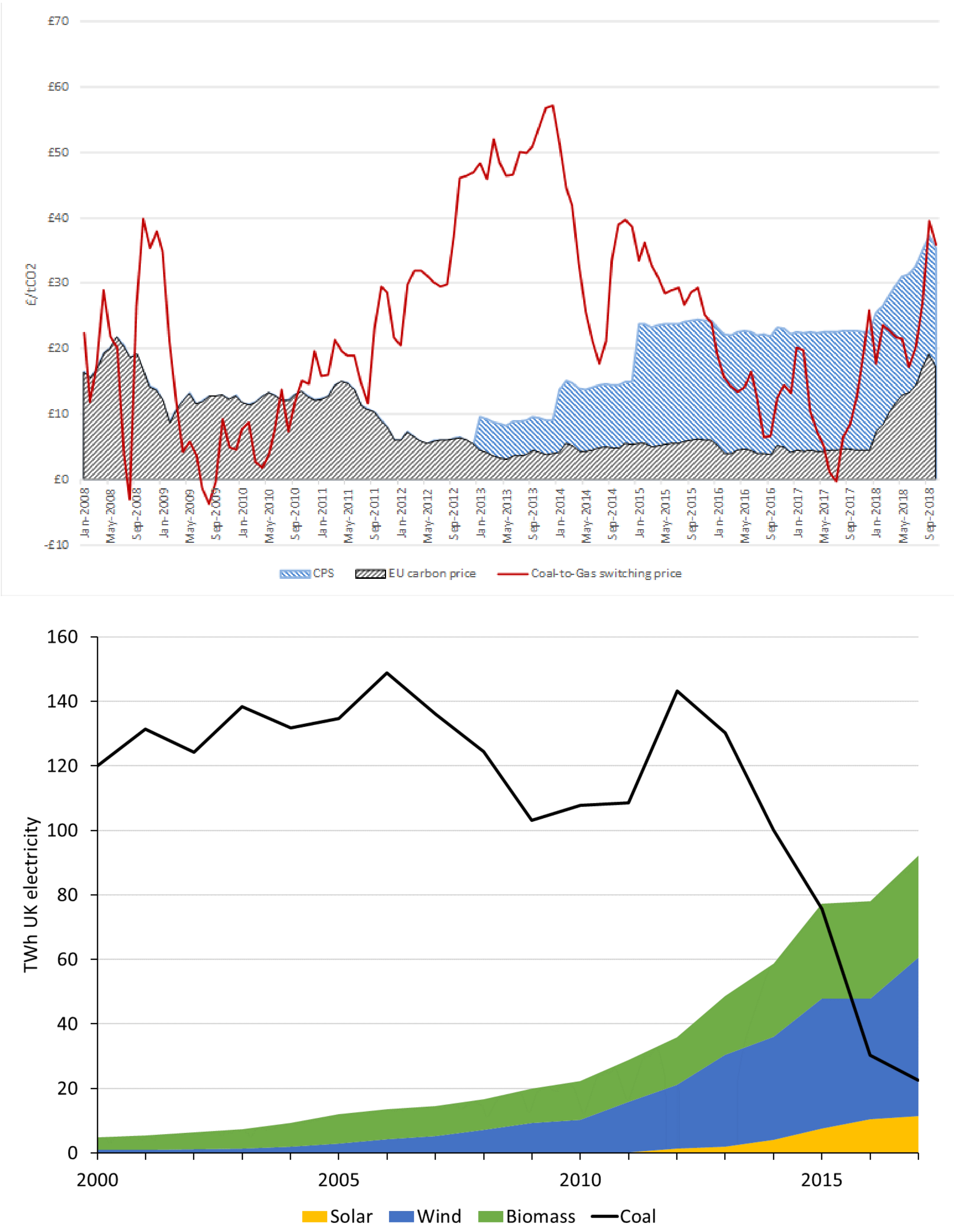
These actors are deterred by the cost differential that remains between EVs and conventional cars. But acting together, they could be confident that their combined policy signals would rapidly shift investment throughout the global industry, accelerating the increase in EV production and the decrease in EV costs. By bringing forward the cost-parity tipping point, this could trigger a spatial cascade of tipping points in consumer behavior through the global network of national car markets, replicating on a global scale what we now see happening in Norway.

This positive-sum cooperation could in turn increase the chances of crossing other important tipping points. First, the massive scaling up of batteries and electric drivetrain technology within the automotive sector would bring down the costs of zero emission trucks. Second, a rapid transition in road transport would deprive oil companies of their largest market, strongly incentivizing diversification of investment, potentially into hydrogen or synthetic fuel production - critical for the decarbonisation of industry, aviation and shipping. Third, accelerated growth of battery production and reduction in battery cost would make cheaper energy storage available for the power sector, supporting cost-effective integration of renewable power into electricity systems. This could help to tip the power sector – where emissions are still growing – into an irreversible transition.

Power

Over recent years, the UK has decarbonised its power sector faster than any other large country (Staffell *et al.* 2018). Tipping points have played a role in this performance.

a



b

Fig. 2. Tipping point for coal in UK power generation. a. Coal-to-gas switching price (at which they are equally profitable) in the UK 2008-2018 (red; £ tCO_2^{-1}; see Supplementary Information) compared to the UK's carbon price; the EU Emissions Trading Scheme price (grey) plus the UK Carbon Price Support (CPS) tax (blue). Data from ICIS, Intercontinental Exchange and Bloomberg. Chart created by Philippe Guiblin. **b.** UK electricity generation (TWh) from coal and renewables 2000-2017.

Between late 2015 and 2018, the UK's carbon price – a combination of a fixed tax (of £9/tCO_2 from April 2013, and £18/tCO_2 since April 2015) and the price generated by the EU Emissions Trading Scheme – exceeded the coal-to-gas switching price, making gas cheaper than coal (Fig. 2a). This tipped the system, reversing the position of these two fuels in the merit order – by which different technologies are called on to meet demand for electricity. This substantially decreased the number of hours coal plants could generate electricity – and revenue.

Even before this tipping point was crossed, coal use had been falling as renewables, air quality regulations and carbon pricing cut its market share and profitability. These factors combined with crossing the coal-to-gas tipping point to push the system past a second tipping point: that of coal plant profitability. As the utility analyst Peter Atherton commented in April 2016: "The economics of coal have deteriorated dramatically over the last 18 months… the increase in the carbon tax… flipped the economics over from barely profitable to loss-making." The fall in coal power generation accelerated after 2015, as the tipping into unprofitability hastened the closure of coal plants – an irreversible change, since it involved the demolition of physical assets.

Crossing these two tipping points at the national level resulted in a ~75% reduction in coal use over ~5 years (Fig. 2b). Arguably this gave the UK government the confidence to launch a global campaign in 2017 to phase out unabated coal from the power sector – the Powering Past Coal Alliance (PPCA). Now with nearly a hundred members committed to this goal, covering more than a third of coal capacity in the OECD, the PPCA can reasonably claim to be influencing investor and policymaker expectations about the global future of coal power.

Solar and wind can already generate electricity more cheaply than fossil fuels, but their high financing costs are a barrier to investment in many countries. If the PPCA's strengthening of negative investor expectations contributes to increasing the cost of capital for new coal plants, then it could help trigger a third tipping point in power systems around the world: the point at which in each market, the cost of capital for new renewable generation dips below that of coal.

Positive-sum cooperation between small groups of countries could bring this tipping point closer. China, Japan and South Korea together provide much of the international financing for new coal power plants (Urgewald 2019). Each has industrial interests for doing so, conflicting with their interest in climate stability. If one were to stop, they risk the other two stepping in to take the market. An agreement between the three to stop financing new coal could overcome this disincentive, and significantly raise the cost of coal capital globally.

Policy reforms and concessional lending can quickly reduce the cost of capital for renewables. If donor countries and multilateral development banks come together to offer low cost finance and technical assistance, and if recipient countries implement the market reforms necessary for renewables to compete effectively within their power systems, the cost of capital of renewables could be brought below that of coal in all of the countries that are currently planning to build new coal plants (Global Energy Monitor 2020).

This would be likely to accelerate the trend of cancellations of planned new coal plants. If current plans to build a further 500 GW of coal power capacity – on top of the 2000 GW in operation – were to be replaced with plans for more renewables, global power sector emissions would finally begin to go down instead of up. And a decarbonising global power system would expand the options for decarbonisation of large parts of transport, heating and cooling, and industry (Energy Transitions Commission 2017).

A different principle for policy

Our two examples show that tax and subsidy policies that bring clean technologies below the threshold of cost-parity with fossil fuel technologies can lead to disproportionately rapid decarbonisation, when applied in a context of other supporting policies. Although this may seem obvious, it is not yet a widely taken approach: our two examples have both led to world-leading rates of decarbonisation within their sectors.

If carbon prices are set equal to some estimated 'social cost of carbon', based on the concept of 'pricing the externality' of dangerous climate change, these opportunities could easily be missed. The finding and activation of decarbonisation tipping points offers an alternative guiding principle for policy.

Similarly, the opportunity to activate upward-scaling tipping cascades will be missed if the value of decarbonisation policies is judged only on their immediate effects. Marginal abatement costs curves can be used to rank policies according to the cost per tonne of emissions reduction directly achieved. However, this calculation reflects neither the potential for clean technology costs to come down through learning and economies of scale, nor the possibility of influencing wider changes in the same or other sectors. The aim of activating tipping cascades can serve as a different starting point for policy, and for diplomacy.

A tipping point in cooperation

The positive tipping cascades that we have described are by no means inevitable. Many barriers to transition exist, which will need many policies to overcome. But our examples do suggest a plausible route through which a relatively small number of initial actions could catalyze large changes at the global scale.

We offer these two examples to illustrate the logic of tipping cascades, and to encourage potential partners to join together in doing the tipping. The UK government is actively working to catalyze these processes of change in its role as Presidency of the UN COP26 climate change talks (Sharma 2020).

If either of these efforts – in power or road transport – succeed, the most important effect could be to tip perceptions of the potential for international cooperation on climate change. Academic literature has often portrayed global emissions reduction as a negative-sum or zero-sum game, assuming that it can only come at a cost. Diplomacy is now largely focused on encouraging countries to strengthen their unilateral commitments (‘Nationally Determined Contributions’). The demonstration of positive-sum cooperation, with a small number of actions leading to large-scale changes in the global economy and emissions, could change this, leading to an increasing focus on the search for similar opportunities in other sectors.

Conclusions

The activation of tipping points can lead to rapid change in the global economy. A more deliberate search for tipping points and tipping cascades could identify opportunities to accelerate decarbonisation, offering plausible grounds for hope that the Paris Agreement goals could still be met. This implies a new and different guiding principle for both policy and diplomacy.

Acknowledgments

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Supplementary information

Data sources

Fig. 1 cost data for electric vehicles sourced from: https://www.leaseplan.com/corporate/~/media/Files/L/Leaseplan/documents/news-articles/2019/press-release-2019-car-cost-index.pdf and market share data from: https://www.statista.com/statistics/625795/eu-electric-vehicle-market-share-by-country/.

Fig. 2a data for power, coal and gas prices from ICIS, available at https://www.icis.com/explore/services/market-intelligence/price-reports/; data for EU ETS price from Intercontinental Exchange, available at https://www.theice.com/market-data and https://www.theice.com/emissions/auctions; data for exchange rates from Bloomberg, available at https://www.bloomberg.com/markets/currencies.

Fig. 2b data for UK electricity generation from BEIS available at: https://ember-climate.org/project/coal-to-clean/.

Calculation of coal-to-gas switching price (Fig. 2a)

Chart created by Philippe Guiblin.

Switching price is the level at which coal and gas are equally profitable within the UK market, based on the UK power price, the ICE Rotterdam coal future price, the UK National Balance Point price for gas, average efficiencies for coal and gas plants, the CO_2 emission intensities of gas and coal (from https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2016), the EU Carbon Emission Allowance (EUA) price, and the UK Carbon Price Support tax (CPS) price.

The switch price is obtained when Clean Dark Spread = Clean Spark Spread

Clean Dark Spread = Power cost – [Fuel cost (coal) + CPS(coal) + EUA(coal)]

Clean Spark Spread = Power cost – [Fuel cost (gas) + CPS(gas) + EUA(gas)]

with prices in £ MWh^{-1}.

At the switch price:

$$\text{Fuel cost (coal)} + \text{CPS(coal)} + \text{EUA(coal)} = \text{Fuel cost (gas)} + \text{CPS(gas)} + \text{EUA(gas)} \quad (1)$$

Assuming:

C = Fuel cost (coal) in £ MWh^{-1}

G = Fuel cost (gas) in £ MWh^{-1}

P_{CO2} = Total price of CO_2 (EUA + CPS) in £ tCO_2^{-1}

I_{gas} = emission intensity (gas) = 0.194 tCO_2 MWh^{-1}

I_{coal} = emission intensity (coal) = 0.307 tCO_2 MWh^{-1}

E_{gas} = efficiency for gas (49.13%)

E_{coal} = net efficiency for coal (34%)

Then (1) becomes:

$$C + P_{CO2}(I_{coal}/E_{coal}) = G + P_{CO2}(I_{gas}/E_{gas}) \quad (2)$$

Rearranging (2):

$$P_{CO2} = (G - C) / [(I_{coal}/E_{coal}) - (I_{gas}/E_{gas})] \quad (3)$$

Daily price data were averaged per month for plotting in Fig. 2a.

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