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DOI: 10.14324/111.444/000184.v1
Preprint first posted online: 31 October 2022
Keywords: carbon, climate change, carbon price, net zero, engineering, loss and damage, The Environment, Climate, Sustainable development, Built environment

A virtual global carbon price enabling engineers to drive essential and rapid decarbonization

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Abstract

Climate change is now an infrastructure challenge. Within the next 30 years our energy generation must switch from fossil fuels to renewables. New buildings need to be zero-carbon and existing buildings need to retrofitted. Our global transportation network will need to be transformed. Delivering the Net Zero world is an engineering challenge (Clarke and Maslin, 2022). But to do this we need a globally agreed virtual carbon price so that every single infrastructure project can be assessed in terms of its impact on carbon emissions and thus planetary health. We propose a loss and damage-based carbon price that is enhanced (or reduced) by variable, national impact factors. Carbon intensity weighting would further increase the price's impact.

Introduction

The behaviors of engineers are triangulated by the needs of their employer, their education, training, experience, character, and the guidance and rules of their professional bodies. While some employers are far-sighted and wholistic, many are not. So, it is incumbent on the professional bodies to be the guardians of public wellbeing, safety and the environment (Martin, 2021).

Much has been achieved. Safety engineering has become a discipline in itself. Energy efficiency, resource utilization, local pollution abatement and cost reductions have enabled mass access to transport, technology, and cheap food. But this has been done at the expense of the global environment. A more holistic approach to ‘safety’ is required to deal with global issues such as greenhouse gas emissions and plastic pollution. Total lifecycle thinking must become the norm for all engineers and project developers.

For example, if a power plant were to be built today, and Net Zero 2050 is the target, then it would, in theory, need to emit less than half as much CO_2 as a plant commissioned 40 years ago. And, if that cannot be done, or is uneconomic, then the engineering bodies should have the authority to prohibit such a project anywhere across the globe and propose alternatives which are in keeping with the principles of planetary health. If the forces of insurance, the law and international treaties are combined, the engineers will be clear to act on producing sustainable energy, products, and food without hinderance.

Data

The underlying data behind Figure 1 comes from World Urbanization Prospects (WUP, United Nations, New York), NOAA annual temperature anomalies, historical / projected temperature anomaly trends by country (NASA-GISS) and Munich Re (disaster and catastrophe frequencies and losses, by location and peril, 1980-2018).

The data behind Figure 2 includes population, GDP per capita and granular emissions data by territory; these has been compiled and curated by Our World in Data (OWiD, Oxford). The diagram uses, where available, the cumulative consumption emissions from 1750-2017; the consumption emissions of nations include emissions associated with imported goods and services. Bubble colors reflect the changes from 2016-17.

Methods

Carbon Intensity Weighting

A particular problem in carbon pricing is that a one-size-fits-all carbon price is a blunt instrument for encouraging behavioural change. A spectrum of prices based on impact (carbon intensity) would be more effective as well as future-proof (Clarke, 2016). For a carbon price to be credible it has to provide a sustained signal of significant magnitude, one that is both verifiable and to some extent predictable. This, we believe, is where the SIMPLE-1Y x $\mathbf{W}_{eff}$ loss-and-damage-based carbon price (Figure 1) has an advantage.

Two things then become apparent. Firstly, to incentivise the movement from 'dirty' carbon-intensive fuels to 'clean' low-carbon fuels or energy, there may need to be an even stronger price signal, whatever the base price. Secondly, to ensure continuing best practice it will be necessary, from the very start, to link the carbon prices to all energy types and not just fossil fuels.

For every fuel or energy source there is a ratio **e**, the amount of CO_2 emitted divided by the useful energy the source produces. This is called 'carbon intensity'. For coal, **e** is about 1 tonne / MWh; for gas it is about 0.46 tonne / MWh but even with renewable energy and nuclear sources there is a hidden **e** of between 0.01 – 0.05 tonne / MWh due to their materials of construction. We use this information to create a Carbon Intensity Weighting factor **CIW**.

By using the CIW method, the carbon price $\mathbf{y}_i$ for fuel/energy type i is given by:

$$\mathbf{y}_i = \mathbf{y} \times \mathbf{CIW} = \mathbf{y} \times \mathbf{e}_i \times \mathbf{z} \times \mathbf{f}$$

The carbon intensity weighting factor **f** is defined as:

$$\mathbf{f} = \Sigma\, \mathbf{E}_i / \Sigma\, (\mathbf{E}_i \times \mathbf{e}_i)$$

A “revenue weighting” factor **z** is defined as the weighting needed to ensure that the total premium from individual fuel prices $\mathbf{y}_i$ is consistent with premium using a global, unadjusted carbon price **y**.

$$\mathbf{z} = (\Sigma(\mathbf{E}_i \times \mathbf{e}_i))^2 \ / \ (\Sigma\mathbf{E}_i \times \Sigma(\mathbf{E}_i \times \mathbf{e}_i^2))$$

where:

$\mathbf{E}_i$ = amount of fuel type i used globally (or by country or sector or, perhaps, by company) (GWh)

$\mathbf{e}_i$ = emission factor for fuel type i (tonne CO_2/GWh)

$\mathbf{y}_i$ = carbon price for a given fuel type i (US$/tonne CO_2)

y = global carbon price (US$/tonne CO_2) e.g. **y** = SIMPLE-1Y x $\mathbf{W}_{eff}$

Carbon Pricing for Engineers

An alternative approach is to address the loss and damage caused by CO_2 specifically. We argue there needs to be an internationally agreed, virtual carbon pricing system that can readily be used by engineers to estimate the economic impact of each tonne of CO_2 or any other GHG emitted (Figure 1). Those costs should be included in the economic assessment of every project (Kennelly et al., 2021). When and where a project takes place are significant factors.

Carbon markets are unpredictable, and other carbon pricing tools are complex to use or they are encumbered by social discounting considerations (Pindyck, 2019). An engineer needs an equation. We propose that a loss and damage-based carbon price is used in all projects where carbon or GHG emissions occur. This would include direct and embodied emissions e.g. steel or concrete.

In Figure 1 the base carbon price (blue line) represents the ‘spot’ carbon price that would compensate for the cumulative, climate attributable economic impact (**G**.***x***) of CO_2 emissions (**C**).

G is the economic damage from acute physical risks (extreme weather) and ***x*** is the extent to which those losses are climate attributable. Future emissions are those consistent with COP26 Glasgow Nationally Determined Contributions (NDC) or 'pledges' that could limit warming to 2°C. This base price is then factored by a time-varying, country weighting factor ($\mathbf{W}_{eff}$, see Figure 2) as the historic emissions and their associated economic development should be considered, to address the need for climate justice. Additionally, a Carbon Intensity Weighting (**CIW**) term can be included to particularly highlight high carbon intensity emissions (Methods). Thus,

Carbon Price = SIMPLE-1Y (dashed blue line) x $\mathbf{W}_{eff}$ x **CIW**

As an example, coal emissions in Luxembourg in 2030 would attract a carbon price of over \$100/tonne CO_2 = \$10 x 6 x 1.67. The **CIW** term depends on the future energy mix and scope. This price is in line with the proposals of the Carbon Pricing Leadership Coalition's High-Level Commission. The base price would be higher still if the economic impacts of increasing, slow onset physical risks are considered (Callaghan and Mankin, 2022).

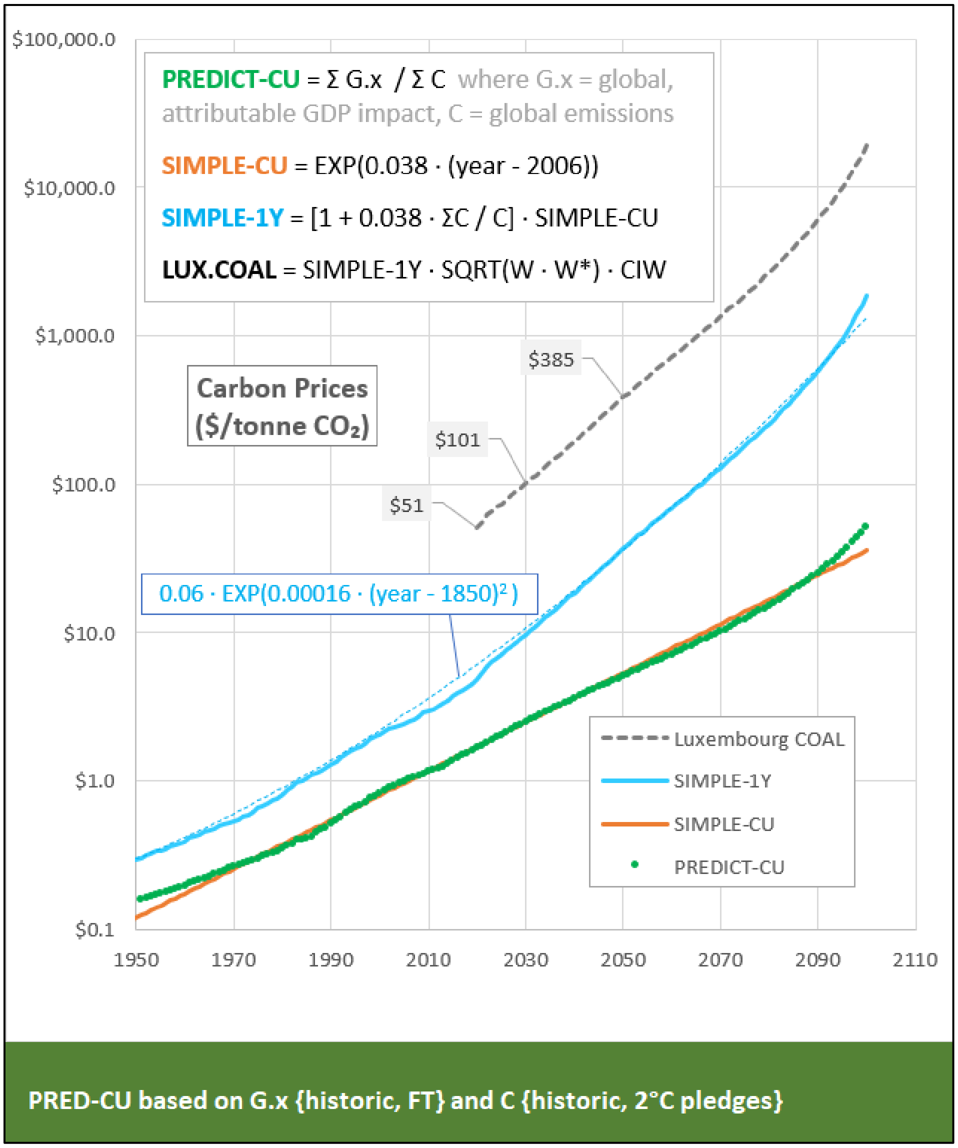

Figure 1: (caption) The cumulative (CU) economic cost of carbon emissions has escalated since the 1950's (green/orange line) and continued 'business as usual' (FT) emissions are expected to lead to catastrophic losses. The one-year (1Y) price of carbon (blue line) captures the modelled, 154 countries weighted, global average Physical Risk (Extreme Weather) historical and future costs using the Ortec Finance PREDICT tool.

Prioritizing infrastructure changes in the Developed World first

The engineering challenge of Net Zero (IPCC, 2018) is even harder when it is realized that not even the richest countries have truly started to decouple their energy use from emissions (IPCC, 2022). The terms carbon inheritance and carbon liability convey the immutable relationship between economic wealth (GDP/capita) and energy (kWh/GDP) see Webster and Clarke (2017).

We define carbon inheritance (**W**) as the wealth that nations have attained by using fossil fuels since the beginning of the Industrial Revolution or as data permits. More specifically, this inheritance relates to work and energy but, in practice, nearly all that energy has come from fossil energy. **W** is expressed as the ratio of $(\text{GDP/capita})_{\text{country}}$ / $(\text{GDP/capita})_{\text{world}}$, so the exact definition of GDP is immaterial.

The second term, carbon liability (**W***), we define as the cumulative carbon emissions **D** of a country divided by its current population ($\mathbf{D}_c/\mathbf{P}_c$). That ratio is then scaled by the world's cumulative emissions and population to obtain $\mathbf{W}^*$. We argue that the current populations represent the net outcome of all the progress, toil, conflict, health and other factors that have led to the emissions and wealth of a country today.

Overall, we find there is a direct relationship between cumulative wealth and cumulative emissions, as shown in Figure 2. For each country, the emissions and wealth have been normalised using the global average values. The size of the bubbles is proportional to the current population of each nation. On the log-log plot there is roughly a 1:1 relationship between scaled emissions and scaled GDP, with a few outliers.

There is a huge difference between the DR Congo and the United States, over two orders of magnitude in fact. The relationship is strongest if consumption, rather than domestic-only emissions are included (Data). The diagram makes a compelling case for action by the industrialized, first-tier economies. When their populations are factored-in, the batting order becomes United States, China, Japan, Germany, United Kingdom. Whatever else they do, these countries need to fully commit to Net Zero, and allow engineers to lead the infrastructure revolution, to enable the energy transition. The benefits to these countries and all the others would be transformational. To take a specific example, the United Kingdom is blessed with copious quantities of offshore and onshore wind and yet the UK Government has recently committed to yet more North Sea oil production and that may not pass the Net Zero tests, as determined by the UK Government's own Committee on Climate Change (CCC, 2022). Rather, the UK should lead on the seasonal energy storage technologies that are needed to make a renewables-dominated grid dependable. Moreover, there are too many instances in which the

UK Government is being taken to court due to non-compliance with legislation it previously enacted e.g. meeting its 2030 targets or poor home insulation uptake. Currently, the developing economies and India, in particular, look to the UK for leadership as one of the founders of the industrial age.

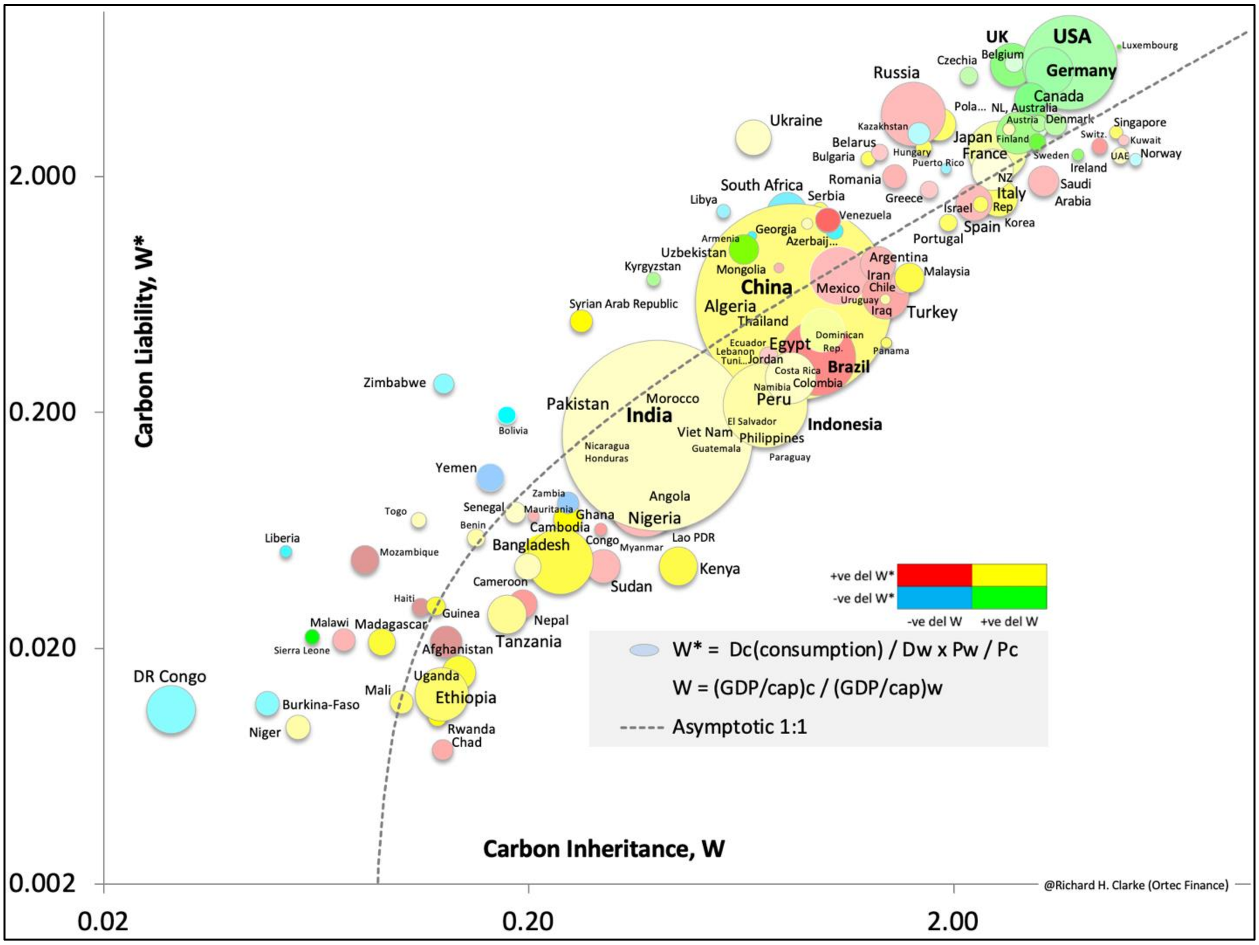

Figure 2: (caption) GDP-emissions plot: ($\mathbf{P}_w$/$\mathbf{P}_c$ x $\mathbf{D}c$/$\mathbf{D}_w$) v. $(GDP/cap)_c$ / $(GDP/cap)_w$ at time t, where $\mathbf{P}_w$ = world population, $\mathbf{P}_c$ = country population, $\mathbf{D}_c$ = country (domestic or consumption) cumulative emissions, $\mathbf{D}_w$ = world cumulative emissions. The effective country weighting, $\mathbf{W}_{eff}$ is $(\mathbf{W} \times \mathbf{W^*})^{0.5}$. The bubbles are colored according to the color key e.g if a country's W decreases and W* increase, the bubble will be a shade of red.

The underlying data (see the section above on 'Data') behind Figure 2 includes population, GDP data and all-forms of emissions data and these can be regularly updated. This leads to the possibility that the diagram could be used as a tool for tracking the progress of nations towards Net Zero.

For example, if a bubble moves:

1. Horizontally right – economy is growing faster than global average with low emissions (good, a shade of green).
2. Right and up – that is 'business as usual' growth (must do better, a shade of yellow)
3. Stands still – in line with global average (fair, yellow)
4. Left and down – economy in trouble (blue, action needed)
5. Up and left, pink as per Brazil or red as per Venezuela (deep trouble, emigration, and possible collapse)
6. Right and down – has Sweden started transitioning as its population grows? (good, a deeper shade of green)

The need for rapid transition to renewable energy has become central to the discussion of energy security. The Russian invasion of Ukraine has led to huge increase in fossil fuel prices which is affecting everything from industry, agriculture to the cost of living. In terms of infrastructure, a mixed response is emerging: the EU is moving away from Russian gas as quickly as possible, having pledged to double the installation of renewable energy this decade (Chestney and Zinets, 2022); meanwhile, in the US the Biden administration opened the door to selling new oil and gas drilling leases in the Gulf of Mexico and Alaska to help it ensure self-sufficiency in fossil fuels. It has proposed as many as 11 lease sales over the next five years, including 10 in the Gulf of Mexico and one in the Cook Inlet off the Alaskan coast (Newburger, 2022). Drilling, however, off both the Atlantic and Pacific coasts are not included. Meanwhile China, and to a lesser extent India, have leapt at the opportunity to buy cheap Russian oil, due to western sanctions on Russian exports. Imports of Russian oil rose by 55 per cent from a year earlier to a record level in May, displacing Saudi Arabia as China's biggest provider (Reuters, 2022).

Longer term, the invasion of Ukraine has put energy security back on the top of governments' agendas. For countries with no or little access to domestic fossil fuel reserves, renewables are set to become very attractive — they are already cheaper to build and maintain than coal fired power stations (IEA). Hence a diagram such as Figure 2 will enable us to track how countries are doing not only in decarbonization but also how secure their energy will be in the future.

Discussion and Recommendations

As well as an agreed virtual carbon price, professional bodies need to dissuade companies and individuals from the defensive patenting of clean technologies and should instead support licensing agreements to ensure that smart ideas reach the market. This will give a clear signal to incumbents that they need to transition their technologies or move to new markets. As the Carbon Disclosure Project (CDP, 2022), highlights; it is policy and attitude as well as low emissions that makes for a clean, Net Zero-aligned corporation. On every board and division, there needs to be an executive level officer who is responsible for transition compliance and lifecycle engineering.

So, to empower engineers and to kick-start the Net Zero revolution in the Developed Markets followed by the rapidly Emerging Markets we call for four actions:

1) Engineering professional bodies across the world need to support engineers so they are empowered to do the job they need to do, to enable economies to decarbonize their energy, infrastructure, manufacturing, and food industries.

2) Every company needs a Net Zero Transition Compliance Officer who alongside the Safety Compliance officer ensures every project and decision helps develop the green, low carbon economy.

3) Develop the carbon inheritance / carbon liability diagram (Figure 2) to monitor the movements of countries to determine if and to what extent they are on track during the Energy Transition. Ideally, the clock rate on this should be much less than one year.

4) Establish a usable yet meaningful globally agreed virtual carbon price, together with carbon auditing tools (Flannery, 2022) so that engineers and other actors can include the cost of emitting each tonne of CO_2 in determining the economic feasibility of projects. A method is suggested above but, ideally, all engineers in the world need to be using the same tool to check that every infrastructure project complies with the Paris Agreement decarbonization pathway.

A huge side benefit of all this will be to draw the world's exceptionally talented individuals into the engineering profession, to work on wholistic solutions to today's and tomorrow's needs.

Conflicts of interest

The authors declare no conflicts of interest in connection with this article

References

Callahan, C.W., Mankin, J.S. National attribution of historical climate damages. Climatic Change 172, 40 (2022).

CCC (2022) https://www.theccc.org.uk/publication/letter-climate-compatibility-of-new-oil-and-gas-fields/

CDP (Carbon Disclosure Project) (2022) https:// www.cdp.net/en (accessed 12/09/2022).

Chestney, N. and N. Zinets Russia resumes some gas flows to Germany as its forces home in on power plant in Ukraine https://www.euronews.com/2022/07/22/us-ukraine-crisis

Clarke, R.H. Carbon Intensity Weighting (Chapter 10) *in* Predicting the Price of Carbon Predict Ability Limited (PAL) (2016)

Clarke, R.H. and M.A. Maslin Civil engineers need to promise not to cause harm to the environment. Civil Engineering Volume 175 Issue 4 November 2022 https://doi.org/10.1680/jcien.2022.175.4.150

Engineering Council (2014) https://www.engc.org.uk/engcdocuments/internet/Website/UK-SPEC%20third%20edition%20(1).pdf

Flannery, B. The Greenhouse Gas Index: A Metric for Greenhouse Gas–Intensive Products Resources for the Future (2022) https://www.resources.org/common-resources/the-greenhouse-gas-index-a-metric-for-greenhouse-gasintensive-products/

IPCC, 2022*: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926

IEA (2020), Projected Costs of Generating Electricity 2020, IEA, Paris https://www.iea.org/reports/projected-costs-of-generating-electricity-2020

Kennelly, C., M. Berners-Lee, C.N. Hewitt. Hybrid life-cycle assessment for robust, best-practice carbon accounting. Journal of Cleaner Production, 208, 35-43 (2019)

Martin, V. (2021) It is time for civil engineers to have the difficult conversations to turn climate talk into climate action https://www.ice.org.uk/news-and-insight/latest-ice-news/state-of-the-nation-2021-how-enable-low-carbon

Newburger, E., Biden opens the possibility of more offshore oil drilling in the Gulf of Mexico https://www.cnbc.com/2022/07/01/biden-interior-dept-offers-option-for-new-oil-leases-in-gulf-of-mexico.html

Pindyck, R.S. The social cost of carbon revisited. Journal of Environmental Economics and Management, 94, 140-160 (2019)

Reuters. Russian oil supplies to China up 22% on year, close second to Saudi https://www.reuters.com/business/energy/russian-oil-supplies-china-up-22-year-close-second-saudi-data-2022-10-24

Webster, A., Clarke, R. Insurance companies should collect a carbon levy. *Nature* 549, 152–154 (2017). https://doi.org/10.1038/549152a