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LETTER

Potential impacts of rapidly changing european use of fossil fuels on global warming

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Abstract

The balance of primary energy sources for Europe has been changing rapidly over recent decades, shifting towards more renewables and using fossil fuels with lower carbon emissions. However, the latter is being impacted by the Russia-Ukraine conflict. Here, we determine the potential bounds of how this may affect global warming, based on whether the European use of Russian gas and oil is replaced with either less efficient burning of coal (with and without the gas and oil then used in new markets elsewhere) or with renewables. We perform calculations as perturbations from a baseline carbon dioxide (CO_2) trajectory associated with 'middle range' and 'low' Shared Socioeconomic Pathways (SSP), SSP2-45 and SSP1-26. We calculate the CO_2 perturbations as a simulated step change in emissions for the year 2023, which then decays linearly to zero by 2043. The emission profiles drive the FaIR simple climate model. FaIR links greenhouse gas emissions to global warming levels and includes a representation of warming uncertainty based on projections made using more complex Earth system models. We find that the direct impact of the conflict on the global mean temperature is likely to be relatively small, amounting to the worst case of nearly one-hundredth of a degree. This warming is equivalent to approximately an extra half year of current global CO_2 emissions. However, we suggest that it is important to consider the implications of the precedents set by the European response to the reduced availability of Russian gas and oil. Such action may reveal the potential for faster uptake of low-carbon energy sources or the converse of backtracking on current Nationally Determined Contributions (NDCs).

Introduction

The current Russia-Ukraine conflict has caused much debate regarding European energy security. Europe is currently heavily dependent on gas and oil exported from Russia (Tollefson 2022). For a range of policy reasons by either Europe or Russia, such exports may decline dramatically (a possibility already suggested, pre-conflict; United Nations Chronicle 2015) and the replacement energy provision may differ substantially. Related to such changes is the question of how much they might affect global warming. For instance, gas is relatively efficient in terms of CO_2 emitted per unit of energy created, and its replacement with less efficient coal sourced in Europe could increase emissions. Alternatively, a rapid move to renewables would substantially lower emissions by Europe. The potentially worst-case scenario, in terms of CO_2 emissions, would be for Europe to transition to more 'dirty' fossil fuels, while simultaneously, Russian gas and oil that would otherwise be exported to Europe are instead used in new markets. Other researchers have considered scenarios to assess the regional economic impacts of the energy disruption caused by the Russian-Ukraine conflict (Creutzig 2022, Halser and Paraschiv 2022, Liu *et al* 2023). For example, Liu *et al* (2023) conduct simulations to focus on the economic implications of possible responses to such energy disruptions and find that most affected regions show losses in

Gross Domestic Product (GDP) in the near future. Here, however, we consider different scenarios of energy disruption using a 'top-down' approach and instead focus on the climate outcomes. Our analysis aims to account for the uncertainty in the climate system.

Earth System Models (ESMs) provide a simulation framework to map between emissions of Greenhouse Gases (GHGs) and changes in local or regional climates. Outputs from ESMs built by climate modelling centers worldwide are placed in common databases such as the recent Coupled Model Intercomparison Project Phase 6 (CMIP6) ensemble (Eyring *et al* 2016). While ESMs represent remarkable achievements in simulating the climate system, their projections contain differences, representing uncertainty in our current understanding of the Earth system and how we model it. Furthermore, while ESMs provide high levels of geographical information, this is associated with models that require huge computational availability that can preclude their operation for a broad range of novel or test emission scenarios. Instead, simple climate models (e.g. Nicholls *et al* 2021) map global total emissions to a single spatially averaged metric of global warming. Such models are calibrated against ESMs to capture many of their differences. Additionally, by definition, simple models are fast to operate, allowing straightforward extrapolation to determine the effects of a broader range of alternative future emission scenarios. An example of a simple climate model is the Finite Amplitude Impulse Response (FaIR) simulation framework (Smith *et al* 2018).

Methods

Here, we develop a set of perturbations to the emission trajectories associated with the SSP1-26 and SSP2-45 scenarios (defined by O'Neill *et al* 2016 and modelled by Nicholls *et al* 2020). Specifically, we aim to capture the outer bounds of the potential effects of changes in the Russian supply of gas and oil to Europe. We use these new emission pathways to drive the FaIR model and provide an alternative distribution of potential global temperature outcomes compared to any baseline assumptions. FaIR generates a spread of projected global temperature changes based on calibration against multiple ESMs. Our main baseline scenario of interest is SSP2-45, chosen to represent the current view that contemporary policies aim for a substantially reduced peak in 21st Century global warming compared to scenarios where emissions continue to grow rapidly, such as SSP5-85. SSP2-45 provides a median warming by the year 2100 across scenarios, in line with many estimates of current policies (ref AR6 WG3), although it corresponds to only a small chance of limiting warming to below 1.5 °C or even 2.0 °C. We also consider the SSP1-26 scenario, which has rapid and sustained reductions in future global greenhouse gas emissions and a much greater chance of limiting warming to at least below 2.0 °C in 2100. We chose a twenty-year time frame to represent the disruption to the European oil and gas markets resulting from the Russia-Ukraine conflict. The twenty-year period is a subsequent timescale of response to the sudden potential changes to energy use triggered by the conflict, not an estimate that the conflict will last for that length of time. Instead, this timeframe may represent more planned changes to structures for energy provision and in response to the conflict. We assume that post-disruption, Europe will continue efforts to reduce its reliance on fossil fuels, following an originally planned future emissions pathway which may include, for example, a commitment to achieve 'Net Zero'. As such, in this idealised numerical study, we regard the year 2023 as when the conflict has a maximal impact on CO_2 emission changes, with the effects declining linearly until 2043.

Currently, Europe uses approximately 160 bcm (billion cubic metres) of Russian gas per year (IEA 2022a; value inferred from the year 2021 histogram column in the report and as shown in the first figure). When burned, gas releases 0.055 kg CO_2 per cubic foot (EPA 2022a - in subsection 'Home energy use'), that is 1.944 kg CO_2 m^{-3}. Hence, the current Russian gas exports to Europe cause annual emissions of $E_G = 0.311$ Gt CO_2 yr^{-1}.

We consider how these emissions would change if instead coal was burned to produce equivalent levels of thermal energy. Using representative values from the US inventory of energy (EPA 2022b: table A-13 p A68; Row 'Total Coal' Columns 4 & 11) and using their units, presented are typical values that show that in the year 2017, 614.1 Trillion British thermal units (TBtu) were generated by burning coal in the USA, releasing 58.7 Million Metric tons (MMt) of CO_2. For burning natural gas, 8872.4 TBtu of energy was released, generating 469.5 MMt of CO_2 (EPA 2022b: Row 'Natural Gas', table A-13 p A68; Columns 4 & 11). These four numbers allow the calculation of the inefficiency of burning coal compared to gas, expressed by a non-dimensional ratio of the value of (MMt CO_2 release/TBtu energy) for coal divided by the same quantity for gas. Therefore this statistic is $(58.7/614.1)/(469.5/8872.4) = 1.807$, and where the value greater than unity implies less efficiency with coal with respect to emitting CO_2. Hence, if all of the current Russian gas exported to Europe was replaced with coal to produce the same amount of thermal energy, this would cause an additional release to the atmosphere of $E_{G\text{-}C} = 0.806 \times 0.311 = 0.25$ Gt CO_2 yr^{-1}. We also present in equation form, in table 1, these derivations of values for $E_{G\text{-}C}$ (and similarly for quantity $E_{O\text{-}C}$ defined below).

A similar derivation can determine the impact on emissions of replacing oil with coal. For the Organisation for Economic Co-operation and Development (OECD) definition of Europe, those locations currently use 4492

Table 1. Derivation of the additional CO_2 emissions if the European use of Russian gas is replaced with coal ($E_{G\text{-}C}$; Step 12) and if Russian oil is replaced with coal ($E_{O\text{-}C}$; Step 21). This table shows in tabular form identical calculations presented in the main text. Related references are also provided in the main text, which also provides values in identical units to those used here.

Step	Calculations from earlier steps	Variable	Units	Value
1		European use of Russian gas	Billion Cubic Metres (BCM yr^{-1})	160
2		CO_2 released from the burning of a unit of gas	kg CO_2 (cubic feet) $^{-1}$	0.055
3	Units change of [**2**] above	CO_2 released from the burning of a unit of gas	kg CO_2 m^{-3}	1.944
4	[1] × [3]	**Total CO_2 released from the use of Russian gas**	Gt CO_2 yr^{-1}	0.311
5		Annual energy generated from burning coal (representative numbers from the US)	Trillion British thermal units (TBtu)	614.1
6		Total CO_2 released through burning coal (representative numbers from the US)	Million metric tonnes (MMt CO_2)	58.7
7	[6]/[5]	**CO_2 released in burning coal per unit of energy created**	MMt CO_2 $(TBtu)^{-1}$	$58.7/614.1 = 0.09559$
8		Annual energy generated from burning gas (representative numbers from the US)	Trillion British thermal units (TBtu)	8872.4
9		Total CO_2 released through burning gas (representative numbers from the US)	Million metric tonnes (MMt CO_2)	469.5
10	[9]/[8]	**CO_2 released in burning gas per unit of energy created**	MMt CO_2 $(TBtu)^{-1}$	$469.5/8872.4 = 0.05291$
11	[7]/[**10**]	Inefficiency ratio of burning coal instead of gas (ratio > unity implies more CO_2 released)	Unitless	$0.09559/0.05291 = 1.807$
12	[4] × ([11]—1)	**Additional CO_2 released through burning coal instead of Russian gas for the same energy. This is $E_{G\text{-}C}$**	Gt CO_2 yr^{-1}	$0.311 \times (1.807\text{-}1) = 0.25$
13		European use of Russian oil	Barrels day^{-1}	4492.0×10^3
14	Units change of [**13**] above	European use of Russian oil	Barrels yr^{-1}	1.640×10^9
15		CO_2 released from the burning of a barrel of oil	kg CO_2 $(Barrel)^{-1}$	431.87
16	[**14**] × [**15**]	**Total CO_2 released from the use of Russian oil**	Gt CO_2 yr^{-1}	$1.640 \times 431.87 \times 10^{-3} = 0.708$
17		Annual energy generated from burning oil (representative numbers from the US)	Trillion British thermal units (TBtu)	3512.7
18		Total CO_2 released through burning oil (representative numbers from the US)	Million metric tonnes (MMt CO_2)	261.9
19	[**18/17**]	**CO_2 released in burning oil per unit of energy created**	MMt CO_2 $(TBtu)^{-1}$	$261.9/3512.7 = 0.07456$
20	[7]/[**19**]	Inefficiency ratio of burning coal instead of oil (ratio > unity implies more CO_2 released)	Unitless	$0.09559/0.07456 = 1.282$
21	[16] × ([20]—1)	**Additional CO_2 released through burning coal instead of Russian gas for the same energy. This is $E_{O\text{-}C}$**	Gt CO_2 yr^{-1}	$0.708 \times (1.282\text{-}1) = 0.20$

Table 2. Summary of the four scenarios simulated to determine the potential impacts on CO_2 emissions due to the Russia-Ukraine conflict. Column one is the scenario name used throughout the text, column two is a brief title for each scenario, and column three provides more details of assumptions. Finally, column four presents each scenario in equation format.

Run Name (SSP is the baseline and either SSP1-26 or SSP2-45)	Summary name	Emission pathway details	Emissions equation
SSP	No Change	This pathway assumes the Russia-Ukraine conflict has no impact on global CO_2 emissions. Therefore, this baseline scenario corresponds to either the SSP2-45 or SSP1-26 scenario (O'Neill *et al* 2016, Nicholls *et al* 2020).	$E = E_B$
SSP.EUcoal	Replacement with coal in Europe	This pathway assumes that all Russian gas and oil exports are replaced by coal for identical energy creation in Europe. Expressed with an initial perturbation from the baseline scenario that starts in 2023, subsiding linearly to zero by 2043. The Russian gas and oil that would have been exported remain unused (so E_G and E_O are zero).	$E = E_B + E_{G\text{-}C} + E_{O\text{-}C}$
SSP.EUcoal.NewRU'	Replacement with coal in Europe plus new Russian markets	This pathway assumes that all Russian gas and oil exports are replaced by coal for identical energy provision in Europe. Additionally, new markets are found elsewhere from Europe for the Russian gas and oil that would otherwise have been burnt in Europe. Expressed with an initial perturbation from the baseline scenario that starts in 2023, subsiding linearly to zero by 2043.	$E = E_B + E_{G\text{-}C} + E_{O\text{-}C} + E_G + E_O$
SSP.EUren	Replacement with non-fossil fuels in Europe and no new markets	This pathway assumes that all Russian exports of gas and oil to the EU are replaced by non-fossil fuel sources across Europe. Expressed with an initial perturbation from the baseline scenario that starts in 2023, subsiding linearly to zero by 2043 in the baseline pathway. Furthermore, no new markets are found for the Russian gas and oil that would otherwise have been burnt in Europe.	$E = E_B - E_G - E_O$

thousand barrels of Russian oil per day (IEA 2022b; table entitled 'OECD oil imports, column of total and from Russia, November 2021' last row labelled 'OECD Europe'), that is 1.640×10^9 barrels per year. Using the reference EPA (2022a), the 'Home energy use' section states that burning a standard 42-gallon barrel of oil releases 431.87 kg CO_2. Hence, the European burning of Russian oil corresponds to $E_O = 1.640 \times 431.87 \times 10^9$ kg CO_2 $yr^{-1} = 0.708$ Gt CO_2 yr^{-1}.

We can again calculate an efficiency factor (EPA 2022b: Row 'Total Petroleum' Table A-13 p A68; Columns 4 and 11). For oil and using figures for the US, 3512.7 TBtu of energy is associated with releasing 261.9 MMt CO_2, so the inefficiency ratio is $(58.7/614.1)/(261.9/3512.7) = 1.282$. Hence if coal replaced all current Russian oil exports to Europe, generating the same amount of energy would create an additional release of $E_{O\text{-}C} = 0.282 \times 0.708 = 0.20$ Gt CO_2 yr^{-1} into the atmosphere (see also table 1 for the presentation of calculations lead to this value for $E_{O\text{-}C}$).

We can now derive three idealized perturbations (listed in table 2) to the background SSP-based trajectory of global CO_2 emissions (SSP2-45 or SSP1-26). These new scenarios capture the implications of the aforementioned quantities. Although highly conceptual, we intend such adjustments to provide outer bounds on emissions variation caused by potential changes to the European use of Russian gas and oil. Each CO_2 adjustment assumes a step increase or decrease in emissions for the year 2023, followed by a linear reduction in magnitude to zero over the subsequent 20 years. Hence, by the year 2043, emission profiles will be identical to the background trajectory ($E_B(t)$ (Gt CO_2 yr^{-1}) of SSP2-45 or SSP1-26; figure 1(a)).

Specifically, the four CO_2 emission pathways, $E(t)$ (Gt CO_2 yr^{-1}), consist of a baseline SSP scenario, two perturbed pathways where the use of Russian oil and gas in Europe is replaced with coal use (which we call 'SSP.EUcoal' and 'SSP.EUcoal.NewRU') and a further perturbed pathway where Russian oil and gas use in Europe is replaced by energy production from renewable sources ('SSP.EUren'). The SSP.EUcoal.NewRU scenario also

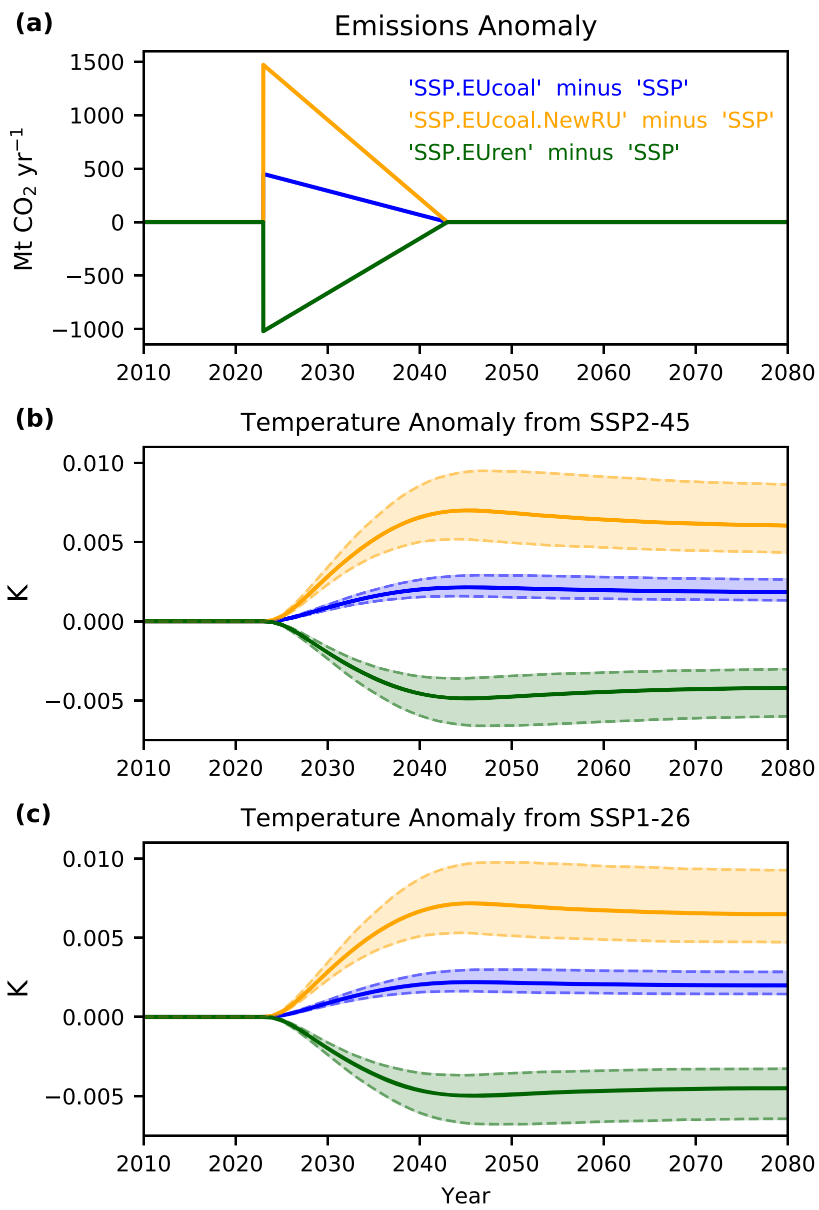

Figure 1. Calculations of change in global temperature corresponding to altered emissions pathways that may occur due to the Russia-Ukraine conflict. Panel (a) shows the change in emissions corresponding to the three scenarios of 'SSP.EUcoal', 'SSP.EUcoal.NewRU' and 'SSP.EUren' (table 2). These changes are relative to any background emissions profile. Panel (b) is the change in global warming for these three scenarios, and relative to temperature change associated with the SSP2-45 'SSP' scenario. Panel (c) is identical to panel (b), except that the background emissions scenario is SSP1-26. The colour legend shown in panel (a) is common to all three panels. In panels (b) and (c), the thick coloured lines are the median 50th percentile calculations of temperature change. The plumes are derived from the 5th and 95th percentile bounds for the baseline SSP temperature calculations.

assumes new non-European markets for Russian oil and gas that would otherwise have been exported to Europe. The renewable capacity in SSP.EUren consists of sources regarded as easy to implement, therefore assuming that these would have been implemented by 2043 anyway. However, this scenario should be regarded as an outer bound, in the event that full and immediate replacement by renewables is not feasible. Also, this assumption fits our modelled relaxation back to the baseline emissions by the year 2043. Table 2 provides more details on these scenarios.

Table 2 provides details for the background SSP scenario ('SSP') and for the three different perturbations (SSP.EUcoal, SSP.EUcoal.NewRU and SSP.EUren). Using the equations presented in table 2 and the values of E_B, $E_{G\text{-}C}$ and $E_{O\text{-}C}$ derived in the text above, the SSP.EUcoal scenario corresponds to additional emissions in the year 2023 of $0.25 + 0.2 = 0.45$ Gt CO_2 yr^{-1}. For the SSP.EUcoal.NewRu scenario, based further on values E_G and E_O, the additional emissions in the year 2023 are $0.25 + 0.2 + 0.311 + 0.708 = 1.47$ Gt CO_2 yr^{-1}. For SSP.EUren, there would instead be a reduction in emissions compared to the baseline, in the year 2023, with a change of $-0.311 - 0.708 = -1.02$ Gt CO_2 yr^{-1}. In all three cases, these values decline yearly to zero over the period 2023–2043 (figure 1(a)). All three emissions perturbations are combined with SSP values (i.e., the baseline following either the SSP2-45 or the SSP1-26 pathway) to drive a simple climate model. The perturbed scenarios are idealized to offer broad order-of-magnitude estimates of the impact on global warming. We do not include changes in other species of greenhouse gases, atmospheric aerosols, or their precursors, whose emissions might also change should the mix of fossil fuel emissions vary. We reiterate that, in the SSP.EUcoal.NewRU scenario, if Russian fossil fuels are used elsewhere, these new non-European markets will cause additional emissions and therefore do not replace emissions from other sources.

We use the FaIRv1.6.2 climate emulator (Smith *et al* 2018) to link the emission scenarios to time-evolving global warming levels. FaIR is an open-source, simple and computationally fast climate emulator of full-complexity ESMs. FaIR is one of the models used in the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (AR6) Working Group WGI and WGIII reports (IPCC 2021, IPCC 2022, Kikstra *et al* 2022). The model consists of a simplified representation of the global carbon cycle coupled with a climate response model with two ocean layers (Millar *et al* 2017, Smith *et al* 2018). We use FaIRv1.6.2 with the 'AR6 calibration' (Smith *et al* 2021). This calibration involved an order million-member ensemble used to derive the climate and carbon cycle parameters based on the AR6 WGI assessment (Forster *et al* 2021) and ESMs in the CMIP6 ensemble (Eyring *et al* 2016, Smith *et al* 2021). The FaIR ensemble was constrained using multiple lines of evidence, including the known historical global surface air temperature, ocean heat uptake, CO_2 concentrations to the year 2014, and the CO_2 airborne fraction from the 1% per year increase in CO_2 concentration simulations assessed in AR6 WGI (Canadell *et al* 2021). The remaining constrained ensemble consists of 2237 members. This smaller ensemble is characterized by Equilibrium Climate Sensitivity (ECS) and Transient Climate Response (TCR) distributions that agree with the assessed likely ranges presented in AR6 WGI (Canadell *et al* 2021). We first drive FaIR with two standard multigas emissions associated with the baseline scenarios, SSP2-45 and SSP1-26 (O'Neill *et al* 2016). Then, as outlined above and described in table 2, we perturb the CO_2 emissions in these baseline scenarios in three ways. These three alterations represent potential changes in the emissions caused by major adjustments to the supply of gas and oil from Russian sources to Europe. In the next section, we analyze the 50th percentile temperature time series, along with 5% and 95% uncertainty bounds, derived from the FaIR probabilistic temperature projections for each pathway described in table 2.

Results

We present our FaIR-based numerical calculations in figure 1. Panel (a) shows our idealized alterations to emissions, each potentially caused by the Russia-Ukraine conflict. These changes are added to the CO_2 emissions associated with the SSP2-45 or SSP1-26 emissions scenario (data from RCMIP; Nicholls *et al* 2020). Panels (b) and (c) show the change in mean global warming caused by each of the three new scenarios, compared with the background SSP2-45 and SSP1-26 scenarios. Shown are the FaIR-based 50-percentile estimates of temperature deviation from the respective SSPs. Also presented are the 5th and 95th uncertainty bounds derived from the same bounds on the projected warming of the background SSP calculations but scaled to the perturbations only.

As expected, scenarios SSP.EUcoal and SSP.EUcoal.NewRU both result in increased levels of global warming (figures 1(b), (c)), with the largest temperature rise in the latter case. As also anticipated, the SSP.EUren scenario leads to a lower global temperature pathway. The relatively small changes in global temperature caused by our alteration to the background emission profile are driven by three factors. First, because of the long lifetime of atmospheric CO_2, the effects on global temperature rise are cumulative in emissions (Allen *et al* 2009), and are therefore influenced by the entire span of fossil fuel-based energy generation since preindustrial times. In comparison, our changes in emissions are only for a twenty-year period. Second, our changes decline throughout the amendment period, towards the background SSP emission profile. Third, although energy changes have a considerable impact on the countries involved, our modelled effects on emissions only represent a regional perturbation that is relatively small compared to the overall global CO_2 emissions. However, the changes occurring during the perturbation period, of years 2023 to 2043, persist for many decades afterwards, again reflecting the long atmospheric lifetime of CO_2 (figures 1(b), (c)).

Discussion and conclusions

Our analysis uses the FaIR simple climate model, first driven by emissions from two baseline scenarios, SSP2-45 and SSP1-26. These are global multigas scenarios and therefore include emissions for a range of GHG species. FaIR outputs an estimate of the CO_2 concentration, radiative forcing and critically, global temperature changes for each prescribed time-evolving emission pathway. We only perturb the CO_2 emissions from the two background scenarios, leaving the other species in the altered scenarios unchanged from the baselines. Therefore, we use the emissions of CO_2 to characterize the potential changes in fossil fuel use that result from any European move away from Russian oil and gas. We find that, for the assumptions associated with each calculation, the largest addition to global temperatures would occur if all Russian gas and oil exports to Europe were redirected to new markets elsewhere, while simultaneously Europe replaced these with burning locally mined coal for identical energy provision. In this highest emissions case, we derive a related statistic by noting that emissions of 1000 $GtCO_2$ create 0.45 °C of global warming, based on the central estimate of the Transient Climate Response to cumulative carbon Emissions (TCRE). Hence, using this TCRE statistic, our highest modelled value of almost 0.01 °C (figure 1) corresponds to approximately 22 $GtCO_2$. In the context of current global fossil fuel emissions of the order of 37 GtCO2, this value suggests that the conflict could create nearly half a year of additional CO_2 emissions.

The headline effect of replacing Russian fossil fuel exports is relatively small in terms of global average temperature changes and the remaining global carbon budget compatible with 1.5 °C of warming. However, it is helpful to consider what precedents any European shift away from Russian oil and gas exports might lead to. Could the scenario that generates the temperature decrease be amplified? First, the current situation provides an opportunity to consider the potential for the uptake of low-carbon alternatives for energy provision. The WG3 report of the IPCC 6th Assessment Report (IPCC 2022) highlights the potential for supply side emission reductions, with wind and solar having significant further capacity at low cost to provide a greater share of primary energy. In addition, nuclear power may have a lower cost potential to take up some of the energy provisions currently filled by Russian fossil fuel exports. Second, there is also evidence of greater potential for demand-side energy reductions (e.g. Scott *et al* 2022), which could offset some need for fossil fuel energy currently supplied by oil and gas. Further real-world evidence of the potential for demand-side reductions comes from global reductions in carbon emissions during the first year of the COronaVIrus Disease (COVID19) pandemic response (Le Quere et al 2020). Thus, rising energy prices driven by both the Ukrainian conflict and other global factors may offer an opportunity to better understand the potential uptake of low-carbon alternatives as their cost decreases relative to fossil fuel alternatives. Furthermore, the more general current debate on energy security presents the possible benefit of discussing demand reduction and locally sourced renewable energy potential more intensely. Hence the knowledge gained from this faster conflict-driven transition might have future benefits by scaling up renewable penetration levels even more in Europe or could accelerate the adoption of renewables in other world regions. This could occur by demonstrating the real-world feasibility of a fast transition, and potentially by accelerating technological development with concomitant cost reductions.

Specifically, society can consider energy policy outcomes applicable to nations that are unaffected by the conflict. This may include an acknowledgement that investment in new fossil fuel generation, such as domestic increases in coal, oil or gas production in some nations, is inconsistent with achieving the near-term emission reductions needed to meet the 1.5 °C global warming target. The IPCC reports have stated that available carbon budgets are fast running out if society wishes to constrain global warming, implying less investment in fossil fuels because they will ‘lock in’ future emissions. That is, fossil fuel-based energy provision methods require long payback periods (likely beyond timescales associated with conflicts) to justify the investment and avoid stranded assets. Analysis by Wiltshire *et al* (2022) demonstrates that we are not yet on an emissions pathway to maintain global warming at or below 1.5 °C. Smith *et al* (2019) highlight that any delay in phasing out carbon-intensive infrastructure will reduce the chance of meeting a 1.5 °C warming limit. Further, new fossil fuel development may cause backtracking on existing emission reduction pledges contained in Nationally Determined Contributions (NDCs) or national net zero pledges. Climate change impacts are widely recognized as a ‘threat multiplier’, so their consideration must remain high on the national and international agenda, even during periods of regional difficulty. Available to support policymaker decisions is the concept of unextractable fossil fuels (i.e. the volumes of fossil fuels that need to stay in the ground, regardless of end use; Welsby *et al* 2021) to avoid crossing key global warming thresholds.

Our analysis is highly idealized and is designed only to provide conceptual outer bounds of global warming change caused by the impact of the Russia-Ukraine conflict on European energy provision. For simplicity, we only consider perturbations to CO_2 emissions. In practice, changes between different fossil fuel types will also impact other non-CO_2 greenhouse gas emissions (e.g., methane) and potentially other species, including aerosols. Additional methane emissions will increase global warming, whereas extra sulfate aerosols might offset some of the potential additional warming. Furthermore, our perturbation experiments do not use a more detailed Integrated Assessment Model (IAM) approach to account for factors such as technology learning rates, ‘scale-up’ rates and costs, and therefore, feasibility. A final caveat is that in this analysis, we do not consider longer supply chains, where Russian oil or gas is processed and downstream products such as Liquid Petroleum Gas (LPG) are subsequently redistributed to European destinations. This activity could have an impact on emissions, although it could be difficult to quantify. However, although these caveats associated with other GHGs and aerosols will change the absolute values presented in figure 1, the overall order of magnitude of warming changes of ~0.01 K is expected to remain. We also note that the properties of coal vary between countries and lead to different CO_2 emissions per unit of energy produced (BEIS 2017). However, this report suggests that the Carbon Emission Factors (CEFs) for coal exported from either USA and Russia to the UK have been very similar for the period between 1990 and 2015. We have initially used recent data to determine efficiencies from the US (EPA 2022a, EPA 2022b) as this is given in more detail, but future work may also refine our parameterisation of coal, oil and gas parameters to be more specific to Russia itself.

In summary, researchers or analysts assess a range of other contemporary factors that may impact levels of global warming, including the COVID crisis (Le Quere et al 2020), economic factors associated with the Russia-Ukraine conflict (Creutzig 2022, Halser and Paraschiv 2022, Liu *et al* 2023) and general energy transition effects (IEA 2022a, 2022b). Here we add to that list, making an initial and direct estimate of the impact on the climate of energy transitions due to the conflict. We find that the direct effect on global warming caused by potential conflict-driven alteration to European energy provision could have an impact of up to order one hundredth of a degree of global warming. While this value appears low, further consideration of the indirect effects that might follow elsewhere from the response to changed energy provision is needed. In particular, the imposed requirement for Europe to develop at speed energy policy, as caused by the Russia-Ukraine conflict, is likely to reveal the feasibility of rapidly moving away from fossil fuels elsewhere. This, in turn, may allow a deeper understanding of the likelihood of constraining global warming to 1.5 °C or 2.0 °C above preindustrial levels.

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Data availability statement

All data that support the findings of this study are included within the article.

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Ethical compliance

No ethical issues are raised by the analysis presented in this manuscript.

Conflict of interest declaration

The authors declare that they have no affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

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