Transforming a Synthetic World

The Political Economy of Petrochemical Transitions

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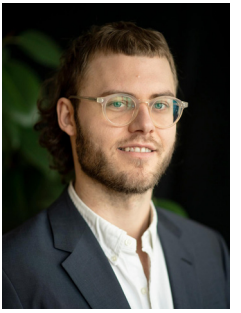
Transforming a Synthetic World

The Political Economy of Petrochemical Transitions

JOACHIM PETER TILSTED
TECHNOLOGY AND SOCIETY | FACULTY OF ENGINEERING | LUND UNIVERSITY

Chemicals are, quite literally, everywhere. In the form of fertilizers, plastics, and other synthetics, chemicals are used for almost everything, from paints to pharmaceuticals to clothes. We produce our food with, wrap everything in, and clean ourselves with synthetic products. Once we notice them, it is hard to even imagine a world without chemicals. And that is precisely the issue. Because when something becomes taken for granted, it is hard to change. This thesis seeks to unpack what we can learn from realising that we live in a world of synthetics in the hopes of seeing its transformation.



JOACHIM PETER TILSTED has a background in international political economy and environmental economics from Copenhagen Business School and the University of Copenhagen. He is a member of the Danish Climate and Transition Council (KOR).

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The Political Economy of Petrochemical Transitions

Joachim Peter Tilsted

LUND UNIVERSITY

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Transforming a Synthetic World—The Political Economy of Petrochemical Transitions

Abstract:

Operating enormous, integrated refineries and clusters, the petrochemical industry runs processes in which hydrocarbons are turned into the fundamental components for plastics and other synthetic materials. Continuing a historical trend of consistent output growth, petrochemicals are the largest current driver of oil demand growth. At the same time, the industry is under increasing pressure to transform because of its contribution to what earth system scientists and ecotoxicologists refer to as the triple planetary crisis of climate change, pollution, and biodiversity decline. In short, the petrochemical producers find themselves at a critical juncture. In this vein, this thesis explores the political economy of petrochemical transitions and the features that define the contestation over the future of fossil-based industry growth. Reframing energy transitions as a matter of not only decarbonisation but of defossilisation, the thesis investigates the linkages between fossil fuels, chemicals, and synthetic materials and the material, institutional, and discursive power of petrochemical incumbents. Drawing on social network, document, and narrative analysis, as well as field observations at industry conferences and global databases, the thesis consists of five interlinked papers and a cover essay. Each paper takes up distinct research questions relating to the political economy of petrochemicals, looking at the past, present, and future of fossil-based synthetics. In the cover essay, I build on the findings of these five papers to argue that the proclaimed forthcoming energy revolution faces intricate difficulties given the structural role of fossil fuels as feedstock, which confers material power upon the actors occupying the petroleum-chemical-synthetics nexus. This power enables incumbent actors to navigate growing transition pressures and pursue production growth. This insight underlines the substantial implications that arise for the political economy of energy transitions from understanding fossil fuels not only as energy carriers but as feedstock. On this basis, I argue that transformative industrial change demands an expanded supply-side focus that goes beyond fossil fuels as energy carriers and insists on an ethics that takes human needs as its point of departure.

Key words: Petrochemicals, energy transitions, synthetics, defossilisation, plastic

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Abstract

Operating enormous, integrated refineries and clusters, the petrochemical industry runs processes in which hydrocarbons are turned into the fundamental components for plastics and other synthetic materials. Continuing a historical trend of consistent output growth, petrochemicals are the largest current driver of oil demand growth. At the same time, the industry is under increasing pressure to transform because of its contribution to what earth system scientists and ecotoxicologists refer to as the triple planetary crisis of climate change, pollution, and biodiversity decline. In short, the petrochemical producers find themselves at a critical juncture. In this vein, this thesis explores the political economy of petrochemical transitions and the features that define the contestation over the future of fossil-based industry growth. Reframing energy transitions as a matter of not only decarbonisation but of defossilisation, the thesis investigates the linkages between fossil fuels, chemicals, and synthetic materials and the material, institutional, and discursive power of petrochemical incumbents.

Drawing on social network, document, and narrative analysis, as well as field observations at industry conferences and global databases, the thesis consists of five interlinked papers and a cover essay. Each paper takes up distinct research questions relating to the political economy of petrochemicals, looking at the past, present, and future of fossil-based synthetics. In the cover essay, I build on the findings of these five papers to argue that the proclaimed forthcoming energy revolution faces intricate difficulties given the structural role of fossil fuels as feedstock, which confers material power upon the actors occupying the petroleum-chemical-synthetics nexus. This power enables incumbent actors to navigate growing transition pressures and pursue production growth. This insight underlines the substantial implications that arise for the political economy of energy transitions from understanding fossil fuels not only as energy carriers but as feedstock. On this basis, I argue that transformative industrial change demands an expanded supply-side focus that goes beyond fossil fuels as energy carriers and insists on an ethics that takes human needs as its point of departure.

Popular science summary

Chemicals are, quite literally, everywhere. In the form of fertilizers, plastics, and other synthetic materials, chemicals are used for almost everything, from paints to pharmaceuticals to clothes. We produce our food with, wrap everything in, and clean ourselves with synthetic products. It is hard to even imagine a world without them. And that is precisely the issue.

Chemical production causes all sorts of problems. The world's chemical production is completely dependent on fossil fuels, which are utilized not only to create the heat needed for the production process but also as the material basis for chemical production. In large facilities spanning many tens of thousands of square meters, oil, gas, and chemical companies change the molecular structure of fossil fuels to make chemicals. Therefore, the chemical industry is the industrial sector with the highest demand for energy of all and a significant contributor to exacerbating climate catastrophe. The chemical industry is also under fire for its involvement in the plastic pollution crisis. Because plastics are made from chemicals, and chemicals are put into plastics to colour them, make them flexible, and for all other sorts of purposes, plastic and chemical production are in many ways synonymous. To top it all off, chemical production is the biggest driver of growth in oil use because the industry is expanding and expects that plastic use across the world can continue to grow.

In this thesis, I investigate how all of this plays out, what industry actors do in response to the climate crisis, and what the consequences of their approach to transitioning the chemical industry are. I study the climate initiatives that multinational chemical producers take, their ties to each other, the stories they tell, and their visions for the future. I argue that the future industry actors are pursuing is one in which the growth of the industry goes unquestioned and where fossil fuel extraction is likely to continue on a significant scale. Because chemicals are almost omni-present, industry actors can use their position to resist change and even take advantage of the push for decarbonisation to expand. This dynamic poses a threat to equitable energy transitions. Recognizing fossil fuels not just as energy sources but also as raw materials show the complexity of transitioning away from them and means that it is critically important to prioritize the use of synthetic materials to meet human needs.

Populärvetenskaplig sammanfattning

Kemikalier finns bokstavligen överallt. I form av gödningsmedel, plaster och andra syntetiska material används kemikalier till nästan allt, från färger till läkemedel och kläder. Vi producerar vår mat med, förpackar allt i och rengör oss själva med syntetiska produkter. Det är svårt att ens föreställa sig en värld utan dem. Och det är just det som är grejen.

Kemikalieproduktionen orsakar alla möjliga problem. Världens kemikalieproduktion är helt beroende av fossila bränslen, som inte bara används för att skapa den värme som behövs för produktionsprocessen utan också som materialbas för kemikalieproduktionen. I stora anläggningar på många tiotusentals kvadratmeter omvandlar olje-, gas- och kemiföretagen den kemiska strukturen hos fossila bränslen till kemikalier. Därför är den kemiska industrin den industrisektor som har den högsta efterfrågan på energi av alla, och den bidrar i hög grad till att förvärra klimatkatastrofen. Den kemiska industrin kritiseras också för sin inblandning i plastföroreningskrisen. Eftersom plast tillverkas av kemikalier, och kemikalier används i plast för att färga den, göra den flexibel och för alla möjliga andra ändamål, är plast och kemisk produktion på många sätt synonyma. Till råga på allt är kemisk produktion den största drivkraften bakom tillväxten i användningen av fossila bränslen, eftersom industrin expanderar och förväntar sig att plastanvändningen i världen kan fortsätta att växa.

I den här avhandlingen undersöker jag vad branschaktörer gör som svar på klimatkrisen, och vilka konsekvenser deras strategi för att ställa om den kemiska industrin får. Jag studerar de klimatinitiativ som multinationella kemikalieproducenter tar, deras band till varandra, de historier de berättar och deras visioner för framtiden. Jag hävdar att den framtid som branschaktörerna strävar efter är en framtid där tillväxten inte ifrågasätts och där utvinningen av fossila bränslen fortsätter i stor skala. Eftersom kemikalier är nästan allestädes närvarande kan branschaktörer använda sin position för att motstå förändringar och till och med dra nytta av kravet på minskade koldioxidutsläpp för att utöka produktionen. Denna dynamik utgör ett hinder för en rättvis energiomställning. Att erkänna fossila bränslen inte bara som energikällor utan även som råmaterial visar hur komplicerat det är att ställa om från dem, vilket kräver en strategi som prioriterar användningen av syntetiska material för att tillgodose mänskliga behov.

List of Papers

Paper I

Bauer, F., **Tilsted, J. P.**, Pfister, S., Oberschelp, C., & Kulionis, V. (2023). Mapping GHG emissions and prospects for renewable energy in the chemical industry. *Current Opinion in Chemical Engineering*, *39*. doi.org/10.1016/j.coche.2022.100881

Paper II

Tilsted, J. P., & Bauer, F. (2024). Connected we stand: Lead firm ownership ties in the global petrochemical industry. *Ecological Economics*, *224*, 108261. https://doi.org/10.1016/j.ecolecon.2024.108261

Paper III

Tilsted, J. P., Mah, A., Nielsen, T., Finkill, G. D., & Bauer, F. (2022). Petrochemical transition narratives: Selling fossil fuel solutions in a decarbonizing world. *Energy Research & Social Science*, *94*. doi.org/10.1016/j.erss.2022.102880

Paper IV

Palm E, **Tilsted JP**, Vogl V, & Nikoleris, A. (2024). Imagining circular carbon: A mitigation (deterrence) strategy for the petrochemical industry. *Environmental Science & Policy 151*: 103640. doi.org/10.1016/j.envsci.2023.103640

Paper V

Tilsted, J. P., Bauer, F., Birkbeck, C. D., Skovgaard, J., & Rootzén, J. (2023). Ending fossil-based growth: Confronting the political economy of petrochemical plastics. *One Earth*. doi.org/10.1016/j.oneear.2023.05.018

Author's contribution to the papers

Paper I

I am the second author of this paper, contributing to its framing, conceptualisation, empirical investigation, and writing. I carried out the analysis of and drafted the section on climate-related initiatives and corporate climate targets in the petrochemical sector, while co-authors took the leading role in other sections of the paper.

Paper II

I am the first author of Paper II and played the leading role in developing all aspects of this paper except the specific visualisation of the network analysis used in the paper. This work included developing a method for extracting and organising data to reveal ownership ties, as well as coding and conducting social network analysis.

Paper III

I am the first author of this paper, playing a leading role in developing all aspects of the paper, including data analysis, conceptual development, visualisation, and writing, while my co-authors played different roles and contributed to various aspects of the paper.

Paper IV

On this paper, I share first authorship with Ellen Palm, reflecting a collaborative effort between us and our other co-authors. I initially pitched the idea and conceptualisation for the project and played a leading role in terms of theoretical refinement, while Ellen had the role of project lead and coordinator and conducted the participant observations and interviews.

Paper V

I am the first author of Paper V, taking a leading and coordinating role in all stages of the research process, including the initial framing and conceptualisation. While I took the lead, all authors contributed to the writing and editing based on their specific expertise.

Other relevant publications

Peer-reviewed articles

Hunt, O. B., & **Tilsted, J. P.** (2024). 'Risk on steroids': Investing in the hydrogen economy. *Environment and Planning A: Economy and Space*, 0308518X241255225. https://doi.org/10.1177/0308518X241255225

Tilsted, J. P., Palm, E., Bjørn, A., & Lund, J. F. (2023). Corporate climate futures in the making: Why we need research on the politics of Science-Based Targets. *Energy Research & Social Science*, 103, 103229. https://doi.org/10.1016/j.erss.2023.103229

Tilsted, J. P., & Bjørn, A. (2023). Green frontrunner or indebted culprit? Assessing Denmark's climate targets in light of fair contributions under the Paris Agreement. *Climatic Change*, 176(8), 103. https://doi.org/10.1007/s10584-023-03583-4

Bjørn, A., **Tilsted, J. P**., Addas, A., & Lloyd, S. M. (2022). Can Science-Based Targets Make the Private Sector Paris-Aligned? A Review of the Emerging Evidence. *Current Climate Change Reports*. doi.org/10.1007/s40641-022-00182-w

Tilsted, J. P., Bjørn, A., Majeau-Bettez, G., & Lund, J. F. (2021). Accounting matters: Revisiting claims of decoupling and genuine green growth in Nordic countries. *Ecological Economics*, 187. doi.org/10.1016/j.ecolecon.2021.107101

Reports and working papers

Bauer, F., **Tilsted, J. P.**, Deere Birkbeck, C., Skovgaard, J., Rootzén, J., Karltorp, K., Åhman, M., Finkill, G. D., Cortat, L., & Nyberg, T. (2023). *Petrochemicals and climate change: Powerful fossil fuel lock-ins and interventions for transformative change*. (IMES/EESS report; Vol. 130). Environmental and Energy Systems Studies, Lund university.

Bauer, F., Kulionis, V., Oberschelp, C., Pfister, S., **Tilsted, J. P**., Finkill, G. D., & Fjäll, S. (2022). *Petrochemicals and Climate Change: Tracing Globally Growing Emissions and Key Blind Spots in a Fossil-Based Industry*. (IMES/EESS report; Vol. 126). Lund University.

Bauer, F., **Tilsted, J. P.,** Nielsen, T., Ostrovnaya, A. And Erlandsson, U. (2021). *Petrochemicals: Major credits, carbon risks, green bonds*. Anthropocene Fixed Income Institute working paper.

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The acknowledgement section is, in an important way, the thesis-equivalent of an acceptance speech. Here, it becomes clear that the thesis relies on the work, care, and support of others, despite only one name ending up on the cover.

I owe a huge debt of gratitude to many wonderful people. First, a huge thanks to Fredric, who, although not formally my main supervisor, has been it in almost every other way, for each of which I am thankful. And to Lars, who has trusted and aided me through ups and downs over the last four years.

An enormous thanks to my colleagues at IMES. Because I started my time at LTH during the pandemic and ended it doing multiple guest research stays elsewhere than Lund, I have for long periods of time not been present, and yet I have received heaps of collegial support, for which I am truly grateful. I am deeply thankful to Valentin, who made me feel like I was in the right place from the moment I arrived, and to Ellen, who is a true hero of academia in countless ways. Thanks to my comrade Jonas, a beacon of engaged leftist thinking (and music-making), as well as to the other PhD students, new and old, who have shaped my IMES experience, including Zhenxi, Eugène, Hannes, Johanna, Jens, Malin, and Lovisa, not to mention my old officemate, Malin. Best of luck to the newer PhDs I did not get the opportunity to work alongside. Thanks to Alexandra, with whom I had the wonderful privilege of teaching, offering me numerous learning experiences, and to the IMES colleagues who have helped me countless times with all sorts of affairs required to obtain a PhD, including André, Jamil, Astrid, Helena, Petra, and Ina.

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Thanks so much to all my dear friends, whom I am grateful to have in my life and appreciate beyond words. Thanks to my treasured youth friends from Holstebro, to Viktor and Thomas, to CBS Sport, to my friends from my student years at CBS and UCPH, to bogklubben, and to friends from other communities I have been so fortunate to take part in during my time as a PhD student. I am especially grateful to the friends I made in and through Rethinking Economics Danmark, including Asker, Mads, Ida, and Oskar, whose friendship and dedication to

challenging dominant modes of reasoning have played a significant role in my academic life. I also owe a great debt of thanks to the friends I got to share my PhD life with at Christian IX's Gade: Anna, Thomas, Maria, Tao, Magnus, and Jens.

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Joachim Peter Tilsted
Copenhagen, July 2024

Preface

'Plastic is a material that contributes to sustainable development (…) [and] promotes economic growth in various sectors (…). We should not [pursue policies] to the detriment of food security and our ability to meet the Sustainable Development Goals.'

So were the words of the Saudi Arabian opening statement at the second leg of the International Negotiation Committee for a legally binding instrument to end plastic pollution known as the Global Plastics Treaty in Paris in May 2023. The Saudi sentiment was by no means unique but was backed by several other delegates at the negotiations. Singapore, for example, noted the importance of plastics for 'economies and societies', a standpoint commonly echoed by fossil fuel extracting and petrochemical producing states. The solution, as voiced by these diplomats in the halls of the UNESCO headquarters, where the negotiations took place, was not to address the production of petrochemical plastics as such but to rely on recycling. Qatar, for example, explained that they recycled '100 percent' [sic] of the waste from the 2022 World Cup in football, suggesting that if all other countries followed in their path, the plastic pollution crisis would be no crisis at all.

Being present in Paris, I was somewhat taken aback by the rhetoric. Not long before the negotiations, in December 2022, we published a paper on transition narratives in the petrochemical industry (a paper that is part of this thesis) laying out the content and rationale of such statements. But here, in this 'house of peace'—the words UNESCO uses to refer to their headquarters—I witnessed it first-hand. Not mobilised by incumbent firms, as I studied in the paper, but by state diplomats. And although strong ties exist between firm and state actors, and state and hybrid ownership are relatively common, I still found myself caught off guard, listening to tactics of delay and accommodation on the biggest possible stage in multilateral environmental governance.

A couple of days earlier, observers had been invited to ask questions before the Paris negotiations officially began. On that occasion, lobbyists from various organisations associated with petrochemicals had invoked similar rhetoric—a rhetoric I had grown quite familiar with by the time after two years studying the industry—but here it was popping again, this time being repeated in the plenary session. I could not help feeling a strong sense of unease.

When I defend this thesis, the fifth round of the International Negotiation Committee is not far away, and the treaty negotiations are supposed to soon be finalised. Hailed as the most important multilateral environmental development since the Paris Agreement, a lot is at stake. No matter the outcome and the path dependencies it instils, however, the future of the synthetic world remains open. I hope that this thesis helps clarify why and how that matters.

Abbreviations

BTX	Benzene, toluene, and mixed xylenes
IEA	International Energy Agency
INC	International Negotiation Committee
SABIC	Saudi Basic Industries Corporation

Units

CO_2eq	Carbon dioxide equivalents
Gt	Gigaton
HCFC-22	Chlorodifluoromethane
M^2	Square meters
Mt	Million tonnes
N_2O	Nitrous oxide

1 Introduction: Looking upstream the plastic tap

At the fifth session of the United Nations Environmental Assembly held in Nairobi in February–March 2022, the future of plastics appeared to be on the line. In front of the United Nations Environment Programme headquarters, where the assembly was held, a three-story-tall sculpture demanded the attention of participants and passersby. Created by Benjamin Von Wong with the help of local residents from Kibera, this artwork emulated a giant water tap. But instead of water, the tap—appearing to flow freely in the air—spewed single-use plastic. An online campaign with the slogan #TurnOffThePlasticTap (2022) spread on social media, promoting the tap as a metaphor for the continuing and seemingly never-ending flow of virgin plastics and the accumulation of synthetic entities in the natural environment. On the face of it, the sculpture was extremely timely, coinciding with a moment of strong political will as parties at the 2022 assembly reached a resolution to 'end plastic pollution.' Recognised as the biggest moment in multilateral environmental governance since the Paris Agreement in 2015, the resolution calls for a legally binding instrument to address the 'full life cycle' of plastics (United Nations Environment Assembly, 2022). As such, the resolution includes attention to the supply of plastics encapsulated by Von Wong's plastic tap. With the negotiations for a global plastics treaty set to end this year, however, the prospects of turning off the tap are out of sight.

Expanding global plastic governance beyond waste management and mainstream circular economy discourse to include the production and supply of plastics reorients our attention to the petrochemical industry, which constitutes the foundation for plastic production. The petrochemical industry, deeply rooted in the fossil energy order, operates enormous, integrated clusters and refineries to crack hydrocarbons for chemical production. The industry produces the material basis for the entire host of synthetics—defined as substance formed through

chemical alterations—most prominently plastics, fibres and rubber as well as fertilizer and industrial gases. Banking on expanding operations and continuing the historical trend of consistent output growth, petrochemicals are poised to remain the largest driver of oil demand growth in this decade and onwards (IEA, 2018, 2023b). Turning off the petrochemical plastics tap would thus imply calling off the industry's main accumulation strategy, challenging not only vested interests in the plastics economy but the fossil-based energy order and the chemicals that catalyse mass production and consumption.

The petrochemical industry generally refers to the sector that uses fossil fuels as feedstock to make chemicals. Today, this industry uses around 16% of global oil and 8% of global natural gas production (IEA, 2018, p. 27; 2023b, p. 27). At one end of the production process, coal, natural gas and oil undergo processing and refining to create intermediates for various chemicals. At the other end, petrochemicals function as the material basis for the full range of synthetic materials and the additives on which they rely. These processes take place in networked and specialised facilities that are grouped in large-scale billion-dollar petrochemical clusters, often integrating refineries and chemical production (Bauer, Tilsted, Deere Birkbeck, et al., 2023; Janipour et al., 2022). Because chemicals are used for a wide range of industrial purposes, the petrochemical industry has ties to a wide range of sectors. Apart from plastics, the second largest demand segment is fertiliser (Levi & Cullen, 2018), channelling what Moore refers to as 'petro-farming' (2015, p. 251). Petrochemicals also enable and thereby underpin the growth of the pharmaceutical industry (Huber, 2013), while the emergence of hyper-fast fashion is based on synthetic fibres (Dzhengiz et al., 2023). In short, for material consumption to grow, so must the chemical industry and its demand for hydrocarbons. To 'end the fossil fuel age', as voiced by social movements (Paterson, 2021), thus requires not only leaving behind the use of oil, gas and coal as fuel but also as feedstock.

This pivotal point is not well appreciated in what Hanieh refers to as the 'radical scholarship on oil' (2021, p. 25). This literature, he explains, has focused on fossil fuels mostly as energy carriers rather than as feedstock and on the role of oil and gas rather than petrochemical incumbents in maintaining the fossil energy order. But for energy transitions, a mutually reinforcing relationship exists between energy, extraction and synthetic materials, which has co-evolved since the emergence of the chemical industry (Bennett, 2007). The utilisation of by-

products and waste streams from crude oil refinement as feedstock for petrochemicals was critical to the Fordist model of mass production and consumption, both in terms of its make-up as well as its ability to scale (Hanieh, 2021; Huber, 2013). The development of this evolving relationship, in its totality, is thus key to the ongoing and future energy transitions and a central aspect of climate change and energy system dynamics more broadly.

To study transitions in the petrochemical industry, there is merit in taking an approach that is global in scope in an effort to complement the longstanding activist scholarship on environmental justice focused on chemicals. Emerging from grassroot activism and 'real-life problems', this literature foregrounds place-specific accounts of environmental pollution, toxicity and environmental racism (Davies & Mah, 2020, p. 7). Such analysis has underscored the capacity of petrochemical producers to, in the face of local opposition, impose the social and environmental burdens of toxicity onto vulnerable communities elsewhere, perpetually displacing socio-ecological harms (Hallowes, 2011; Mah, 2023). By taking an approach that is global in scope, there is an opportunity to account for the interrelationships between developments in different places and simultaneously unfolding transitions and their multiple social and ecological inequalities (Newell, 2005; Newell & Bumpus, 2012).

And so, what happens when we see the global plastics crisis as not predominantly a matter of waste, litter, reuse, recycling and repair but one of interlinked socio-ecological crises of fossil fuels, growth, distribution and power? Conversely, what are the implications for energy transitions when we see fossil fuels not only as energy carriers but as raw materials? Addressing these questions, this thesis explores the political economy of petrochemical transitions, including the operations and features of power that define the struggle over the future of fossil fuels for non-energy purposes. Reframing energy transitions not only as a matter of phasing out fossil fuels as energy carriers but also as feedstock, this thesis investigates the material, institutional and discursive power of petrochemical incumbents and the linkages between fossil fuels, chemicals and synthetic materials. I thereby seek to answer the overall research question of how, on what basis, to what end and with what consequences, petrochemical incumbents navigate transition pressures related to their involvement in socio-ecological crises.

1.1 Aim and contribution

This thesis consists of five interlinked papers that each take up distinct research questions pertaining to petrochemical transitions, as well as this cover essay. To answer these, I draw on a variety of methods and data, including social network, document and narrative analysis, as well as field observations, interviews and global databases. Looking at the past, present and future of fossil-based synthetics, each of the research questions in the papers is set up to help me answer one or more aspects of the overall question of how and with what consequences incumbents navigate transition pressures. More specifically, I enquire into the prospects of rapidly reducing industry greenhouse gas emissions, global intra-industry relations, corporate discursive strategies and possible pathways for transformation (I elaborate on and review the links between the overall research question and the paper-specific questions in Chapter 5). Across the thesis papers, I: i) review global sector emission trends and industry initiatives; ii) investigate global ownership networks; iii) map petrochemical transition narratives and their similarity to and differences from oil and gas majors; iv) explore the emerging industry imaginary of a future built around the notion of circular carbon; and v) suggest pathways for undoing carbon lock-ins across various domains. Together, these papers illustrate the material, institutional and discursive aspects of power that incumbents mobilise to shape petrochemical transitions. This cover essay seeks to introduce, synthesise and reflect on the findings from these five papers.

Aiming to unfold the political economy of petrochemical transitions, this thesis makes a range of contributions that are both empirical and theoretical in nature. The overall empirical contribution relates to the scope of the thesis, which is the petrochemical sector. Despite being the industrial sector with the highest energy demand of all, energy-oriented social science research has long overlooked petrochemicals. In the words of Fatih Birol, the executive director of the International Energy Agency, the petrochemical industry has been a 'blind spot' in debates on global energy, not least amongst policymakers (IEA, 2018). While my main focus is on the largest producers and polluters, I seek to understand them in relation to key actors present in the social, economic and institutional contexts in which various petrochemical producers operate. By exploring material, discursive and institutional dimensions of transitions, the thesis at hand addresses the empirical gap on petrochemicals, complementing an emerging scholarship on

the relationship between chemicals and fossil fuels as well as the wider social science scholarship on energy more generally (see Chapter 3). In terms of the need to decarbonise petrochemicals, this thesis aims to unpack transition dynamics by answering the questions of how petrochemical incumbents navigate growing transition pressures and why they pursue these strategies. In doing so, I seek to understand the conditions that shape the prospects for radically lowering emissions from this industry.

In terms of theoretical contributions, this thesis makes a number of advancements. As an overall ambition, I aim to invoke insights from the international political economy scholarship to study sustainability transitions, thereby answering recent calls to foreground and situate capitalist dynamics to understand transition processes (Feola, 2020; Newell, 2020). I do this by relating to different traditions within critical political economy on climate and energy, bringing together a range of concepts from canonical as well as more recent work. Most prominently, I centre on and add to the neo-Gramscian notion of trasformismo as a form of limited transition that keeps power relations intact and paves the way for accumulation-driven energy transitions (Newell, 2019).

A first theoretical contribution lies in better conceptualising the mechanisms and dynamics of trasformismo in the context of transitions. Across the five papers, I do so primarily in two ways, theorising i) the role of global producer networks in shaping and strengthening trasformismo and ii) how trasformismo operates in its discursive form, putting forward the concept of narrative realignment. These contributions nuance and expand the understanding of how trasformismo operates and unfolds, without which the notion of trasformismo risks becoming a black box concept that is hardly distinguishable from notions of incremental change. Through invoking the theorisation put forward in this thesis, I am in a position to argue how processes of trasformismo result in not only undermining climate action but also the continued and growing accumulation of synthetics, entrenching existing inequalities and environmental injustices as well as contributing to new ones.

A related but second main theoretical contribution lies in putting forward an understanding of how the pursuit or foregrounding of certain visions and pathways can obstruct action in various socio-ecological domains. More specifically, this thesis conceptualises how and why promises of solutions or fixes can lead to failure to address multiple crises, expanding the understanding of

deterrence found in the literature on the cultural political economy of mitigation deterrence and technical fixes. In short, mitigation deterrence is conceptualised as the process in which a consideration of a certain climate intervention distracts from the pursuit of other interventions that can reduce greenhouse gas emissions. To explain this phenomenon, scholars have applied a cultural political economy lens, emphasising the alignment between political and innovation regimes and the fit between specific technological functionalities and the interests of dominant economic blocs (Carton et al., 2023). As part of this thesis, Paper IV considers mitigation deterrence, the main concept in this literature, which has been preoccupied with negative emission technologies, in relation to technologies and promises that purportedly address multiple socio-ecological crises. In doing so, I show how we can build on this conceptual apparatus to theorise other forms of deterrence—in particular the deterrence of plastic pollution reduction through promises of circularity—and understand the appeal of certain frames and technological functions through their assurance of a double dividend: the promise to fix not only one but two ecological crises.

In this cover essay, I synthesise these contributions and reflect on their implications to build the overall argument that the proclaimed forthcoming renewable energy transition faces intricate difficulties linked to the structural role of fossil fuels as feedstock, which confers material power to the petrochemical-producing actors occupying the petroleum-chemical-synthetics nexus. This power enables incumbent actors to navigate growing transition pressures and, in the face of these, maintain fossil-based production, mobilising the decarbonisation imperative to pursue new forms of accumulation that threaten to undermine just transition projects. This insight underlines the substantial implications that arise for energy transitions from understanding fossil fuels not only as energy carriers but as feedstock. On this basis, I argue that transformative socio-ecological change demands an expanded supply-side focus that goes beyond fossil fuels as energy and insists on an ethics built on logics of sufficiency and attention to human needs.

1.2 Thesis outline

To sketch the contours of a political economy of petrochemical transitions, I follow this introduction with a chapter that familiarises the reader with the petrochemical industry and its contributions and involvement in socio-ecological crises. This chapter also includes a brief history of the industry (highlighting themes that I take up later in the thesis) and lays out the current patterns of fossil-based petrochemical production and investments. The third chapter maps out the theoretical and scholarly foundation of the thesis and invites a reflection on what it means to see transitions through a 'fossil fuel as feedstock' lens. In the fourth chapter, I introduce the thesis methodology, reflecting on issues of philosophy of science and methods while positioning the thesis as broadly consistent with critical realist perspectives. In chapter five, I present my arguments and findings from the five papers, drawing connections and parallels between them that relate to the history of the petrochemical industry. In the penultimate chapter, I discuss the implications of appreciating fossil fuels as feedstock and the societal role of fossil fuels for non-energy purposes, pointing to the lines of contestation that are likely to define petrochemical transitions in the coming decades. The final chapter concludes the thesis.

To end this introduction, I want to make a brief note on the boundaries of the petrochemical industry. Working with chemicals involves a myriad of acronyms, with thousands upon thousands of different chemicals, additives and types of plastics, each with their own unique molecular structure and material properties. My focus, however, lies on fossil fuels as feedstock and the chemical industry in a general sense. Therefore, in most cases, I refrain from engaging in such a level of detail. Acknowledging this limitation up front, I want to define the petrochemical industry, whose boundaries are difficult to pin-point exactly and consistently because they intersect and overlap with adjacent sectors.

In this thesis, I apply a purposefully broad definition of petrochemicals, understanding them as chemicals materially derived from fossil fuels, thereby including the production of thermo- and thermoset plastics, elastomers including rubbers, synthetic fibres and additives, as well as ammonia for nitrogen fertilizer. In practice, this definition makes the chemical industry the petrochemical industry, since virtually all chemical production today uses fossil fuels as feedstock. When I still use this term, although the lack of specificity might not sit well with

ecotoxicologists and chemical engineers, it is to make the fossil-chemical-synthetic link visible. To situate petrochemicals, I emphasise the 'petro' origin.

2 Expanding petrochemical production capacity in a time of socio-ecological crises

In a time of socio-ecological crises, the outlook for petrochemical transitions is one of fossil-based production expansion. To set the scene and lay the groundwork for the main argument of this thesis, this chapter begins by unfolding petrochemical production and its multifaceted environmental, climate and health-related consequences. In a second section, I provide a brief account of the history of the chemical industry, with particular attention to shifts in feedstock and previous engagements in shaping dominant understandings of petrochemicals. In the final section of this chapter, I trace and map the patterns of investment and growth in the industry over the last decade, which contribute to making petrochemicals the primary driver of oil demand growth.

2.1 From extraction to everywhere: The planetary crisis of plastics and chemicals

The consequences of chemical production mean that the industry is at the centre of what ecotoxicologists and earth system scientists now refer to as the planetary crisis of chemicals and plastics (Almroth et al., 2022; Diamond et al., 2015; Persson et al., 2022). The notion of a planetary crisis builds on the assessment that petrochemicals constitute a key driver of the triple burden of climate change, biodiversity loss and pollution to a point that amounts to a threat to 'planetary health' (Almroth et al., 2022, p. 1070). Considering that the value chain of petrochemicals spans from fossil fuel extraction to incineration and landfills,

harmful impacts might not come as a big surprise. Yet, the full range and acute nature of the effects related to petrochemicals in all their varieties are overwhelming. Below, I provide a short introduction to petrochemical production and a non-exhaustive review of the climate-, environmental- and health-related consequences of petrochemicals and plastics.

2.1.1 Producing petrochemicals

The petrochemical value chains all start, in essence, with the extraction of hydrocarbons, be they coal, oil, or fossil gas, which are then transported to refineries and integrated clusters to manufacture platform chemicals. In the case of the crude-oil-based feedstock naphtha (one of the outputs from the refining process alongside bunker fuel for shipping, diesel, etc.) and fossil gas, these inputs are broken apart in large steam crackers. These vessels use steam to 'crack' long chains of hydrogen and carbon into shorter molecules in giant ovens reaching around 850 degrees before being distilled to produce the petrochemicals that constitute the basis for further production, often on-site (Bauer et al., 2022; Tilsted et al., 2023). Such steam crackers are incredibly vast and demand substantial amounts of energy. The biggest of the two steam crackers in the largest integrated chemical complex in Ludwigshafen run by German petrochemical major BASF, for example, with its array of pipes, furnaces and compressors, spans an astounding 64,000 m^2 (corresponding to around 13 football fields). In terms of production capacity, the Ludwigshafen cracker II, as it is called, is around the size of the median European cracker (BASF, n.d.; Petrochemicals Europe, n.d.).

The output from such processes counts most of the important platform chemicals, including the light olefins ethylene, propylene and butadiene, aromatics in the form of benzene, toluene and mixed xylenes (commonly referred to collectively as BTX), as well as hydrogen, which is used for other refining purposes (IEA, 2018). Apart from hydrogen, these are monomers that, through high temperatures, pressure and a catalyst, can be polymerised to create the fundamental components for plastics (Shrivastava, 2018). When not polymerised, monomers serve a host of other purposes. Ethylene, for example, is used for functions as different as wielding and seed germination (Pässler et al., 2011; Santos & Garcia, 2023), while propylene is used as an ingredient for, inter alia, pharmaceuticals, toothpaste and cosmetics (Okolie, 2022). Collectively, olefins and aromatics are referred to as high-value chemicals because their price is multiple times that of ammonia and

methanol, two other primary chemicals (IEA, 2018). Methanol and ammonia are both generated from synthesis gas, which is produced through the reforming or gasification of fossil gas, petroleum, or coal in high-temperature, high-pressure, energy-intensive processes (Khosravani et al., 2023). In the case of ammonia, nitrogen and hydrogen are reacted in processes around 400–500 °C and pressures above 100 bar (Appl, 2011), whereas methanol synthesis entails reacting carbon monoxide and hydrogen at temperatures of 200–300 °C and pressures of 50–100 bar (Khosravani et al., 2023). As a simple alcohol, methanol is used as a solvent as well as for adhesives, plastic resins and fuel additives, whereas ammonia constitutes the basis of nitrogen fertilisers (Bauer et al., 2022).

High-value chemicals, methanol and ammonia constitute the primary chemicals and make up the majority of petrochemical production, accounting for around two-thirds of total energy demand (IEA, 2018). In a comprehensive assessment of global material flows, Levi and Cullen (2018) found that through the transformation of 1.6 billion tonnes of raw materials every year (677 million tonnes of fossil feedstock, 274 million tonnes of water and 686 million tonnes of secondary reactants), the chemical industry produced close to 1 billion tonnes of synthetic products in 2013.

2.1.2 The impacts associated with petrochemical production

The impact pathway of petrochemicals starts with the toxic, environmental and climate-related impacts of fossil fuel extraction and transportation (Healy et al., 2019). In the next link of the chain, production results in toxic emissions. Significant research on occupational health documents an increased risk of adverse haematological effects (see, e.g. Axelsson et al., 2010; Moshiran et al., 2021), and so does epidemiological research on people living in the vicinity of petrochemical complexes (Lin et al., 2018). In a meta-review, for example, Jephcote et. al (2020) found a 30% higher risk of developing leukaemia for people living within five kilometres of a petrochemical facility. The consequences of toxic emissions vary depending on, for example, the types of chemicals produced, the facilities in which these processes are carried out, and the socioeconomic deprivation of the ones who are subject to pollution (Jephcote & Mah, 2019). Because of the time horizon and spatial ambiguity associated with the secretion of toxicants, it can be difficult to establish causality—what Davies refers to as 'the oppressive nature of uncertain temporalities' (2018, p. 1537). It is the attritional characteristic of

toxicity that makes it a form of 'slow violence' (Nixon, 2011). This feature does not mean that the consequences of toxins are not visible or 'out of sight' but rather that the voices of those who experience the racialised and uneven consequences rarely count; to be sure, slow violence is a product of the 'political structures that sustain uneven geographies of pollution' (Davies, 2019).

The energy-intensive processes associated with petrochemical production also result in significant amounts of greenhouse gas emissions, both from the processes themselves as well as from the combustion of fossil fuels for energy. The exact figure varies depending on data, approach and assumptions, but relying on the widely recognised multi-regional input-output database EXIOBASE, we found in a recent report that direct greenhouse gas emissions from petrochemicals constitute around 4 percent of global emissions and that the total amount of greenhouse gas emissions associated with petrochemicals have more than doubled from 1995 to 2020 (Bauer et al., 2022). In terms of greenhouse gas emissions, industry actors—particularly in Europe—point to substantial decreases over time. Measured in CO_2-equivalents, greenhouse gas emissions fell by around 55 percent from 1990 to 2020 while production increased (Cefic, 2023). This reduction, however, is almost exclusively driven by reductions in N_2O and HCFC-22, which can, despite limitations, be lowered markedly by installing abatement equipment at the plant level (Alves et al., 2022; Geels, 2022). These greenhouse gases are powerful but short-lived gasses, and so their mitigation cannot, as such, directly substitute for reductions in CO_2 emissions since carbon is a long-lived climate forcer (M. R. Allen et al., 2022; Matthews et al., 2020). In that regard, the CO_2 emission intensity of European production has stagnated and remained flat since 2015 (Cefic, 2023).

Moving further down the value chain to the use of synthetics in all their forms, the consequences, known and unknown, balloon. The research on, in particular, human health and plastic-associated chemicals has exploded in recent years, and the number of studies published per year on such issues increased fivefold from 2010 to 2022 (Seewoo et al., 2023). Notwithstanding impacts on ecosystems and endangerment of non-human organisms (Groh et al., 2022), studies document everything from human exposure to micro- and nanoplastics as a consequence of the use of saline solutions in hospitals (Çağlayan et al., 2024) to the effects of phthalate exposure amongst nail salon workers (Varshavsky et al., 2020). Across the vast literature exploring such issues, scholars have found that plastic products

and the chemicals therein, in particular endocrine-disrupting chemicals, are associated with an increased risk of cancer, heart disease, diabetes, neurological disorders, infertility and early menopause (Gore et al., 2024). The existence of micro- and nanoplastic fragments has been documented in the most worrisome of places, including human placentas (Ragusa et al., 2021) and bloodstreams (Leslie et al., 2022), the latter of which was recently found to be associated with more than 4.5 times higher risk of 'myocardial infarction, stroke, or death from any cause' (Marfella et al., 2024, p. 900).

Researchers also worry about that which is not known. Most chemicals used today have not undergone a safety assessment. For example, around 80% of the chemicals registered as part of the EU Registration, Evaluation, Authorisation and Restriction of Chemicals have not been adequately tested, prompting ecotoxicologists to raise the flag (Persson et al., 2022; Wang & Praetorius, 2022). This circumstance has left earth system scientists in the most recent update of the hugely influential planetary boundaries framework to conclude that the boundary for so-called novel entities, that is, geologically new chemicals and synthetics, is breached, arguing that no chemicals should be used without beyond subject to such assessments (Richardson et al., 2023). In a comprehensive review report from 2024 on plastic chemicals, toxicologists and environmental chemists published the most comprehensive database on plastic chemicals to date. Mapping the scope of 'known unknowns', they concluded that of a list of 16,000 known plastic chemicals, hazard data is unavailable for almost 11,000 of those, and that for 9,000 plastic chemicals, public information on which plastics the chemicals are used for is not available (Wagner et al., 2024). Despite the huge gaps in transparency and public available information, the report concluded that at least 4,200 plastic chemicals are 'persistent, bioaccumulative, mobile, and/or toxic', and identified 'more than 400 chemicals of concern across all major polymer types' (Jones, 2024). In fact, the amount of 'non-hazardous' chemicals amounted to a mere ~1 percent, and even this classification was based on incomplete evidence.

The final stage of the petrochemical value chain is oftentimes referred to as 'end-of-life' and includes the broad scope of activities that occur after final use, including waste management and recycling. This is the part of the value chain perhaps most clearly associated with plastic pollution, namely visible pollution in the form of landfills and accumulating amounts of synthetic materials in the

marine environment. At this stage, the list of climate-related, environmental and health impacts grows even longer and includes the release of toxic additives and microplastics during recycling, the greenhouse gas emissions and air pollution from incineration and open burning of plastics, and the pollution of soil and waterways from landfilling (Brown et al., 2023; Hahladakis et al., 2018; Hamilton & Feit, 2019; Shen et al., 2020). Research also suggests that plastics release greenhouse gases in the form of CH_4, methane, and C_2H_4, ethylene, as they degrade when exposed to sunlight (Royer et al., 2018), while the very efforts to clean up plastics somewhat ironically can cause harms that outweigh potential environmental benefits (Bergmann et al., 2023).

Taken together, the range of concerns is overwhelming. Highly unequal and unjust impacts occur at different and between different points in petrochemical value chains, resulting in wide-ranging socio-ecological consequences. Starting as fossil fuels in geological depots, petrochemicals end up essentially everywhere in the form of micro- and nano-fragments, if not incinerated, further contributing to increasing atmospheric concentrations of carbon dioxide. Many of the consequences associated with petrochemical production mentioned in this section have been subject to much public, media and political attention, and social movements across the globe have mobilised against petrochemical producers in various ways, including by collecting evidence of the harms done (Mah, 2023).

With increased attention to the consequences of petrochemical production, think tanks focusing on transition-related financial risks have sought to warn private investors of exposure to stranded assets and various forms of liabilities associated with investing in the industry. Arguing that 'the future is not in plastics', these think tanks have invoked the logics of finance and the rhetoric of financial capital to convince investors against banking on petrochemical growth (Bond, 2020; Gray, 2020; Holzman & Romo, 2021; Planet Tracker, 2023). Given the evidence reviewed above and the elevation of the accumulating toxicants and synthetic materials to the highest order of socio-ecological issues by proclaimed scientists—that is, conceiving them as a threat to 'planetary health'—one could think that industry actors and investors would change course; that the prospects of stranded assets and decreasing profitability would induce major shifts in investment patterns towards low-carbon production or other sectors. Yet, investments in new fossil-based petrochemical production capacity remain at their all-time high. This

inclination towards continuous growth in the face of criticism and injustice, however, is not new. In fact, it is the perpetuation of a long-standing trend.

2.2 How did we get here? A brief history of the chemical industry

On a global scale, petrochemical production has been growing consistently since its emergence in the early 20th century. From the birth of the German coal-based industry fuelled by the First World War, over the emergence of oil-based chemical production in the United States on the basis of the Second World War, to the use of shale gas for commodity plastics in this century (Hanieh, 2021; Sicotte, 2020), the remarkable growth of synthetics has far outstripped that of any other bulk materials, dwarfing both cement and steel and far surpassing GDP growth (IEA, 2018). Today, the accumulated plastic mass outweighs all animals by two to one (Elhacham et al., 2020). Kicked off by the petrochemical revolution, this growth trajectory was a key pillar of post-World War II Fordist-style industrialism, vastly increasing the scope of consumer goods. To understand the starting point for petrochemical transitions today, we need to appreciate the history of the industry's growth trajectory.

2.2.1 The evolution of the energy-chemical nexus

Throughout its existence, the fate of the chemical industry has been intimately tied to that of energy. The two sectors have been moving in tandem, or co-evolving, interacting and influencing each other (Bennett, 2007). The interdependence of energy and synthetics has existed ever since the emergence of the modern chemical industry (associated with the accidental discovery of the synthetic dye mauveine, or aniline purple, in 1856), which would not have been possible without the rise of coal-gas for illumination in Britain (Bennett, 2007; Freeman, 2020). Rooted in the fossil-based energy revolution, coal dominated chemical production until the middle of the 20th century. In particular, at the start of the century, the German chemical industry was a central pillar of coal-based chemical production, supplying up to 90 percent of the global output of synthetic dyes and producing a range of platform chemicals on commercial scales for the

first time (Spitz, 1988; Steen, 2014). Producing synthetic nitrates for explosives and fertilizer and developing poison gas for military purposes, the First World War helped to strengthen the German chemical industry (Hanieh, 2021).

The reorientation from coal to petroleum-based chemical production followed the outbreak of the Second World War. With the need for war supplies and a scarcity of metals, natural rubber, wood and cotton, the use of synthetics proliferated (Freinkel, 2011; Hanieh, 2021). Enabled by new (catalytic) cracking processes and elevated by state funding to aid the war effort, the war saw a definite change from coal to oil in the American chemical industry. With oil and gas in the United States being relatively abundant, petrochemical production could grow exponentially (Hanieh, 2021). Subject to post-war planning, the coal-based chemical industry in Germany (essential to and deeply entangled with German warfare and the Nazi regime) also saw a reorientation from coal to oil as feedstock in European chemical production. And so, by the 1960s, petroleum was also the most prominent feedstock in Germany, completing the 'petrochemical revolution' (Galambos et al., 2007; Hanieh, 2021).

The chemical industry has also responded to subsequent changes in global energy history. In the 1970s, for example, instigated by the energy crisis, interest in alternative feedstock increased, mainly in the form of seemingly abundant coal but also hydrogen (Bennett, 2007). But the chemical industry is not just a passive responder to the changes in energy systems—they evolve together. The pursuit and expansion of various forms of fuels and energy carriers relies on their by-products, or wastes, as feedstock, making chemicals and energy mutually dependent (Bennett, 2007; Hanieh, 2021). With the expansion of fracking in the United States—the so-called shale gas boom—producers have struggled to make profits with squeezed margins and vast supply, but precisely because of the usefulness of ethane (a natural gas liquid and a by-product of fracking) as feedstock, the shale gas boom has kept booming (Sicotte, 2020). Even mainstream institutions such as the International Energy Agency see the deep-seated entanglements between fossil-fuel extraction and petrochemical production, describing the current Chinese import of US liquefied natural gas as feedstock as a form of 'symbiosis' (IEA, 2023a). The open question currently facing the industry is therefore not so much whether but more how the co-evolution of energy and chemicals will continue. Will the petrochemical sector lose its petro-

prefix as part of a renewable energy transition or continue to function as a bedrock of continued fossil fuel extraction in a warming world?

2.2.2 The magic of petrochemicals

The 1956 cartoon *Destination Earth*, sponsored by the American Petroleum Institute, follows the Martian Colonel Cosmic as he goes to Earth to learn about the energy sources on other planets. To his amazement, he soon realises that human societies—represented as white, middle-class and North American—are entirely powered by oil. Encouraged by his findings, he returns to Mars to explain the wonders of oil to his fellow Martians, who are quick to pursue an oil-fuelled future for themselves. This cartoon, with its clear idolising purpose of influencing how US citizens and policymakers thought about and acted upon oil, is interesting in several ways. It is emblematic of who was considered the American public (all people in the cartoon are white); it illustrates the emergence of public relations and lobbying as storytelling; and it mobilises the video format to position oil as the cornerstone of the good life. For the purpose of this thesis, however, what is of particular interest is how the cartoon goes beyond oil as energy, explaining the role of oil as feedstock. In his address to the Martians, Colonel Cosmic does emphasise the role of petroleum as fuel, its high energy density and its advantages as an energy carrier. It is, however, not these features alone that make oil superior to other energy sources. The magic of oil, Colonel Cosmic explains, comes from understanding the materiality and possibilities of oil as *feedstock*.

In the scene laying out the possibilities of oil as feedstock for petrochemicals, two smiling, white, middle-aged men in lab coats—the trope of a scientist if there ever was one—use wands to stir in oil barrels. Waving their wands, a myriad of consumer products levitate from the oil barrels, illustrating the real-life 'magic' of petrochemical production (Figure 1). Explaining this marvel to the Martians and, by extension, the viewer, Colonel Cosmic narrates these pictures, accentuating the range of everyday products that are, in fact, synthetic:

> Crude oil, like everything else, is made up by billions of tiny molecules, and using the magic of research, oil companies compete with each other in taking the petroleum molecules apart and rearranging them into… you name it: fabrics, toothbrushes, tires, insecticides, cosmetics, weed killers—a whole galaxy of things to make a better life on Earth (John Suther-land Productions, 1956, 10:15).

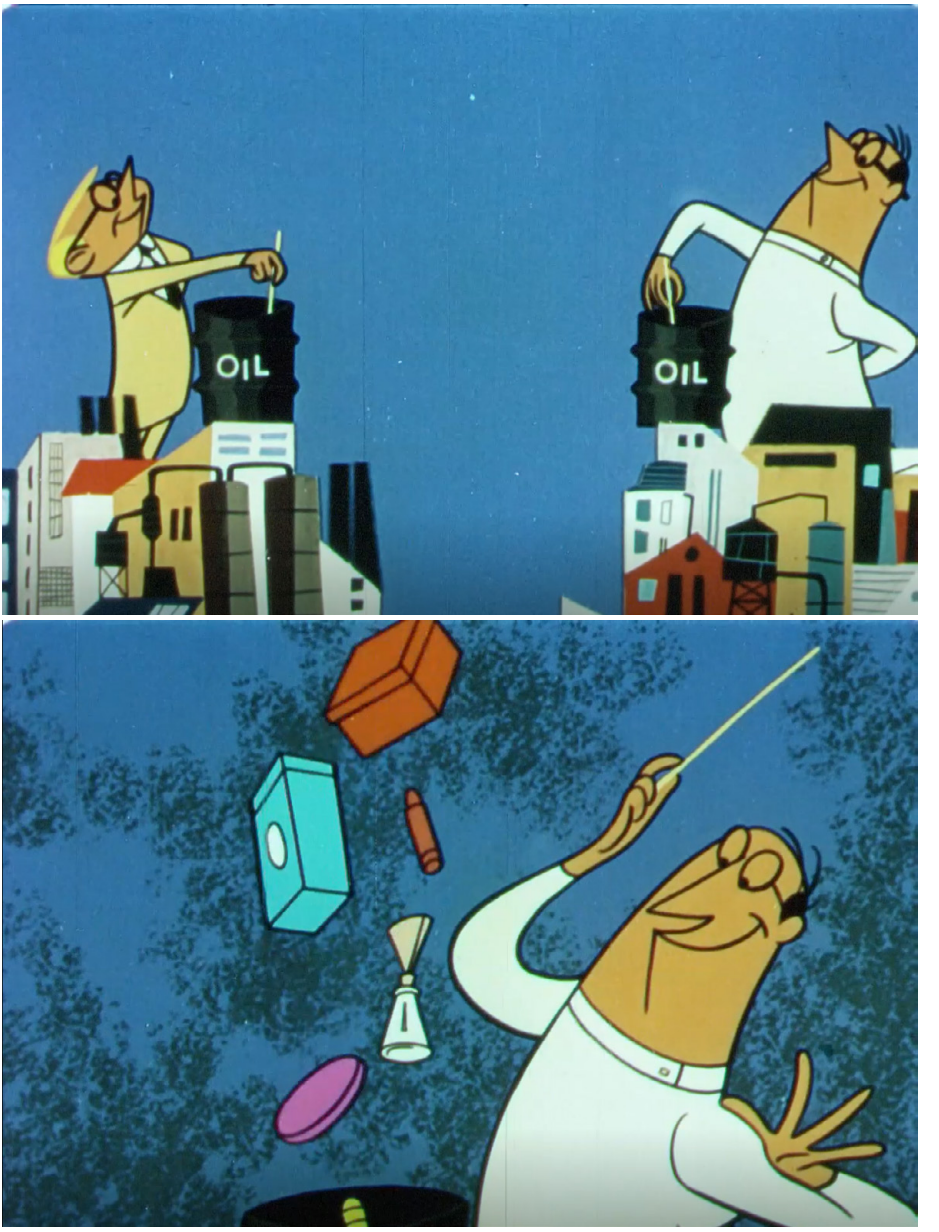


Figure 1. Stills from 'Destination Earth'
Destination Earth is a 1956 13-minute-long cartoon funded by the American Petroleum Institute that depicts the travels of Colonel Cosmic, lionising the oil industry. The still images are from 10:25 and 10:15. (John Suther-land Productions, 1956).

The fetishisation of the petrochemical industry and oil as feedstock in this passage is remarkable yet not surprising given the historical context. When this cartoon was released, the oil-based chemical industry was about to rise to dominance globally, consolidating and entrenching the fossil energy order and what international relations scholars later referred to as oil hegemony (Bromley, 1991). Moreover, the 1950's marked the beginning of the era of post-war capitalism's so-called 'Golden Age', with the emergence of the middle class in the United States and the Global North more broadly, who experienced and lived through the rise of mass consumption. Perhaps no wonder, then, that the American Petroleum Institute wanted to be credited with this development.

The role of synthetics in making mass consumption possible, that is, the necessity of petrochemicals to make possible the portrayed consumerist version of 'the good life' on display in Destination Earth, characterised a broader commercial strategy of oil and chemical companies at the time. In his book on the role of oil in popular culture in the United States, Matt Huber describes how petrochemicals and the synthetic products derived from them were critical in making oil 'constitutive of a specific cultural politics of life in the United States', defining 'ideas of "the American way of life' (the book also includes a quick aside on Destination Earth) (Huber, 2013, p. xii). Including an analysis of the role of plastics, fertiliser and petrochemicals more broadly, Huber argues that 'the petroleum industry both materially and ideologically situated the vast array of petroleum products at the center of a particular vision of entrepreneurial life' (Huber, 2013, p. 92). Standard Oil (which today is ExxonMobil), for example, noted in a 57th-anniversary television special that '[rubber, manmade fibres, roads, medicines are] all made from that incredible chemical wonderbox petroleum', emphasising the relationship between oil and 'this thing called progress' (cited in Huber, 2013, p. 72). In a more expansive ad campaign promoted by Shell in 1956, 'From A to Z—An Alphabet of Good Things about Petroleum', the company listed an imaginative range of products and activities to which the oil industry claimed affiliation, that is, the '1,001 good things oil brings you'. For one, Shell noted that H was for hydrocarbon: 'Shell's scientists are hydrocarbon experts [who] (…) know how to rearrange the carbon and hydrogen atoms to get exciting new compounds not found in nature' (cited in Huber, 2013, p. 83). Tying petrochemicals to 'modern life', H was also for home because 'home is a house that oil built'—stressing that paints, polish, plastics and asphalt-shingled roofs were all fossil-based. Using these as well as several other examples, Hubert shows

that such efforts created 'the appearance of an individuated or fractionated life' with oil as the foundation on which social reproduction depended.

The efforts to make individuated understandings of the connections between petrochemicals and mass consumption visible later faded, which Huber suggests is a result of increased 'social anxiety over the environmental and health effects of petro-capitalism' (2013, p. 92). However, efforts to frame and promote the necessity of petrochemicals for 'modern life' and the efforts to erase and downplay alternatives to such modes of living constitute an engrained part of the industry's self-understanding (Mah, 2023; Palm, 2024). In fact, as I argue in this thesis, not only have such efforts reemerged and are gaining momentum, they are also integral to the political economy of petrochemical transitions.

2.2.3 A legacy of 'deceit and denial'

At this point, I want to raise a final aspect of the history of the chemical industry that plays into the political economy of petrochemical transitions, namely the propensity for producers to continuously play down the environmental and health-related consequences of production. To justify and legitimise toxic production, producers and others who saw their interests align with those of the chemical industry simultaneously worked on two fronts: accentuating benefits and talking down negative impacts. That is, incumbent actors have not only sought to, as we have just seen, lionise the industry on the basis of its outputs (with the Destination Earth cartoon and the Shell A to Z campaign exemplifying such fetishisation). They have also played down and framed out the environmental and health-related impacts of chemical production when faced with opposition.

To explain the workings of the petrochemical industry, Mah emphasises how the sector is infused with what she refers to as 'militaristic' strategies, that is, large producers rely on military logic and a language of risk assessment to plan their operations (2023, p. 9). With the industry originating from war (cf. Section 2.2.1), having a long history of cartels and price collusion, and needing to navigate the geopolitics of energy, these logics are historically rooted (Buch-Hansen & Henriksen, 2019; Mah, 2023, pp. 25–30). It is perhaps no wonder then that the history of petrochemicals is riddled with instances of strategic manoeuvring when industry actors have come under pressure. A notorious example is the Responsible

Care programme from 1985, a voluntary industry initiative adopted worldwide by industry associations. Instigated by chemical disasters, new environmental regulations and protests, the legacy of the programme is one of failure and opportunistic behaviour, showcasing the limits of voluntary industry-led environmental initiatives (King & Lenox, 2000). And not only did the programme itself not instigate substantial changes, it also functioned as an attempt to anticipate further regulation, hoping to delay or even block such policies (Mah, 2022, 2023).

One of the most well-established critiques of the chemical industry is the 'deceit and denial' of toxic health hazards (Markowitz & Rosner, 2013). The basic tenet of this tactic is to hide or spread uncertainty, that is, 'manufacturing doubt' around the toxicity of various petrochemicals, so as to deny or, at the very least, obfuscate their negative health effects (Michaels, 2008). Providing an overview of such tactics, Goldberg and Vendernberg identify 28 unique strategies, including attacking studies on the basis of issues that have small effects on outcomes, using absolutist and inflated language to describe critiques and cherry-picking data (2021). This legacy has also propelled researchers studying the toxicity of chemicals and plastics to warn against conflicts of interest in the ongoing plastic treaty negotiations as well as the intergovernmental science-policy panel on chemicals, waste and pollution prevention (that in 2022 was decided to be set up alongside the intergovernmental panels on climate change and biodiversity) (Schäffer et al., 2023; Wagner, 2024).

One of the most recent revelations that directly ties into petrochemical transitions relates to the issue of recycling. In a report published in 2024 by the advocacy group the Center for Climate Integrity, the organisation builds on previously revealed as well as hitherto unknown internal documents from petrochemical plastic producers and industry associations, showing internal scepticism towards recycling to address plastic pollution while promoting it publicly as a silver bullet (D. Allen et al., 2024; Sullivan, 2020). The most famous example is that of the chasing arrows, the 'Voluntary Plastic Container Coding System' introduced in 1988 by the Society of the Plastics Industry (today the Plastics Industry Association) (Freinkel, 2011; Noor, 2024). Found everywhere on plastic containers, the number refers to different types of resins, and the arrows symbolise recycling. But despite giving the impression that products are recycled or, at the very least, recyclable, the system had little practical significance and did not

improve recyclability. In fact, the classification system met opposition from before it was put into use, being criticised for creating confusion and misinterpretations of the state of recycling. Still, industry actors pushed for the adoption of the arrows, benefiting from instilling the idea that recycling was the norm (D. Allen et al., 2024, pp. 12–13). With these aspects of the history of petrochemicals in mind, I now turn to the ongoing petrochemical expansion.

2.3 Expanding production capacity: A record-breaking decade

The historical growth trajectory of the petrochemical industry does not appear to be stopping any time soon. On the basis of expectations of increasing future demand for synthetics, a recent OECD report projected almost a tripling of plastic use by 2060 compared to today's levels under existing policy (OECD, 2022), while the International Energy Agency, in a big report from 2018, warned that petrochemicals would drive around half of the growth in oil demand until 2050, far outstripping all other channels (IEA, 2018). This outlook has given rise to the notion that petrochemicals are 'the future of oil,' as an industry magazine put it in 2019 (Tullo, 2019), and recent analysis confirms that developers, companies, investors, and public financial institutions agree (in terms of the latter see Skovgaard et al., 2023). At the very least, petrochemicals are now the definitive driver of fossil fuel demand growth. And, when considering planned investments and the industrial clusters that are currently under construction, this trend is set to continue in the ongoing decade (Bauer & Fontenit, 2021; IEA, 2023a, 2023b).

The reason why petrochemicals are projected to be the main driver of oil demand growth comes down to the continuation of investments in further production complexes. Across the world, new facilities are opening and under construction, and records are shattered on a yearly basis. In 2017, for example, the world's largest integrated petrochemical facility ever built in one phase, Sadara, opened for commercial operation. As a joint venture between the American chemical major Dow and the world's biggest oil-producing company, Aramco, the Sadara project produces more than three million tonnes of chemicals and plastics every year, cracking naphtha on a massive scale (Aramco, n.d.). In 2021, after the construction of the second of three phases of construction, the so-called green

petrochemical base in Zhoushan in East China became the largest integrated petrochemical and refining complex and the world's biggest crude-to-chemicals complex (NS Energy, n.d.; The State Council of the People's Republic of China, n.d.). The complex, in which Aramco also has a stake, has a production capacity of 4.2 million tonnes of ethylene per year and almost 12 million tonnes of aromatics, alongside 40 million metric tonnes of refined oil, according to Chinese state media (China Daily & Zhoushan Daily, 2023). The volumes are almost unfathomable.

It is not just oil but all forms of hydrocarbon demand that are fuelled by record-breaking petrochemical buildout. New plants also source natural gas, natural gas liquids (mostly ethane, a by-product of extraction), and coal as chemical feedstock. For example, in 2019 alone, 13 cracker projects started across the United States, the highest number ever up until that point, according to the accounting giant Deloitte (Dickson et al., 2020). And in early 2024, the construction of the Ras Laffan project began, which is set to become the largest ethane cracker in the Middle East, when QatarEnergy and Chevron Phillips jointly committed to sourcing fossil gas for petrochemical plastics. When finished in 2026, the site will produce an additional 3.8 million tonnes per year (Brelsford, 2024). In another instance of fossil lock-in, the British petrochemical major has committed to expanding production in Europe, which has otherwise been exempt from the investment frenzy. In Antwerp, INEOS is set to source ethane enabled by fracking in the United States for petrochemical plastic production in the first steam cracker on the continent in the last two decades (Pooler, 2019). And as for petrochemicals and coal, the growth in emissions from plastics production relates to the expansion of coal-based petrochemical production in China and elsewhere, where coal continues to be integral to the energy system (for overviews of the geography of production and the largest producers, see the thesis papers) (Cabernard et al., 2021).

At the same time as fossil-based production capacity is growing, the time for changing course towards decarbonisation is running out. If one is to rely on answers from techno-economic modelling, all new investments must be 'near-zero' production facilities by the end of this decade, for a chance of avoiding the most catastrophic impacts of run-away climate change (IEA, 2021a). This logic follows the cycle of large-scale infrastructure investment. Because chemical facilities typically run for half a century before they are retired, being revamped

once every 25 years on average, investments in this decade are particularly important (IEA, 2021b). The critical nature of investments and the urgency to change practices are thus not only in terms of greenfield sites but also opportunities for reconfiguring existing facilities.

The ongoing expansion of production capacity comes with important implications for the prospects of such investments. As the supply of various petrochemicals continues to increase on a global scale, producers are further subjected to the dynamics of competition in an industry where cost-minimisation and process optimising are key. New facilities like the ones pointed to above are premised on massive production volumes and low-cost feedstock to optimise costs (IEA, 2018, 2023b), and with clear cost-disadvantaged and high uncertainties around low-carbon alternatives, fossil-based investments are the safe bet. As explained by Shell CEO Wael Sawan on an earnings call in February 2024 on a question concerning Shell's new cracker in Pennsylvania, margins are the name of the game:

> Our focus right now is on volume, on just pushing the volume through the plant. And why is that? That [is] because the differentials at the moment between the gas price and the product price are significant. (Seeking Alpha Transcripts, 2024)

This type of expansion and the price competition it entails for petrochemicals globally puts pressure on operating rates and profit margins, 'weighing' on petrochemicals, as the leading industry consultancy S&P Global put it in an analysis of the market situation at the beginning of 2024 (Westervelt, 2024). In fact, the outlook for petrochemicals, the International Energy Agency argued, raised what the agency referred to as 'the spectre' of plant closures (IEA, 2023b, p. 29). And so, industry market dynamics, rather than the imperative of lowering emissions and plastic pollution, might drive old facilities out of production.

Along the same lines, European industry actors have continuously been warning of a future of decreasing competitiveness and low margins (see, for example, Cefic, 2019, 2021, 2023), dreading the 'overcapacity' that lowers the profitability of European production and calling for European politicians to subsidise the industry (Young, 2023). Such rhetoric has been a long-standing strategy of European industry actors in general, successfully influencing European environmental and climate policy (Sato et al., 2022; Wood et al., 2020). The intensification of international competition is, however, a trend across industrial

sectors that has become increasingly prominent since the 2010s (Alami et al., 2023; Schwartz, 2022). And with increasing international competition and a business built around cost minimisation, promoting one's decarbonisation efforts—which ultimately requires making billion-dollar investments in high-risk, immature technologies critically reliant on vast infrastructural developments—might not be the most obvious business strategy. That is, unless such tactics bolster against criticism, allow for the continued operation of legacy assets and introduce potential new sites of capital accumulation.

3 Foundations

To grapple with the political economy of petrochemical transitions, this thesis engages with various traditions in the social science literature on energy. These are implied by the terminology I use to frame the matter. That is, I take a political economy approach to studying sustainability transitions. Associated with different theoretical foundations, disciplines and strands of thinking, political economy and sustainability transitions research have increasingly been considered in tandem, with scholars exploring questions that are foundational to the various approaches related to political economy in their efforts to understand socio-technical systems. At the same time, scholars in international political economy and beyond have sought to make up for the discipline's historical inattention to matters of ecology and climate, immensely enriching the social science literature on energy transitions. In this chapter, I briefly review transition studies and the political economy of energy transitions literature as the theoretical underpinnings of this thesis, focusing on the contested nature of change processes. I position the thesis in relation to this scholarship, starting from the position that transition-oriented research should engage with questions of political economy to address the politico-economic dynamics of various and differentiated socio-technical reconfigurations that constitute industrial decarbonisation. First, however, I contextualise the notion of petrochemicals as a blind spot.

3.1 The petrochemical blind spot

In the introduction, I noted how the International Energy Agency director, Fatih Birol, in the forewords to a comprehensive 2018 report on the industry, declared that petrochemicals constituted a 'blind spot in global energy.' With this wording, Birol did not call for energy transition scholars to untangle the role of petrochemicals and oil as feedstock in global configurations of power and the fossil

energy order. Instead, he called attention to the energy consumption of chemicals in a more direct, limited way: as a major area of energy demand (IEA, 2018, p. 3). The report was one in a series on areas of high energy demand worthy of attention, the others being air conditioning and trucks (with particular attention to energy efficiency). But while these subject matters are certainly important for energy transitions in their own right, playing key roles in cooling and mobility systems, and with their own set of contested futures, the role of petrochemicals cannot be reduced to substituting a set of artefacts in specific socio-technical systems. Petrochemicals sit elsewhere, reaching into many more domains, including cooling and mobility systems. In fact, neither air conditioning nor trucks would exist in their current form if we did not live in a synthetic world. Going beyond its face value, the blind spot that Birol pointed to, that is, the recognition of petrochemicals as a key energy concern by a central institution in the international liberal energy order, is a signifier of the importance of the function of hydrocarbons as feedstock to that very order.

To be fair, there are several accounts of the petrochemical industry, its emergence and its deep entanglements with fossil fuel interests. These, however, are mostly written by chemical engineers from the vantage point of industry. Reviewing the scholarly engagement with the history of petrochemicals in a 2021 article in New Left Review, Adam Hanieh references some of the most notable work written from an insider perspective (cf. Chapman, 1991; Spitz, 1988), but also emphasises the lack of (recent) engagement from scholars of approaches associated with critical political economy. Exceptions exist, Hanieh notes (for example, Huber (2013), Moore (2015), or Bridge and Le Billion (2017)), but these vary in terms of their consideration of petrochemicals and have their main focus elsewhere. Hanieh, therefore, goes on to address this gap, mapping the history of petrochemicals and the co-development of fossil fuels and chemicals in the 20th century. Moreover, although the petrochemical industry has attracted relatively little attention in the macro- and meso-oriented, energy-focused social science literature, plastics and chemicals more broadly have been subject to research for decades. In terms of plastic and chemical governance and policy, however, such work has tended to mirror the orientation of mainstream policy discourse and focus on pollution, toxicity and waste management (Nielsen et al., 2020; Palm, 2024).

There are also several important accounts and analyses that focus on the power struggles related to chemical production, in particular the literature on environmental justice and environmental racism (among the most prominent are B. L. Allen, 2003; Bullard, 1993, 2000; Davies & Mah, 2020; Lerner, 2005, 2010), as well as work in decolonial traditions. For example, writing from an anticolonial perspective, Liboiron foregrounds colonial land relations rather than capitalist structures as such. In their analysis of pollution, they emphasise how settler mentalities persist and justify the claiming of indigenous lands as sacrifice zones for pollution and toxic chemicals, arguing for a practice of anticolonial science to avoid reproducing settler mentalities (Liboiron, 2021). Building on such perspectives, scholars have invoked the notion of plastic waste colonialism to understand the global dynamics of plastic (waste) trade, highlighting the export of toxic waste from countries in the Global North to countries in the Global South to illustrate how the current configuration of plastic waste flows reproduces colonial structures (Gündoğdu, 2024).

In recent years, more research within the social sciences has started to explore the current predicament of petrochemical transitions (see, for example, Mah, 2021; Skovgaard et al., 2023). In two books published in 2022 and 2023, Alice Mah engages with the multi-facetted and multi-scalar dimensions of plastics and petrochemicals (2022, 2023). While the former focuses mainly on plastics, the latter gives one of the most comprehensive introductions to the current complexities of petrochemicals across scales to date. Contemplating a wide range of issues, Mah addresses the ubiquity of petrochemicals in consumer and industrial products, the economic dependence on the industry in certain regions, the state-sponsored oppression of protests and movements and the malintent of industry actors. In this thesis, I take up some of the same themes (one of the papers is in fact co-authored with Mah) but I expand on and add to this work in a number of ways. I do so by directly addressing the contestation over petrochemical *transitions* (as well as working with different concepts, methods and data). What I mean by this is that I work with a different but complementary set of research questions, studying the extent, form and scope of change processes in relation to the imperative to decarbonise that the petrochemical industry faces. Exploring how actors in positions of power favour and push certain socio-technical reconfigurations, my account is primarily transition-focused. Thereby, I seek to add to the long-standing literature on chemicals and environmental justice, complementing it with an account of how incumbents navigate the issue of

climate change, which historically has been a lesser concern in comparison to pollution.

In terms of literature that deals specifically with petrochemical transitions, a whole host of techno-economic scenarios and models have been published since 2018. This work includes both scenarios that strictly focus on plastics, solely consider the climate impact of production, or explore a specific mitigation option, as well as scenarios that model the petrochemical industry as a whole and seek to address multiple impact categories or planetary boundaries (for examples of all the aforementioned categories see Bachmann et al., 2023; Galán-Martín et al., 2021; Gao & Cabrera Serrenho, 2023; Kätelhön et al., 2019; Lau et al., 2020; Meng et al., 2023; Stegmann et al., 2022; Vidal et al., 2024; Zheng & Suh, 2019). This literature, however, remains techno-economical in nature, leaving out questions of power and contestation almost entirely. Instead, questions of model choices, assumptions and feasibility dominate, limiting the type of engagement and the scope of possible transitions that are considered. For example, in their 2020 paper published in Science modelling plastic pollution, the 'System Change' scenario of Lau et al. (2020) entails that the total yearly (not to mention the accumulative) plastic mass that is disposed of and mismanaged every year does not decrease until 20 years after the beginning of the scenario (from 2016 to 2035), only the composition between the two categories changes.

The examples of engagement with chemicals that I focus on here relate to various disciplines in the social sciences and the humanities. It is therefore worth noting that the literature that perhaps most directly takes the (un)sustainability of chemical production as its starting point is that of 'green chemistry', which emerged in the late 90's (Anastas & Kirchhoff, 2002; Erythropel et al., 2018). In response to criticisms of toxicity and pollution, green chemistry research seeks to practice design principles that limit the adverse consequences of production, use and recycling in the name of sustainability. As important as such research arguably is, it operates within and contributes to the wider political economy of petrochemicals. In other words, such research is embedded within a material, institutional and discursive context, a certain social order, and is part of the power relations that shape petrochemical production. Seeking to lower or minimise harm while leaving other aspects of petrochemical production unquestioned normalises synthetics and accepts the notions of progress and modernity that the

industry is premised on. In leaving the sustainability of chemicals to chemists, the political economy of petrochemical transitions is rendered obscure.

Consider this introduction to a 2020 special issue review in Science on the importance of green chemistry:

> The scientific question facing the chemical sector when designing for the future Earth is not whether products of the chemical industry will be necessary, because they surely will be. Rather, the question is, what will be the character, nature, and production processes of synthetic chemicals needed for a sustainable civilization? Chemistry has a long history of inventing essential and beneficial products and processes with extraordinary performance; however, this technological progress has often been realized using a narrow definition of function, which does not account for adverse consequences. (Zimmerman et al., 2020, p. 397)

This justification of the chemical industry, or what in practice is a lack thereof—simply asserting the self-evident necessity of petrochemicals—implies that there is no politics to confront. Why engage in contestation over what we know 'surely will be'? In line with the mentality of post-political environmental and climate governance (cf. Swyngedouw, 2011, 2013), the task of research in petrochemical transitions is limited to the task of 'sound' management and the aim of green chemistry to curb the adverse consequences of chemicals.

To avoid this trap, addressing the petrochemical blind spot is of critical importance to the political economy of energy transitions. If not, we 'frame out' the world of synthetics in debates on the global energy order and its (re)production. Such obfuscation amounts to sidelining the issue of fossil fuels as feedstock, implicitly reducing it to a matter of the sustainability of chemicals, thereby disregarding its regional, global and geopolitical implications. Because the implications of petrochemical transitions are global in scope, and given the ability of vertically and horizontally integrated incumbents to operate across scales, it is important to place studies of specific petrochemical transitions in a global context. Through accounts of the global political economy in which the local, racialised, gendered and classist environmental (in)justices of petrochemicals are embedded, we can come to identify the constellations and dynamics of power that make them possible. When studies of energy transitions disregard fossil fuels as feedstock, we implicitly accept a depoliticisation of the synthetic world in energy debates. As

put by Adam Hanieh, commenting on the lack of engagement with petrochemicals (2021, pp. 28–29):

> In reducing the problem of oil to simply the question of finding an alternative source of energy and transport fuel, we implicitly confirm the invisibility of petrochemicals. We remake our synthetic world as something natural.

In making this argument, I am not trying to imply that there is an independent 'natural' non-synthetic world that a collective 'we' (as environmentalists) should strive for a return to, nor that replacing fossil fuels with, for example, bio-based feedstocks for plastic materials brings us 'closer to nature' in any ontological sense. The materials that make our world synthetic, including the host of thermoplastics, resins, rubber and monomers, as well as the agrochemicals, are used for many different purposes with many different consequences. Therefore, we should engage with the consequences and governance of synthetics alongside the contestations and sources of power that shape such governance. By making the synthetic world visible, it becomes possible to act on it. Following such reasoning, this thesis engages with the synthetic world and its ongoing reproduction.

3.2 Cooperation or conflict—approaching the political economy of energy transitions

Fuelled by an unfolding climate crisis and looming catastrophe, the study of energy transitions and sustainability more broadly is today a mainstream topic in many academic circles. This mainstreaming is, however, a somewhat recent phenomenon. Following years of neglect in the social sciences, be it political science, sociology, or economics, prominent academic outlets now regularly publish commentaries and perspectives calling for urgent action and new forms of engagement while scolding social scientific disciplines for their historical lack of engagement with the climate crisis (for evidence of this neglect see Goodall, 2008; Hadden & Prakash, 2024; Hiltner, 2024; Stern & Oswald, 2019). A similar trend was prominent in political economy, which, like other economy-oriented research tended to think of the ecological consequences of economic affairs as secondary (Paterson, 2020). However, in line with the increasing attention to the consequences of climate breakdown and the institutionalisation

of a decarbonisation imperative, the scholarship on the political economy of energy transitions has expanded immensely, and socio-ecological transformations are today a core research focus in political economy (Newell et al., 2021). Although engagement with the role of chemicals in the energy order is somewhat limited in political economy, the literature has a lot to say on processes of societal change and energy transitions more broadly. In particular, the focus on societal contestation and the ways in which power operates is crucial to understanding why and how various actors seek to influence transitions across space and time.

In contrast to approaches associated with political economy, the sustainability transitions literature emerged as an effort to understand and position transitions as a scholarly topic in and of itself in need of particular attention. Having its roots in, inter alia, innovation studies, economic history and evolutionary economics, transition studies grew from being effectively non-existent in the beginning of the millennium to become an important and influential interdisciplinary field that is still on the rise (Grubler, 2012; Köhler et al., 2019). Focusing on the provision of key societal functions, the various approaches that constitute transition studies bring into focus the socio-technical aspects of transitions, emphasising the co-evolutionary dynamics of the technological and the social at a meso-level (Köhler et al., 2019).

An overall but also somewhat crude dividing line between the approaches associated with transition studies and political economy, respectively, relates to their scholarly origin, which gives rise to different foci and entry points. Whereas sustainability transition studies foreground a co-evolutionary perspective and the co-development and entanglement of the social and the technological, political economy approaches tend to emphasise domination and conflict between actors and groups, which in turn decide distributional outcomes. Whereas sustainability transitions revolve around the socio-technical systems that provide essential societal functions, political economy revolves around explaining and understanding the social forces of capitalist societies. And finally, whereas the central idea of socio-technical regimes in transition studies tends to emphasise mimetic pressures (building on ideas in institutional theory) by analysing regimes, that is, the most strongly institutionalised cultural-cognitive rationalities and logics, political economy approaches tend to emphasise coercive pressures.

The fields of transition studies and political economy have increasingly been brought into dialogue. Scholars of political economy have flagged the relevance of

accounting for socio-technical perspectives (Newell, 2021; Newell et al., 2021; Paterson, 2020), and transition scholars have called for increased and explicit engagement with questions of political economy and capitalism (Feola, 2020; Kungl, 2023). These calls highlight the relevance of engaging transition studies and political economy approaches in tandem—appreciating the particular socio-technical complexities while not framing out the capitalist dynamics that shape transitions. Transition studies have, however, over time and in various ways, been criticised for a lacking and misguided engagement with the politics of transitions (Avelino et al., 2016; Baker et al., 2014; Bridge & Gailing, 2020; Scoones et al., 2015; A. Smith & Stirling, 2010). Newell, for example, highlights Eurocentrism, methodological nationalism, underappreciation of the power of 'regime stakeholders' including multinational firms, and lack of engagement with 'deeper political enabling environments', as limitations of mainstream transitions literature (2021, pp. 30–34). With increasing attention to power and politics in sustainability transitions research, however, the issue is no longer whether studying and understanding contestations of power is relevant—it clearly is—but how to approach, engage with, and conceptualise these issues.

To be sure, this short characterisation of these whole bodies of literature in single paragraphs is rather crude and does not go a long way in doing justice to the nuances of these traditions. Transitions studies as well as political economy both denote a diverse set of approaches and methodologies, and so below I introduce the approaches and contributions that I mobilise in this thesis to conceptualise the political economy of petrochemical transitions.

3.2.1 Political economies of energy transitions and climate change

The notion of political economy is associated with a number of different traditions. From the classical political economists of Marx, Ricardo and Smith, over public choice theory associated with economics and mathematically formalised models of political behaviour, to approaches focusing on questions of global political economy (Paterson & P-Laberge, 2018). In this thesis, I engage with the latter, mainly referencing what collectively has been referred to as 'critical political economy' (Newell et al., 2021; Paterson & P-Laberge, 2018). Newell et al. explain the main tenets of the 'multifaceted and diverse enterprise' that is critical political economy:

> [A] unifying theme and contribution are the operations and contestations of power across time, space and scale (…). Applied to contemporary societies, this amounts to a consideration of the constraints and opportunities posed for transformations of capitalist societies as they navigate a series of contradictions in responding to the climate crisis in particular. (Newell et al., 2021, p. 904)

Amongst these approaches focusing on capitalist contradictions (which include, for example, regulation theory and the dependency research programme), I focus on the application of neo-Gramscian thought to a transition context, as well as the concepts of spatio-temporal and technical fixes, as they have been associated with cultural political economy and the notion of mitigation deterrence. I outline these perspectives in more depth below.

3.2.1.1 Neo-Gramscian perspectives on energy transitions

Recent literature demonstrates the merits of applying the conceptual apparatus of neo-Gramscian theory to understand change dynamics in the context of sustainability transitions (the qualifier reflects a non-doctrinaire reliance on the writings of Antonio Gramsci while acknowledging intellectual debts owed to others) (see, for example, A. Ford & Newell, 2021; A. S. Ford, 2020; Newell, 2019; Szabo, 2022). These dynamics play out in 'wars of position', where contestation between various actors and actor groups in different positions is constantly ongoing and evolving. In this 'endlessly unfolding' process, actors coordinate and leverage power strategically in different spheres (Levy & Egan, 2003, p. 810). I lay out these spheres or dimensions of power below, later mobilising them to structure Chapter 5, before introducing the neo-Gramscian concept of trasformismo, which informs my overall argument in this cover essay.

In their 2021 paper reviewing the relevance of neo-Gramscian thinking for energy transitions, Ford and Newell (2021) outline three dimensions of power, namely material, institutional and discursive. These three are relevant because they relate to the forces that reproduce organisational fields and thus map the contours of corporate political influence (Levy & Egan, 2003). In the neo-Gramscian account, coercive measures also help explain stability in the grander sense. That is, in terms of hegemonic projects, the potential and actual use of force play a constitutive role (Cox, 1999; Levy & Newell, 2002). But to understand the strategies of incumbents in the petrochemical industry and their respective

capacity to influence socio-technical (re)configurations, the three dimensions of power are worth granting particular focus.

Material power arises from controlling what in ecological economics is referred to as the social metabolism, the totality of 'physical processes that convert raw materials and energy, plus labour, into finished products and wastes' (Ayres, 1994, p. 16; Krausmann, 2017). Actors that control production, finance and technologies hold a commanding position in terms of securing core state objectives and facilitating capital accumulation, manifesting material power in the form of physical, human and financial resources (A. Ford & Newell, 2021). In terms of material power, the petrochemical industry is placed in one of the bottom layers of what Herman Daly, in his metaphor of the economy, described as an inverted pyramid—that is, how the wide range of human production and activities is dependent on a limited resource input to be possible, most notably fossil fuel. In this sense, the structural importance of an industry can go way beyond its contribution to monetary value added (Cahen-Fourot et al., 2020; Kemp-Benedict, 2014), as illustrated by how the prices of chemicals are systematically important, influencing general price levels (Weber et al., 2024). In this sense, material power is structural power (A. Ford & Newell, 2021).

Because of their material power, actors also have institutional power. That is, actors that are regarded as important in securing state objectives get to play an important role in decision-making processes, exercising institutional power in both formal and informal contexts (A. Ford & Newell, 2021). Examples of this are numerous and include the whole range of lobbying activities, revolving doors and direct financial support of politicians and parties, whereby industrial actors play important roles in shaping policy (Newell, 2009). Co-evolving with this institutional power is the third and discursive dimension of power, which refers to the capacity to shape the framing of a given issue in order to influence how that issue is approached, made sense of, and thereby responded to and dealt with (Newell, 2009). Like the sphere of institutional power, the avenues of influence are numerous and include public relations, marketing and communications activities of a variety of sorts across the media system.

Together, the three abovementioned dimensions of power help explain differences in influence and means of shaping transitions. Because the overall aim, from a neo-Gramscian perspective, is to maintain a dominant position or hegemony in the web of social relations, transition pressures constitute a challenge for

incumbent actors (Newell, 2019, 2021). To describe and explain the strategies and manoeuvres of incumbents when faced with contestation, the Gramscian notion of trasformismo is particularly relevant. Encompassing the reproduction of hegemony through the exercise of material, discursive and institutional power, trasformismo denotes a process of co-optation that neutralises 'potentially counter-hegemonic ideas and activities' by bringing them 'within hegemonic frameworks' (A. Ford & Newell, 2021, p. 3). What is crucial is that this concept admits that shifts in socio-technical configurations can and do occur, but that the forms that such shifts take, the interests they support and the social relations that facilitate them are critically important. Trasformismo captures 'limited forms of transitions aimed at creating new sites of accumulation' (Newell, 2019, p. 29), that is, the carving out of 'green capital accumulation' by particular actors in reference to the sustainability agenda and the imperative of decarbonisation (Ponte, 2020). In this sense, trasformismo grants attention to adaptation and absorption, in contrast to conceptualising resistance predominantly as inhibition (Bates, 2013; Newell, 2019).

3.2.1.2 The cultural political economy of technical fixes and mitigation deterrence

The second approach related to political economy applied in this thesis builds on the tradition of cultural political economy. More specifically, I relate to and extend the cultural political economy of 'technical fixes' and 'mitigation deterrence' (see Paper 4). In cultural political economy, emphasis is given to the semiotic as well as the material, and social reality cannot be reduced to either. To describe semiotic systems, Jessop invokes the concept of imaginaries. These systems 'inform collective calculation about [an inordinately complex] world' and constitute the 'semiotic moment of a network of social practices in a given social field, institutional order, or a wider social formation (2010, p. 344). In this thesis, I invoke the notion of imaginaries when studying the promises and visions of petrochemical futures promoted by incumbents.

In terms of sustainability transitions and socio-technical configurations, the cultural political lens emphasises the co-evolution of technologies functions alongside innovation and political regimes. Emphasising that these need to be understood in relation to each other, certain technologies gain prominence partly in relation to their 'fit' with prevailing institutions (Markusson et al., 2022). In the case of climate change and negative emission technologies, this fit leads to mitigation deterrence, that is, reduced and delayed mitigation, because the

promise or, in some cases, consideration of large-scale carbon removal discourage other climate interventions (Carton et al., 2023; Markusson et al., 2018). Mitigation deterrence arises from the risks of failure associated with such technologies, unintended spill-overs, and from discouraging other forms of action because of the anticipation of negative emissions (McLaren, 2020). The promise of carbon removal helps to maintain legitimacy and incumbency, shifting the problem to a future point in time (Carton, 2019). Technical fixes are thus, in conceptual terms, a subset of spatio-temporal fixes (Markusson et al., 2017). Here, a link exists to the neo-Gramscian perspective, briefly summarised above, in that technical fixes arguably constitute a manifestation of trasformismo. Such fixes function not only as a means of legitimising dominant actors engaged in the escalation of socio-ecological crises but also as a new frontier of accumulation (Markusson et al., 2017). In this thesis, I build on these insights to argue that the promise of carbon removal not only delays mitigation, but also the reduction of plastic pollution. In the context of petrochemicals, the promises of carbon capture, utilisation and storage, as presented in the circular carbon imaginary, take on a similar function to those of the promises of negative emissions in the case of fossil fuels as energy (for more on this parallel see Paper IV and chapter 5).

3.2.2 Socio-technical transitions and global regimes

The sustainability transitions literature has its origins in a wide range of fields dating back to at least the 1960s (Cherp et al., 2018). Sources of inspiration include innovation studies, science and technology studies, history of technology and more (Geels et al., 2023). Consolidating as a semi-coherent body of literature in the 2000s, a number of various frameworks, most notably the multi-level perspective, grew in influence to become core to tradition studies, (Grubler, 2012; Markard et al., 2012).

The core unit of analysis is the socio-technical system, typically defined as systems that fulfil societal functions such as water, energy, or mobility, or just consumption-production systems (Geels, 2010). These systems are stabilised by infrastructural, technological, institutional and behavioural lock-ins, which by themselves and through interactions foster path dependency (Seto et al., 2016; Simoens et al., 2022). The core and most strongly institutionalised configurations or patterns of technologies, actors and institutions of such systems are denoted regimes, while other and more weakly institutionalised socio-technical

configurations are termed niches (Fuenfschilling, 2019; Fuenfschilling & Truffer, 2016). The regimes include semiotic elements that are also emphasised in cultural political economy, such as rationalities and engineering logics (Fuenfschilling & Binz, 2018). The third and final level in the multi-level perspective, the landscape, captures broader societal pressures and dynamics outside any single system. A transition is then a change in the ways in which systems are structured and function, including cultural and political dimensions (Geels et al., 2023).

The actors that are most 'deeply entrenched' in a given socio-technical regime are said to be incumbent (Galeano Galvan et al., 2020, p. 79). Because this perspective is thereby premised on an alignment between a regime and the practices, rationalities and perceived interests of its incumbents, alternative socio-technical configurations have typically been understood to be threats, conceptualising incumbents as principally antagonistic to transitions. However, this somewhat reductionist perspective has been challenged in reference to the heterogeneity of types, strategies and resources of incumbent actors (Turnheim & Sovacool, 2020), and studies differ in their characterisation of the activities of incumbents (Kungl, 2023). Such arguments give further backing to the relevance of trasformismo as an analytical lens because the concept can help make sense of what can otherwise appear contradictory (such as incumbents simultaneously pursuing parallel strategies of decarbonisation and lock-in). Because I focus on incumbents and in particular incumbent firms, I elaborate on what I mean by this term in the context of this thesis below (see Section 3.3.1).

In the analysis of sustainability transitions, studies tend to focus on the regional or national, limiting their scope to country-level analysis. To address this limitation and to break from the tendency of methodological nationalism in transition studies, Fünfschilling and Binz (2018) introduced the concept of global socio-technical regimes, explicitly theorising a global dimension of socio-technical systems. The global regime concept draws on the literature on global production networks and value chains (bringing it into conversation with international political economy and economic geography), as well as new institutionalism. In their definition of the global regime concept, Fünfschilling and Binz extend the notion of the regime as defined above by noting how it can reach validity 'beyond specific territorial contexts' diffused through internationalised networks (2018, p. 739). To break existing lock-ins and enable transitions at scale, climate and sustainability initiatives therefore need to challenge not only the locally, regionally

and nationally embedded regime but also entrenched global configurations (Bauer & Fuenfschilling, 2019). Using the global regime concept as an entry point, subsequent work has explored the (de-)institutionalisation and re-scaling of global regime rationalities to understand the relationship between the global and specific territorial contexts, as well as the potential for socio-technical reconfiguration (Miörner et al., 2021; Miörner & Binz, 2021).

In this thesis project, the global regime serves as the conceptual basis for exploring the petrochemical industry from a transition studies perspective. In particular, I focus on the internationalised networks that constitute the relational backbone of global regimes and the largest producers in them. The initial conceptualisation of global regimes, however, does not distinguish between and specify the importance of different kinds of internationalised network relations in (re)configuring technologies, actors and institutions across scales. For this reason, I elaborate on the role of networks in global regimes in Paper II, theorising how trasformismo dynamics can play out in and through specific types of relations. In focusing on global petrochemical transitions, I do not engage with in-depth case studies of specific petrochemical clusters or systems. Although I draw on examples from a wide variety of contexts, I remain focused on the global level. The global regime concept thereby functions as a bridge between questions of global political economy, transition studies and specific territorial contexts, justifying the need to understand the global sector in an abstract, aggregated sense while allowing for a myriad of territorially embedded and specific dynamics and contradictions.

3.3 Approaching the political economy of energy transitions by seeing through the feedstock

Having set out the theoretical foundations of this thesis, the next set of issues arise: What perspectives and questions does this theoretical foundation give rise to when seeing fossil fuels as feedstock? In this section, I provide a preliminary answer that guides the summary of the papers and the subsequent discussion. First, however, it is critical to clarify two key concepts that are often subject to confusion and where definitions differ, namely i) incumbents and ii) transitions.

3.3.1 Defining petrochemical incumbents

Incumbents are, as mentioned above, the actors that mobilise regime rationalities, occupying the dominant space in socio-technical systems. There are, however, different and co-existing ways to classify incumbency. In particular, Kungl (2023) points out that for firm actors, there are different 'reference ontologies' as well as different characteristics that are used to identify incumbents. That is, there are different contexts (including market, geography and social field) and benchmarks (including size, resources and age) to evaluate incumbency against. Firms can play an important role in certain markets or geographies while not being entrenched in the globally dominant socio-technical regime. The Danish renewable energy company Ørsted, for example, which divested and sold off its fossil fuel assets in the 2010s, is no longer an incumbent in terms of the fossil energy regime but is arguably an incumbent in terms of renewable energy (at least in a market-oriented sense) as well as in the context of the Danish political economy (Voldsgaard & Rüdiger, 2022). Reviewing what he advocates as a desirable plurality of perspectives on incumbency, Kungl (2023), therefore, suggests that a definition of incumbency requires specifying the reference ontology and characteristics that incumbent actors are defined with respect to.

Across the different papers and this introductory text, I take a market-oriented approach to incumbency, meaning that I select data on the basis of size and chemical sales. I attended industry conferences that included speakers from some of the world's top producers and collected data on the biggest producers ranked according to sales (see also Chapters 4 and 5). Chemical sales are closely associated with production capacity, the size of operations and socio-ecological impacts. The rationale is therefore that, in terms of transitions, incumbency is meaningfully understoond in reference to the actors whose investments and operations need to undergo reconfiguration. This understanding of incumbency is particularly relevant in relation to the chemical industry, where large, long-standing firms are characteristic of regime actors (Bauer & Fuenfschilling, 2019). In the analysis, I do, however, pay particular attention to the ways in which specific firms are more deeply entrenched in the fossil-based chemical regime than other actors. As a results, I distinguish between different types of incumbents in reference to differences in assets, capacities, and, by extension, economic interests, as well as the different political contexts or regimes that the same incumbents operate across. Such distinctions are helpful to make sense of how and why strategies differ across

producers and geographies while retaining the basic distinction between incumbent or dominant actors and actors operating outside the logics and rationalities of the regime.

Incumbency, however, is not reducible to firm actors. While incumbent firms constitute the main analytical focus, it is important to understand the myriad actors that are also meaningfully classified as underpinning and supporting incumbency. These are the other regime actors—civil society and governments, state agencies and academic institutions—who, in various ways, reproduce entrenched social relations and power structures. In neo-Gramscian terms, such actor coalitions are known as a historical bloc (A. Ford & Newell, 2021). Moreover, key regime actors bridge these categories, such as in the case of state owned enterprises or state ownership and investments outside of the domestic context, associated with the 'current aggregate expansion of the state's role as promoter, supervisor and owner of capital across the world economy' (Alami & Dixon, 2023, p. 72). Moreover, incumbent actors can bridge the niche-regime distinction by participating in niches for a variety of purposes (Turnheim & Sovacool, 2020; van Mossel et al., 2018). Holding considerable financial and technological resources, incumbents can take over, engage with and strengthen various niches, such as when dominant firms buy up emerging competitors (which has also been the case in the context of petrochemicals). Expanding on these accounts, this thesis showcases how and why such participation and engagement take place (see Paper II).

3.3.2 Forms and characteristics of change: Transitions and transformations

The study of processes of change and stability is central to both sustainability transitions literature and neo-Gramscian political economy. More broadly, sociotechnical reconfigurations constitute change processes, and the aim of this thesis is to unfold and understand what shapes and influences such processes in the petrochemical industry. Therefore, we need to be attentive to how to conceptualise and categorise change. What does it mean to transition, and what dimensions are we attentive to when classifying certain developments as socio-technical or sustainability transitions? For example, if we focus solely on greenhouse gas emissions, we could classify a reorientation from coal-based to gas-based petrochemical feedstocks in China as a sustainability transition—a socio-

technical reconfiguration markedly lowering the climate impacts of chemical production. However, if we instead consider such developments in terms of changes to the global energy order, we might read a shift from coal to gas-based feedstocks as a strengthening of the already 'symbiotic' relationship between US supply and Chinese demand for petrochemical feedstock (IEA, 2023a), entrenching carbon lock-in through the creation of new and additional interdependencies.

The notion of transitions as a description of change is further complicated by how the term is sometimes used as synonymous with, while at other times in opposition to, transformation or transformative change (Child & Breyer, 2017). If explicitly delineated from one another, transitions are typically regarded as being narrower in scope than transformations. While transitions in this narrow sense involves 'realignment of technology, finance, infrastructures and institutions, where business as usual power configurations persist,' transformations necessitate 'disruptive and deeper change that seeks to chart a different direction, pursue different goals, and consciously unsettle existing power relations' (Newell, 2019, 2021, p. 36; Scoones et al., 2020; Stirling, 2014). Following this line of thinking, Vogl (2023, p. 41) uses transitions 'to describe the destabilisations and reconfigurations of single (socio-technical) systems, while transformations [connote] larger qualitative changes involving multi-system co-evolutionary change.'

As a helpful reference point for the distinction between transition and transformation, Buch-Hansen and Carstensen (2021) introduce a 'fourth' order of change, extending Peter Hall's (1993) seminal policy paradigm framework to capture deep forms of change. Going beyond Hall's third order paradigm shift (developed to make sense of the shift from Keynesian to monetarist economic policy), the fourth order entails 'the deepest form of social change in that it involves changes on all four levels: systemic logic, policy paradigms, instruments and settings' (Buch-Hansen & Carstensen, 2021, p. 312). Buch-Hansen and Carstensen (2021) apply the notion of fourth order change and systemic logic to distinguish between green growth and degrowth. Green growth, at least in principle, involves decarbonisation and electrification, requiring potentially disruptive realignments of the above-mentioned domains (technology, finance, infrastructure and institutions). Degrowth goes beyond this scope by involving changes to not only 'material transactions with nature' but also 'social interactions

between persons, social structure, and people's inner being' (Buch-Hansen & Nesterova, 2023, p. 1). In this sense, green growth involves transitions, while degrowth, by definition, is transformative.

The concept of trasformismo further helps to make sense of the distinction between transition and transformation. In these terms, trasformismo captures the co-optation of transitions to fend off transformations. Trasformismo also speaks to the complicated spatio-temporal entanglements between stability and change: reconfiguration in one place at a particular point in time, for example, a pilot project on electric steam crackers, might be associated with stability over time, to the extent that it functions as a technical fix. In this thesis, while I focus on transitions in the narrow sense, I do so by mapping the political economy of these, which in turn involves processes of trasformismo and, by extension, the closing down of more transformative pathways.

3.3.3 Approaching fossil fuels as feedstock

With the categories of incumbents and transitions delineated, we can turn to the uniting themes and guiding lines of inquiry that I mobilise to sketch a political economy of petrochemical transitions. The purpose of this exercise is to briefly outline what it implies to study fossil fuel as feedstock, that is, what one needs to account for to characterise the fossil fuel-chemical-synthetics nexus and answer the research questions raised in the introduction of how and on what basis petrochemical incumbents navigate transition pressures.

In this thesis, I draw inspiration from neo-Gramscian and cultural political economy approaches to study key elements of petrochemical transitions (incumbency, regimes), taking the use of fossil fuels as feedstock as the starting point. Centring feedstock implies seeing the ubiquity of synthetic materials in systems of production and consumption as co-evolving with the global fossil energy order, granting attention to the momentum of fossil fuels for petrochemical production. By accepting the relationship between energy and chemicals, or between extraction, fuels and synthetic materials, as a premise of rather than an end point for the analysis, the study of petrochemical transitions becomes the study of the development of this relationship. The question, then, as also noted in Section 2, is how a transition to renewable-based feedstocks is

possible, analysing what form it might take and which characteristics define its politics.

In more specific terms, I structure the analysis around an account of the material, discursive and institutional power of the industry to explain their relative influence. Understanding these three dimensions of power provides an answer to the question of on which basis incumbents can influence socio-technical configurations. To provide an account of how incumbents seek to do so, which in the context of socio-ecological crises involves navigating transition pressures, in turn requires explanation of how these various forms of power are mobilised, by which actors, in what settings, and with what consequences. To understand the motivations and actions of petrochemical incumbents, the various approaches reviewed above give related and complementary answers, namely maintaining a dominant position (hegemony), reproducing regimes, or pursuing new frontiers of capital accumulation. Moreover, through the concepts of lock-in, technical fixes and mitigation deterrence, allow for insight into the consequences of incumbents' actions. When taken together, approaching energy transitions from this position provides an entry point to study a single sector while accounting for its much wider implications for energy transitions and transformations.

It is from the foundation sketched out in this chapter that I seek to analyse the political economy of petrochemical transitions. But as with any study, this thesis is not defined alone by its theoretical foundation. In the following, I discuss issues of methodology, including the research paradigm underlying my approach as well as the methods and data that I mobilise across the five papers.

4 Methodology and methods

Issues of methodology are core to the practice of conducting research. Whether recognised explicitly on the part of the researcher or not, methodological assumptions implicitly shape how research is carried out and presented. Methodology is a term that is not to be confused with methods—although the two are closely related—because it speaks to something wider and more general, namely the ways in which the methods and the assumptions applied in scientific inquiry support a given approach to knowledge production (Grix, 2002). To foster reflexivity on the opportunities and limits of the knowledge production that this thesis contributes to, this chapter addresses methodological aspects. By explicitly addressing such concerns, I unfold an aspiration for methodological consistency while acknowledging the possible tensions that exist across the papers of this thesis. The first part of the chapter gives a brief introduction to issues of methodology. In a second section, I introduce the methods across the five papers of the thesis, before I end the chapter with a reflection on methodological consistency and possible tensions within the thesis, pointing to the ways in which I have sought to resolve them.

4.1 Methodology

The issue of methodology extends, as hinted above, beyond discussions on the selection and validity of specific research designs and methods to include ontological and epistemological dimensions of knowledge production. Methodology is, at the same time, not exclusively concerned with questions of ontology ('what is out there to know') and epistemology ('what and how can we know about it'), from which choices on methods and research design logically follow (Hay, 2002, p. 64). Rather, methodology is about the relationships between ontology, epistemology and methods, paying attention to their logic and

their (lack of) coherence (Moses & Knutsen, 2012). Given an ontological position of what there is to know in principle and an epistemological ditto on what and how we can know, methodology asks, 'how can we go about acquiring that knowledge?' (Grix, 2002, p. 180). Answering that question involves decisions on methods, which in turn implies assumptions on the relationship between specific methods, what to know (ontology) and how to know (epistemology).

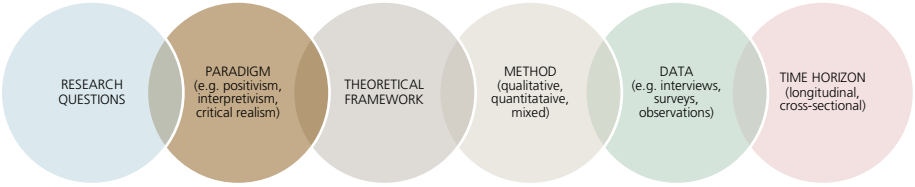


Figure 2. The research onion.
Each level of the onion is embedded within the other, the research question being the inner core, surrounded by the paradigm, and so forth. Adapted from Zolfagharian et. al. (2019).

The concept of the research onion (Figure 2) provides an accessible and intuitive way to address methodology and is a framework that has been widely used across research fields, including in a transitions context (Zolfagharian et al., 2019). It includes various elements of a research project, from the basic questions that a given project seeks to answer and the paradigm (including ontological and epistemological assumptions) in which such questions are rooted to methods and procedures for data collection and analysis. While I focus on some elements in other chapters (chapter 3, for example, is concerned with the choice of theoretical framework), and Section 4.2 of this chapter considers the outer layers, namely methods and data, all elements and their internal relations are part of the research methodology, playing into virtually all aspects of the thesis. A key aspect of methodology, guiding both the research project and the relationships between the different layers, is the underlying research paradigm, to which I now turn.

Mapping the field of transition studies, Zolfagharian et al. define the notion of research paradigms within the context of the research onion as 'the set of key beliefs and assumptions that affect (or guide) method selection' (2019, p. 3). A research paradigm, then, reflects certain ontological and epistemological positions, or, in other words, a philosophy of science, ideal-type examples of

which include (post-)positivism, social constructivism and critical realism (Alvesson & Sköldberg, 2010). Recognising the Weberian ideal-type character of such positions, I am inspired by *critical realist* approaches to conducting research. Because critical realism by now is a 'massive and highly complex field', as Buch-Hansen and Nielsen put it in a recent article on critical realism and the climate crisis (2023, p. 348), I delimit myself here to three aspects of critical realism (introduced in no particular order) that have inspired my work. This delimitation means that although critical realism takes different forms and its content is subject to ongoing negotiation, I focus the discussion here on its relevance in the context of this thesis and the ways in which my work has been influenced by critical realist thinking.

4.1.1 Approaching petrochemical transitions from a critical realist perspective

One of the ways in which I see this thesis as broadly aligning with critical realism is that I have been inspired by the notion of retroduction, which refers to 'reasoning about why things happen including why the data appear the way they do' (Olsen, 2007, p. 1). Retroduction is considered a mode of reasoning in research (others being induction, deduction and abduction) used by critical realists (Olsen, 2007). When I highlight it here, it is because I have sought to reflect on the way I understand and approach my data, considering why different forms of data appear in the way that they do, be it field observations or corporate ownership structures listed in global databases. For example, when reading through field notes from a senior manager's keynote talk at a petrochemical conference, I reasoned about why they accepted it and how that mattered for the content of the talk, as well as the context I was not able to observe, such as the behind-the-scenes dialogues that are part of such conferences. Or when petrochemical companies fill out surveys and questionnaires about their sustainability efforts, or when they report on their climate action in their own corporate sustainability reports, I reflected on what mechanisms that are likely to guide their reporting, influencing data collection choices (see, for example, the methods section in Paper II). More generally and in the context of climate change, Buch-Hansen and Nielsen ask us to consider the retroductive question: 'What must social reality in all likelihood be like for economic growth to continue in the face of an escalating climate breakdown?' (2023, p. 354). Rephrased in terms of

petrochemicals, we arrive at a question inspiring this thesis: What must social reality be like for petrochemical capacity to continue to expand in the face of a triple planetary crisis?

Secondly, I hold that the thesis project is broadly consistent with the basic tenets of critical realism. Without going into substantive depth, I want to highlight examples connected to this thesis and why I claim broad consistency. Critical realism holds that science should be thought of in two dimensions: the transitive and the intransitive. While the intransitive is the dimension of 'the being of objects of scientific investigation', the transitive is the dimension of 'socially produced knowledge of them' (Bhaskar et al., 2010, p. 1). This distinction highlights the social production of knowledge and underpins the critical realist position that scientific knowledge is incomplete, fallible and cannot be value neutral (Buch-Hansen & Nielsen, 2020). That the intransitive dimension exists independently of knowledge and discourse is known as ontological realism, while the social production of knowledge means that it is fallible and historically and socially dependent is the position of epistemological relativism (Buch-Hansen & Nielsen, 2023).

The distinction between transitive and intransitive highlights that the toxic consequences of petrochemicals occur regardless of our (fallible) knowledge of them, while the openness of reality and the multiplicity of mechanisms and processes occurring simultaneously help explain the difficulties of producing the type and form of knowledge accepted by dominant, positivist ideas of science. Identifying the social production of scientific knowledge as distinct from the intransitive dimension underpins the observation that the production of knowledge on the consequences and decarbonisation of petrochemicals is itself subject to and part of processes of contestation and dominance, that is, part of the political economy of petrochemical transitions (an element that pops up in different ways across Papers II, II and IV). In terms of the lack of value neutrality, I take a principled stand and point to the necessity of action in certain domains, readily accepting that this thesis is by no means value neutral, without going so far in the opposite direction as to shy away from making such recommendations because they can be problematised.

Another central tenet of critical realism that I posit illustrates consistency with this thesis is the notion of stratification, implying that the world consists of multiple layers or levels, including the physical, chemical and ecological as well as

the levels of the social world (Bhaskar et al., 2010). These layers are hierarchical in that they constrain one another, but while a given level is dependent on more basic levels, it is not reducible to them. In the context of petrochemicals, the notion of stratification is important because it allows us insights into the limits and possibilities of petrochemical transitions, as lower levels decide the scope of possibility. More specifically, the chemical level establishes the possible chemicals, reactions and methods for their facilitation, thereby defining the possibilities of chemical production. At the same time, a higher order social level provides the conditions for which chemical reactions are pursued. While something might be theoretically possible, for example, the production of fossil-free plastics via green hydrogen and the methanol-to-olefins route, matters of political economy decide the extent to which such operations will occur. At the same time, critical realism explains why the strata of nature are 'more basic than those of the social world, and the structures of nature are more firmly anchored than are those of society' (Buch-Hansen & Nielsen, 2020, pp. 37–38, 95, 2023, p. 350). In this way, while the chemical and physical levels that limit the possibilities of petrochemical production can hardly change, the emergent level of political economy that shapes transitions might.

The third and final aspect of critical realism that I want to highlight here is the approach that this position takes to theory. In critical realism, efforts to avoid the pitfalls of fully fledged realism and relativism, steering around reductionism while not wholeheartedly embracing constructivism (thereby collapsing the transitive and intransitive dimensions of science into one), are thought to be addressed through judgemental rationality. Judgement rationality suggests that theories and concepts applied in studies of social phenomena are not relativistic but that the researcher can give rational grounds for choosing one over the other (Buch-Hansen & Nielsen, 2023; Robert Isaksen, 2016). At the same time, critical realism does not imply a commitment to specific theories and is in this way 'fundamentally pluralistic' (Buch-Hansen & Nielsen, 2023, p. 352; Lawson, 1997). In other words, critical realism insists on openness towards theory choice while maintaining that this does not mean that 'anything goes'—relevant arguments exist to favour some theories and concepts over others in relation to the phenomena they seek to account for.

As mapped out in Chapter 3, this thesis project draws upon different theories and concepts and seeks to put concepts from different traditions into conversation

(most notably in Papers II and III). This aligns with the position that a single, comprehensive theory of social change cannot reflect the nature of social reality in its totality and, instead, 'an eclectic ensemble of theories of mid-level processes and mechanisms' (Little, 2016, p. 260), or theoretical triangulation (Downward & Mearman, 2007), is a better approach to social science. Each paper seeks to uncover related but different phenomena that all fall under the umbrella of petrochemical transitions. Across the papers, I draw on different concepts and theories informed by deliberative choices, which I here justify through the notion of judgement rationality. At the same time, I see consistency with critical realism in that the frameworks I draw upon—be it the cultural political economy of technical fixes, neo-Gramscian perspectives on transitions, or (realist) accounts of socio-technical systems—can all (at least in intention if not in practice) be applied without being either essentially reductionist or relativistic (Markusson et al., 2017; Newell, 2021; Sau, 2021; Svensson & Nikoleris, 2018). As a result, in terms of theory and concepts, I align with both ontological realism and epistemological relativism, making use of theoretical triangulation to support my account of the (lack of) transitions in the global petrochemical industry.

4.1.2 A note on the limits of a global political economy of petrochemical transitions

As cited above, accounts of critical political economy seek to address 'operations and contestations of power across time, space and scale' (Newell et al., 2021, p. 904). But how can one account for operations and contestations of power in a global industry that spans all continents, feeds into virtually all industrial processes and is driving accelerated pollution, climate catastrophe and biodiversity decline? The short answer is that one cannot—at least not within the context of a paper-based thesis mainly focused on decarbonisation. In this, as in all other accounts of some phenomena related to social reality, the issues of what is left out and what is foregrounded are inevitable, partly illustrating the value-laden nature of (social) science. There are limits to any account of the global political economy of petrochemical transitions. Therefore, I briefly want to note what I foreground and what I give less attention to in an effort to make the shortcomings of the thesis clearer.

In Section 3.1, I note how much research critically engaging with the petrochemical industry has focused on environmental injustices, environmental

racism and toxicity, accounting for the struggles and 'operations of power' that maintain such inequities. The flipside of that is that the work I present here does not centre the accounts of communities and peoples who suffer from petrochemical production and expansion, nor does my main analytical focus revolve around toxicity. Instead, this thesis is predominantly concerned with the dominant interests and actors and their responses to the climate crisis. While I have analysed data from several actors and regions, my general attention to issues of climate and energy has been oriented more towards developments in Europe than elsewhere, with an associated focus on renewable energy. My account of petrochemical transition dynamics is rooted in material understandings of capitalist dynamics, and I focus on economic vested interests, petrochemical production and the socio-technical system it operates within, with less attention to their harms and their racialised, classist and gendered dimensions. At the same time, the upstream focus that I take in this thesis grants less focus to the multiplicity of contestations and their associated power dynamics that are more closely related to the downstream aspects of plastic and fertiliser use and 'end-of-life'. In noting this characteristic, my intention is to not obscure the importance of such accounts and what they make visible. Indeed, the harm and injustices of petrochemicals that various communities around the globe experience on a daily basis reveal the social hierarchies that demarcate petrochemical transitions and are thus absolutely at the core of struggles for just transformations.

4.2 Methods

This sub-section considers the outer layers of the research onion, namely the approaches to data collection and the methods of data analysis that I employ across the five papers of the thesis. The thesis adopts a mixed methods or methodological pragmatist approach, using different methods across the five papers. This choice is arguably in line with a critical realist approach to research in rejecting an induction/deduction dualism (cf. the notion of retroduction introduced above) (Downward & Mearman, 2007). Moreover, methodological pragmatism is particularly relevant when studying transitions due to their complexity, uncertainty and open-endedness. The purposes of mixed methods research go beyond triangulation and include the related elements of complementarity, development, initiation and expansion (Greene et al., 1989).

In other words, mixed methods are not only about confirming that the analysis of some forms of data also applies to or is not contradicted by other forms of data. Instead, aiming for a study that is more than 'the sum of its parts' (initiation) (Greene et al., 1989, pp. 259–260; M. L. Smith, 1986, p. 37), mixing methods can elaborate, enhance and clarify results (complementarity); results from one method can inform other methods (development); and the forms of inquiry can be extended to capture elements not uncovered by other methods (expansion). An overview of types, sources and forms of data, as well as their application and analysis across the five papers of the thesis, is available in Table 1.

Table 1. Overview of methods in the thesis papers.
This table summarizes the various types, sources and amount of data as well as the main methods for data analysis applied across the five papers of the thesis.

Paper	Type and source of data	Amount and form of data	Application and data analysis
Paper I: Mapping GHG emissions and prospects for renewable energy in the chemical industry	Input-output tables (EXIOBASE), life-cycle inventory data (Ecoinvent), plant-level data (S&P Global Platts), corporate emissions data (CDP)	CDP corporate dataset counting 113 chemical companies, EXIOBASE 3.8.2 (49 countries and regions 1995-2022, 163 industries), Ecoinvent 3.8 (3000 datasets related to chemicals)	Input-output modelling, LCA-modelling, descriptive statistics, coding of initiatives
Paper II: Connected we stand: Lead firm ownership ties in the global petrochemical industry	Data on corporate ownership structure (Orbis, Bureau van Dijk) Chemical sales data (Chemical & Engineering News)	37,030 observations with 28,455 unique company IDs Data on chemical sales for the top 50 producers	Social network analysis (descriptive statistics and visualisation), clustering
Paper III: Petrochemical transition narratives: Selling fossil fuel solutions in a decarbonizing world	Corporate sustainability reports, corporate sustainability communications, digital field observations and corporate climate disclosure (CDP database)	4 industry conferences with corresponding field notes (in 2019-2021), 11 full corporate sustainability reports and 10 website sections on sustainability	Iterative coding of sustainability communications. Field observations and CDP data for triangulation.
Paper IV: Imagining circular carbon: A mitigation (deterrence) strategy for the chemical industry	Various types of qualitative data across genres (position papers, reports, PR material, legal text, speeches and pictures), digital field observations, in-person participant observations, academic journal articles	45 pieces of data (see Paper IV for full description), field notes and participant observations from the main European plastic industry conference (K2022), participant observations from two online industry conferences	Coding focused on expectations, promises and imagined solutions. Various sources of data are used to triangulate coding results. Iterative discussions in the author group to identify core themes and variations
Paper V: Ending fossil-based growth: Confronting the political economy of petrochemical plastics	ICIS Worldwide Ethylene Plant Report 2020, ECD Global Plastics Outlook database, IJ Global	Steam cracker capacity, plastic use and waste and forms and size of capital investments	Expert-based review and descriptive statistics

4.2.1 Data and data collection

As noted, this thesis draws on both quantitative and qualitative data from a wide range of sources (see Table 1). The qualitative data includes documents of various genres (reports, policy briefs, press releases, sustainability reports, etc.) as well as field observations and notes from industry conferences. Because I started my PhD in 2020 after the onset of the COVID-19 pandemic, almost three years before the World Health Organisation would declare that the pandemic no longer constituted a global health emergency (UN News, 2023), I had no access to in-person conferences or interviews for the first part of my studies. This influenced my methods of data collection and resulted in me attending online industry conferences as well as seminars and other smaller online industry events, amounting to a form of digital field observation, or 'virtual ethnography' (Hine, 2019). Despite the lack of opportunities for active participation at online events such as one-on-one interactions and informal interviews—which persisted despite efforts to create social interactions at online industry conference 'meet-and-greet' platforms—I still gained access to presentations, panels and question and answer sections. These provided ample opportunities to experience how incumbent actors from various organisations and firms positioned themselves and framed issues of sustainability in context when speaking to other incumbents. Not all participant observations were, however, online. For Paper II, some of my co-authors had participated in seminars prior to the pandemic, and for Paper IV, the pandemic had waned in Europe and in-person conferences were again possible. Moreover, I have since the time of submission of Paper IV (March 2023) participated in multiple events and workshops related to petrochemical transitions, including the second section of the International Negotiation Committee for a global plastics treaty in Paris in May 2023, on which the preface draws, and which has also been informing for me in writing this cover essay.

In terms of quantitative data, I rely on a range of online databases. In Paper I, we make use of the S&P Global Platts World Electric Power Plant database, Ecoinvent, EXIOBASE and Best Available Techniques reference documents made available by the European Commission, as well as CDP. Apart from CDP, these databases are all used to inform the input-output modelling and the life cycle assessment analysis used to model the greenhouse gas emissions from the petrochemical industry over time and the implications of reliance on fossil-based electricity production for greenhouse gas emissions from production (accordingly,

my part of the data analysis focused on CDP). The CDP database, which is the most comprehensive database on corporate sustainability disclosure, contains company-level reporting of climate initiatives and climate-related targets, as well as answers to open-ended climate-related questions, which we used in Paper III for triangulation. Paper V similarly draws on data from a range of online databases with data on chemical plants, plastic use and waste, as well as investor information on large-scale investment (see Table 1). The arguably most inventive and novel form of quantitative data collection was conducted for Paper II. To create a dataset containing a comprehensive list of ownership ties between multinational petrochemical producers across geographies and subsidiaries, I relied on the ORBIS database, subtracting complete lists of subsidiaries for each identified parent company and, using different forms of identification, cross-referencing owned entities across ownership levels (for a fuller explanation, see Paper II).

4.2.2 Data analysis

With quantitative and qualitative data follows quantitative and qualitative forms of data analysis. While Papers I and II are mainly quantitative, Papers III and IV are mainly qualitative (Paper V being somewhat of an exception as an expert-based review informed by both qualitative and quantitative data), making the thesis as a whole a mixed methods study.

In Paper I, we draw on a variety of approaches that are not used in other papers, including input-output modelling and life-cycle assessment (as noted above, I did not do the formal data analysis in this regard). Moreover, we make use of descriptive statistics from our coding of corporate initiatives and the CDP database. We also make use of descriptive statistics to inform our analysis in Papers II and V. In Paper II, this includes network statistics on nodes and edges to analyse network characteristics and the relative centrality of actors, while in Paper V, we illustrate the extensiveness of different forms of carbon lock-in with reference to descriptive statistics. For the social network analysis in Paper II, we also use an algorithm to identify different network clusters. Because the social network analysis in Paper II was conducted before commencing the writing of Paper III, IV and V, while the writing of the final version of Paper II was carried out after the finalisation of Paper IV, I was able to infer from and cross-reference the different types of analysis in the different papers (what I above referred to as development in the context of mixed methods).

In terms of qualitative methods, Papers III and IV cover similar but slightly different ground. While Paper III focuses on mapping transition narratives used by incumbents, Paper IV aims at uncovering a wider semiotic system of meaning in the form of an emerging imaginary. While narratives draw upon discourses in the way they give meaning to social reality and, at the same time, can be said to constitute a minor component of a larger discursive system, imaginaries are comprised of 'specific configurations' of discourses and semiotic aspects of ways of acting and being (M. A. Hajer, 1995; Jessop, 2010, p. 344). Simplifying their dialectical relations to a hierarchical one, we can say that narratives are nested within discourses, which are nested within imaginaries. In terms of analytical approaches, this distinction means that whereas the coding for Paper III focuses on problem definitions and solutions in relation to decarbonisation, the coding for Paper IV took a broader approach, inspired by the sociology of expectations. We therefore looked for not only problem definitions but also risks, actors and networks, collaborations, the types of rhetoric and societal goals to identify the elements of circular carbon as a semiotic order. For both papers, however, there are clear commonalities in the analytical approach, including a strong iterative element with ongoing discussions in the author groups and elements of triangulation and testing ideas against other empirical material.

4.3 Tensions and consistency

Methodological consistency entails maintaining alignment with the critical realist dedication to ontological realism and epistemological relativism, or, in the terminology of the research onion, staying within one research paradigm. With the methodology I have laid out above, what tensions might arise, and in what sense and to what extent can the work in this thesis be said to be methodologically consistent? While the answers to such questions can necessarily be subject to negotiation (along the lines of what it entails for a given approach to fall within a specific research paradigm and what demarcates the boundaries of said paradigm), I believe that a brief reflection on these issues is warranted given my claim of broad consistency with critical realism.

On the one hand, this thesis arguably draws upon tools and techniques that can reflect positivist tendencies, such as the various approaches in Paper I or the social

network analysis in Paper II (Buch-Hansen, 2014). This observation does not, on its own, establish sufficient grounds for classifying the ontological and epistemological orientation of this thesis, but it does highlight the importance of supplementing social network analysis with other methods as well as considering how specific approaches are applied. The advantage of social network analysis lies in its uniqueness in terms of mapping and analysing social relations, and when appreciating that this approach alone cannot establish a full understanding of causal mechanisms while maintaining reservations for generalisations beyond the immediate context (based on notions of structural equivalence), the method aligns well with critical realism (Buch-Hansen, 2014; Cronin, 2016). More generally, the question of methods and methodological consistency is long-standing in the philosophy of social science. By advocating a pluralistic approach, I follow the reasoning of Olsen and Morgan (2005), who argue that what determines consistency is the attitude of practice more so than specific methods and their supposed intrinsic qualities. Therefore, by drawing on quantitative methods but supplementing them with other forms of data and analysis, seeking to advance conceptual and theoretical development in the pursuit of broader applicability rather than identifying generalisable regularities or law-like patterns, I do not embrace the positivist tendencies of social network and life cycle analysis.

On the other hand, this thesis has a strong focus on semiotics in the form of narratives and imaginaries. Being so preoccupied with how major producers and other incumbent actors frame, perceive and construct petrochemical transitions, does this thesis give 'ontological priority to culture and semiosis (that is sense and meaning making)' (Sau, 2021, p. 1019)? In this regard, both Papers III and IV do not analyse narratives and imaginaries independently but in relation to 'material' aspects of social reality, drawing on theory and frameworks that stress the discursive *as well as* the material. To avoid the pitfalls of reductionism, both cultural and neo-Gramscian political economy approaches build upon historical materialist thinking but stand in opposition to, for example, structuralist Marxism by studying the semiotic in connection to the material (A. Ford & Newell, 2021; Sau, 2021; Sum & Jessop, 2013).

A final possible tension arises around the issue or notion of problem-solving. In this regard, Paper V seeks to identify 'next steps' to undo carbon lock-in. But in doing so, it arguably instils an 'eagle-eye view' of policy and governance, steering from a 'cock-pit' or standing outside 'looking in' on petrochemical carbon lock-

in (M. Hajer et al., 2015; Hilton, 2009; Stirling, 2019). At the same time, one could argue that Paper V implicitly takes the institutional order as given. In pointing to 'potential next steps on a path away from petrochemical plastics', we start with an account of the given order, reflecting on potential ways for various actors to operate within that. Revoking Cox' seminal distinction between problem-solving and critical theory, such acceptance arguably aligns with the former, where 'prevailing social and power relationships [is the] framework for action' (Cox, 1981, p. 128). In contrast, critical theory enquires into the developments and construction of the existing order, asking 'how that order came about' (Cox, 1981, p. 129). What we emphasise in Paper V, however, is exactly that any transformative approach to petrochemicals and plastics must recognise issues of power and political economy and that just transformations are not possible without confronting existing social and power relationships. In this way, Paper V is arguably more closely aligned with Eckerly's notion of 'situated and critical problem-solving', which seeks to overcome Cox' dichotomy by identifying 'next steps' with the goal of pursuing a transformative project while doing so from existing political conditions (Eckersley, 2021; Vogl, 2023). Likewise, in paper V, we take the existing order as a framework for action only insofar as we point to and reflect on ways in which prevailing socio-ecological and socio-technical configurations can change, asking what would need to happen from this point onwards for just petrochemical transitions to become more likely.

5 Grasping the past, present and future of petrochemical transitions

To understand the political economy of petrochemical transitions and the dynamics of why different actors pursue certain socio-technical reconfigurations over others, we need to engage with material, institutional and discursive elements of petrochemical incumbency. By exploring power along these categories, it is possible to unfold various aspects of ongoing contestation, including the continuous expansion of fossil-based production capacity and the implied financial and material commitments to fossil fuels as feedstock in the face of mounting criticisms, public pressure and scientific evidence of harm. In this chapter, I therefore present and summarise my findings as they speak to these three dimensions of power. Before doing so, I introduce and provide a brief overview of the five papers in this thesis.

5.1 Paper overview

Table 2 provides an overview of the five papers that constitute the basis of this thesis, highlighting the specific research questions that they seek to address, the literature to which they refer, the concepts they invoke, as well as the main dimension of the overall research question they speak to. Paper I is published in a chemical engineering journal (shining through in terms of methods and concepts), while Papers II–IV all speak directly to transition-related disciplines and theories. Across the five papers, I focus on specific aspects of political economy, including questions related to climate governance, ownership, discursive positioning, green capital accumulation, technical fixes and policy. Instead of summarising the findings paper by paper, I summarise them in terms

of the three specified and interrelated forms of power, which the five papers all consider various elements of.

In accordance with the methods they employ, the concepts they invoke, and the theoretical space they occupy, each paper addresses various aspects of the four elements of the main research question (of how, on what basis, to what end and with what consequences, petrochemical incumbents navigate transition pressures) (see Table 2). When I ask *how* petrochemical incumbents navigate transition pressures, I relate to the research questions concerning both concrete climate initiatives and industry collaborations in the form of network structures (Papers I and II) as well as trasformismo-style manoeuvres (Papers II–IV). In particular, the paper-specific research question in Paper III directly mirrors the wording of the overall question, focusing on discursive power, while the research questions in Papers II and IV set me up to address other dimensions of how trasformismo is pursued. When I ask *on what basis*, I—informed by a neo-Gramscian perspective—seek to address what the underlying sources of power are that allow and make it possible for incumbents to do what they do (relating to the research questions of Papers II, III and V). To be able to provide a multi-facetted answer, Paper V enquires into various forms of lock-in (including behavioural, institutional and infrastructural). When I ask *to what end*, I mean to answer why incumbents do what they do in the first place and where they are heading towards, theoretically contextualising their strategies in terms of what I previously in this cover essay have referred to as capitalist dynamics (Papers II–IV). Paper IV, for example, asks what function dominant industry visions have seen from a cultural political economy perspective. And finally, when I ask *with what consequences*, I refer both somewhat narrowly to climate impacts and industrial decarbonisation (that is, the depth, speed and means of decarbonisation in greenhouse gas emission terms) as well as more broadly to the pathways that petrochemical transitions might take, including matters of just transitions, socio-ecological consequences beyond the climate crisis, and the (re)distribution of political power (Papers I–V). While Paper I is the most concrete in its specification of climate consequences, the research questions of Papers II, IV and V speak to the consequences of incumbency in conceptual terms of lock-in, committed emissions and mitigation deterrence. As for the broader consequences, Papers II–IV ask what industry-led transitions entail, and Paper V tentatively seeks to provide some strategically informed ways forward.

Table 2. Overview of the papers included in thesis.
This table sums up the research questions of the five papers that constitutes the thesis and how they are addressed.

Title	Research question (RQ)	Methods	Theoretical space	Concepts	Element of main RQ addressed	Argument and main finding(s)
Paper I: Mapping GHG emissions and prospects for renewable energy in the chemical industry	How have chemical industry GHG emissions developed and through what renewable energy initiatives are industry actors seeking to reduce such emissions?	Life-cycle analysis, input output modelling, descriptive statistics	Environmental engineering, corporate climate governance	Scope 1-3, additionality, market-based instruments	How and with what (GHG emission-related) consequences	Climate initiatives across disclosing chemical companies are focused on efficiency and process optimisation rather than deep decarbonisation.
Paper II: Connected we stand: Lead firm ownership ties in the global petrochemical industry	How are global petrochemical ownership networks structured and how do they matter for the prospects of breaking from fossil fuel dependency?	Social network analysis, descriptive statistics	Transition studies, global political economy	Global regimes, trasformismo, accommodation	How, to what end and with what consequences	Widespread legal and economic ties connect incumbent petrochemical producers and work to facilitate trasformismo-style change in the industry.
Paper III: Petrochemical transition narratives: Selling fossil fuel solutions in a decarbonizing world	How and on what basis do petrochemical incumbents navigate and shape transition pressures through (proactive) means of discursive power?	Narrative analysis, digital field observations	Transition studies, global political economy	Narrative alignment, trasformismo, green capital accumulation	How, on what basis and to what end	Incumbent firms mobilise discursive power through narrative realignment to facilitate a process of trasformismo in the face of transition pressures.
Paper IV: Imagining circular carbon: A mitigation (deterrence) strategy for the chemical industry	What are the dominant visions for how to reach net zero in the petrochemical industry, and which function and what potential consequences do these visions have?	Document analysis, field observations	Cultural political economy, global political economy	Mitigation deterrence, imaginaries, reduction deterrence	How, to what end and with what consequences	The circular carbon imaginary portrays a fossil-compatible future for petrochemicals and risks deterring both climate mitigation and pollution reduction.
Paper V: Ending fossil-based growth: Confronting the political economy of petrochemical plastics	What lock-ins exist across the petrochemical and plastics value chains, and what are possible pathways for transformation and a just transition beyond fossil fuels?	Expert-based review	Plastic governance, political economy of energy transitions	Carbon lock-in, transformative change, supply side policy	*RQ:* On what basis and with what consequences	Strong petrochemical carbon lock-in across domains requires transformative pathways to confront vested industry interests.

5.2 Dimensions of petrochemical power

5.2.1 Material power and petrochemical infrastructure

In terms of material power, petrochemical incumbents are in a unique position. They feed into most industrial production, increasing efficiency (for example, via solvents), adding flexibility (for example, via plastics in a myriad of forms and the options enabled by plastic chemicals) and enhancing durability (for example, via carbon fibre polymers, which are essential for wind turbine blades) (Papers II and III). Understanding chemicals as an enabler that plays this structurally important role, petrochemical incumbents can claim to represent not only the chemical industry but also 'capital-in-general', similar to the claims that fossil fuel firms as energy providers have been in a position to make (Paper III).

Across the papers, I find that the structural role of chemicals in production is key to understanding the ways in which incumbents, building on material power, are able to employ discursive and institutional power and navigate transition pressures. Bearing in mind discussions around the intermittency of renewable energy and the flexibility of fossil fuels, the circumstance that renewables are now readily accepted as substitutes to fossil fuels for electricity generation (and the related momentum of fossil fuel phase-out) means that fossil fuel-as-feedstock is in an advantageous position to that of fossil fuel-as-energy (Paper III). Whereas incumbents have promoted fossil gas as a transition fuel, accepting that phase-out or at least declining use is in the pipeline and necessary in the long term, chemicals remain structurally important. There are no 'transition chemicals', because chemicals are and will remain critical to mass production and consumption (Paper III). Since many of the incumbent firms in the petrochemical and oil and gas industries are the same, this difference in vantage point should not be considered contradictory (Paper II). Rather, firms that pursue these strategies in parallel, mobilising their material power as energy firms in one context while employing material power as chemical incumbents in another, build on the long-standing fossil fuel-chemical nexus and the synergistic relationship between the sectors (Paper II).

The material power of incumbents and the nexus between fossil fuels and petrochemical production are underpinned by and manifested in a globally integrated network of ownership connecting incumbent actors across value chains

(Paper II). These ownership ties represent common material, financial and juridical commitments to petrochemical production, and Paper II shows how the 52 biggest chemical producers in the world on average hold joint ownership in entities together with 9 other incumbent firms. Many of these firms are either state-owned or have a hybrid ownership structure with relatively strong ownership ties to state actors, illustrating widespread state-capital entanglements in the petrochemical industry. The findings indicate that incumbents commit (each other) to fossil-based production, with instances of joint ownership including, for example, crude-to-chemical complexes, petrochemical pipelines and other forms of system infrastructure. In the network, SABIC, the state-owned Saudi petrochemical producer, is the most central node, sharing ownership in various entities with around half the network actors. The political and innovation regime of the Saudi state and its explicit commitment to continued fossil fuel production in its vision for future industry developments (Paper IV) mean that the centrality of SABIC is particularly important. With state-backed commitments to continued fossil fuel extraction, the widespread ties between SABIC and other actors illustrate and exemplify the broader pursuit of petrochemicals as a diversification strategy for fossil fuel incumbents and the intentional strengthening of carbon lock-in through establishing shared economic and financial interests anchored in material and juridical ties (Paper II). The nature of petrochemical investments, their high capital expenses, long pay-back periods and multi-decade investment horizons, imply that once such commitments have been established, they are not easily undone, furthering fossil-based growth (Paper V).

The source of material power is, however, not unproblematic. Owning petrochemical capital comes with contradictions related to its creation of socio-ecological crises. The triple crisis of climate, pollution and biodiversity, the movements and actors that challenge the legitimacy of incumbents on the basis of them and the increased policy focus on petrochemical plastics force incumbents to respond (Paper I–V). They do so proactively, setting climate targets, enlisting in various public-private and industry initiatives and engaging in the development of niche technologies that function as spatio-temporal fixes (Paper I–V). Paper I explores the extent to which incumbents pursue climate initiatives focused on renewables but finds a worrisome lack of engagement with deep decarbonisation, documenting targets and initiatives that map onto continuous efforts to improve energy efficiency (lowering costs and increasing profitability). Incumbent firms buy renewable energy certificates, set targets for a selected and limited part of their

operations and portfolio, or account for the 'avoided emissions' from the increases in efficiency associated with petrochemical use (Papers I and III). Through such measures, incumbents seek fixes that respond to the crises that petrochemicals produce.

5.2.2 Discursive power, narratives and imaginaries

A critical element of shaping socio-technical (re)configurations is the employment of discursive power. In this thesis, I consider the employment of discursive power in relation to two different but related phenomena, namely the transition narratives mobilised by incumbent firms and other industry actors (Paper III) as well as the emergent imaginary of circular carbon (Paper IV). These reveal an intimate connection between the material power of petrochemical incumbents and the employment of discursive power. Building on the structural importance and ubiquity of petrochemicals in industrial processes and consumer goods, incumbent actors are able to strategically frame petrochemical producers as transition enablers and solution providers. However, in doing so, they employ discourses of climate delay and promote not only mitigation deterrence but also plastic reduction deterrence, leading to further production and accumulation of synthetics, with all the consequences associated with that.

Petrochemical incumbents mobilise mainly three types of narratives related to transitions that together function as an overall discursive strategy that fends off transition pressures and positions them to pursue opportunities for green capital accumulation. These three narratives are *realisers of sustainability*, *well underway* and *breakthrough technology pioneers*. The 'realisers of sustainability' narrative holds that critiques leveraged against petrochemical producers are misguided because incumbent firms supply chemicals needed for sustainability, highlighting specific examples of artefacts that are generally regarded as necessary and important for decarbonisation (such as wind turbines and solar photovoltaics) or other sustainability-related purposes (such as food security and health). In contrast, the 'well underway' narrative submits that the energy-intensive nature of production comes with climate consequences but portrays incumbent firms as being on a decarbonisation 'journey' on which they are already outperforming expectations, eagerly and surely pursuing low-carbon reorientation. The last narrative, 'breakthrough technology pioneers', adds that not only are incumbent firms on their way, but they are also the only actors who are in a position to deliver

the technological solutions that are needed to decarbonise the industry. Casting themselves as innovators operating in a vacuum driven by their corporate DNA, this narrative speaks to the paper published in Science cited above (Section 3.1) on the '*long history* of inventing essential and beneficial products and processes with extraordinary performance' [emphasis added] (Zimmerman et al., 2020, p. 397).

The three narratives are examples of what I in Paper III conceptualise as narrative realignment, that is, a form of trasformismo on the discursive scale that 'bring[s] practises and activities of incumbents (back) into line with transition pressures and calls for system-level change' (p. 4). The three narratives all cast incumbent activities (existing production, climate-related activities and research and developments) as not only aligning with but essential to the aims of decarbonisation and circularity. By positioning incumbent firms as transition enablers that, if anything, should receive support to boost their already applaudable efforts, these narratives lay the groundwork for new opportunities for petrochemicals. By legitimising existing production by pointing to sustainability-related purposes while justifying new and more energy efficient petrochemical developments as low-carbon and circular without undoing ties to fossil fuel extraction and production growth, narrative realignment fends off criticisms and enables green capital accumulation.

Although the transition narratives relate to the future of the petrochemical industry, they do not constitute a vision for sustainable chemical production. In this vein, Paper IV explores the employment of discursive power in relation to the idea of circular carbon, an emergent imaginary that incumbent actors across the industry and in alignment with state actors now promote. Fitting with dominant political and economic regimes premised on ideas of control and rational planning, the circular carbon imaginary presents the future of the petrochemical industry as one of 'carbon management.' Recasting carbon emissions and plastics as 'fugitive' carbon, that is, carbon that has ended up in the wrong place, as opposed to 'durable' carbon in wood or plastics in use, the circular carbon economy consists of petrochemical incumbents 'managing' carbon by increasing circularity. Building on frames of substitutability and boundedness, which fit neatly with the frames employed to establish carbon markets, the circular carbon imaginary presents the consequences of petrochemical production as a question of proper management, switching out fossil feedstock with carbon from the air,

living organisms and discarded synthetics. Framing out questions pertaining to the social order, the circular carbon imaginary functions as a technical fix by promising a solution to both plastic pollution and the climate crisis that does not have large immediate material ramifications (as reduce-type strategies arguably would) but is part of a multi-decade transition. Incorporating negative emission technologies and carbon dioxide removal in the vision for the future of petrochemicals, circular carbon thereby deters other mitigation strategies, most notably interventions to reduce use and demand. The notion of mitigation deterrence, however, is relevant outside the limited perspective of greenhouse gas emission reductions. In suggesting a double solution to the twin problem of plastic and climate through promises of 'recycling' plastics and carbon emissions for new synthetic materials, the promoters of circular carbon also deter plastic pollution reduction. If these promises fail to materialise, circular carbon entails not only further emissions but also the further accumulation of synthetic materials.

What is common across various mobilisations of discursive power is the link to material power and the role of chemicals in industrial production. In line with how incumbents have for long invoked the notion that chemicals are essential to 'the good life' (cf. Section 2.2.2), present-day incumbents refer to petrochemicals as the 'building blocks' of both 'modern life' and 'the future,' while referencing carbon as 'the atom of life' (Paper III, p. 2, 7; Paper IV, p. 4). Casting petrochemicals as not only relating to but as the very foundation of modernity, a sustainable future and even life itself, the question of production growth is, in this perspective, always qualitative but never quantitative. Production might need to be carried out in more efficient and climate-friendly ways, but questioning the scale of production effectively amounts to questioning Progress with a capital P. In doing so, the employment of discursive power amounts to climate delay, and the use of the language of necessity obscures the many dimensions of chemical production. It might very well be the case that chemicals are important for a host of purposes, but when mobilising this point in the context of transitions, incumbents cast petrochemicals and carbon-based feedstock as uniquely important. What I mean by that is that when pointing to the role of petrochemicals, incumbents foreground specific applications of chemicals, insinuating a lack of substitutability while disregarding the structural importance of other industries. In the example of wind turbines, for example, petrochemical incumbents do not mention that steel is the main building material, the need for

certain minerals, or the importance of the design and casting of components for cost-competitive manufacturing. Moreover, they do not attribute any agency to non-industry actors (Paper III). This selective framing and its strategic mobilisation in the face of criticisms and calls for decarbonisation and de-toxification of the industry serve the purpose of watering down policy while justifying continued growth.

5.2.3 Institutional power, lobbying and decision-making

The third dimension of power in the neo-Gramscian perspective put forward in this thesis is that of institutional power, which is employed through efforts to influence decision-making. Across the papers, the findings reveal some of the ways in which institutional power plays a role in shaping petrochemical transitions, showing that institutional power builds on material and discursive manifestations of the power of incumbency, mobilising transition narratives and promises of circular carbon while emphasising the structural role of chemicals in policymaking processes (Paper II–IV). The employment of institutional power helps maintain institutional lock-in, that is, an institutional context that favours incumbent actors and carbon-intensive production, such as tax breaks, exemptions from, or the outright lack of climate and environmental regulation (Paper V). Petrochemical incumbents enjoy institutionalised political influence underpinned by close state-capital relations that allow incumbent firms to shape decision-making and regulatory outcomes, striving for potential socio-technical reconfigurations to follow a process of trasformismo (Paper II).

In terms of the formal aspects of institutional power, there is no unified framework for chemical production at the transnational level, with an associated lack of reporting and transparency. While several frameworks exist, these are partial and only address a subset of petrochemicals (Paper V). Multilateral and regional efforts on the plastic crisis have mostly been limited to waste management, and even the recent reorientation towards mid-stream solutions in the form of circular economy does not address upstream aspects of plastic pollution. This governance focus suits industry actors well in that it becomes possible to maintain a focus on recycling and reuse strategies rather than reduction or substitution of synthetic materials as such (Paper V). The compatibility between policy attention to mid- and downstream segments of the value chains of synthetics and incumbents is evident from how this focus aligns with the

discursive strategies mobilised by incumbents, who point to the responsibility of consumers and legitimise production as a function of simply answering to growing demand for petrochemicals and plastics (Papers II and IV).

Petrochemical incumbents seek to influence decision-making processes both formally and informally. In the European context, for example, industry organisations like Cefic (which has the highest lobbying costs of all organisations registered in the EU Transparency Register (Bauer, Tilsted, Deere Birkbeck, et al., 2023)) and Plastics Europe, as well as individual firms like BASF, Shell and ExxonMobil, eagerly and successfully engaged in formal as well as informal lobbying activities, watering down climate and environmental policy and thereby boosting profitability (Papers IV and V). And in the US context, petrochemical incumbents are known as notorious lobbyists, engaging directly in decision-making as well as influencing policy indirectly by funding various actors, including political candidates and historically also the US climate counter movement (Paper III). With extensive state-industry networks, revolving doors and widespread state ownership, industry and state interests overlap, and industry interests are thereby, if not formally represented by petrochemical producers in policy processes, likely to be taken into consideration by state and governmental actors extending incumbency beyond firms (Paper II).

The informal employment of institutional power operates through various forms of lobbying. The ownership analysis in Paper II reveals how industry actors meet and coordinate across spheres, showing ownership ties connecting the biggest producers in not only industry organisations but also think tanks and even football clubs (in the case of the Japanese chemical industry). In the formation of the circular carbon imaginary analysed in Paper IV, for example, Cefic, Plastics Europe and other industry-affiliated actors play an important role in terms of seeking to influence the European Commission and European policymakers. Incumbents lobby in favour of subsidies and other 'policy conditions' that enable firms to 'go even faster' towards circular carbon, as put by a BASF employee (Paper IV, p. 8). Incumbents also push circular carbon in multilateral contexts. Saudi Arabian-based, state-backed actors, including think tanks, research institutes and diplomats have a strategic ambition to promote circular carbon thinking and have done so in UNFCCC forums, while the G20 formally endorsed and backed circular carbon strategies after their 2020 meeting in Riyadh. These examples illustrate how the employment of institutional power is meant to ensure

that low-carbon reorientation is premised on creating new sites of accumulation, for example, 'low-carbon' plastics from 'recycled carbon', leaving existing social structures in check and limiting the speed and depth of transitions (Paper IV).

Lobbying efforts and other instances of the employment of institutional power reveal the interconnections between the material, institutional and discursive. The transition narratives identified in this thesis, building on the material power of petrochemicals, are widely mobilised in various aspects of decision-making (Papers III and IV). During the negotiations for a global plastics treaty (in the so-called International Negotiation Committee), for example, the three narratives have been invoked by petrochemical-producing states, and incumbent actors continue to flag the importance and benefits of petrochemicals when seeking to water down the content of the treaty (Tilsted, 2023). And in the empirical material analysed in the papers in this thesis, incumbents flag their material importance and push the transition narratives over and over both in formal and informal settings in the EU, US and elsewhere (Papers III and IV). In contrast to grassroots, social movements and marginalised actors sustaining environmental injustices from petrochemical production, petrochemical incumbents enjoy a more powerful position, which helps to explain the ongoing petrochemical expansion amidst socio-ecological crises (Paper V).

5.3 Ruptures and continuations in the petrochemical industry

Not unlike other industrial sectors, petrochemical incumbents have for long engaged in wars of position. And with close material, organisational and institutional ties to oil and gas majors, the mobilisation of material, discursive, and institutional power to maintain a fossil-based chemical regime and align reconfigurations with the interests of incumbents is in essence niether new nor surprising (Paper V). Given the long-standing precedent of such efforts, how can we understand the findings mapped out above? In other words, what is different and what is similar about the ways in which petrochemical incumbents navigate the transition pressures related to their current predicament in comparison to historical tendencies in the industry (as mapped out in Section 2.2)? How do climate change, the decarbonisation imperative and the associated socio-ecological

consequences in terms of toxicity and plastic pollution matter? Three issues are worth addressing here, namely the notion of necessity and essentiality, the corporate strategies of deceit and denial, as well as the relationship between chemicals and energy.

Perhaps the most striking degree of similarity is the continuous reference to the ubiquity of synthetics and their physical presence in a host of consumer goods, related to the notion of material power. Not unlike the campaigns and commercials of the 1950s and 1960s promoted by the American Petroleum Institute, Shell and their equivalents, today's petrochemical incumbents too stress the necessity of chemicals. The American Chemical Council (2019), for example, posits that 96 percent of all manufactured goods 'touch' the business of petrochemicals. In the wake of climate change and the sustainability agenda, however, the language of necessity takes on a new form, playing on the critical importance of decarbonisation to justify petrochemical production by and large (Paper III). Petrochemicals are not only needed for a 'modern' and 'better' life, vital to industrialism as a whole and mass consumerism as a key Fordist project of capitalism—they are also necessary for sustainability in all its varieties, including for a renewable-based energy transition; they are necessary for 'the future'.

This strategy, justifying injustices with reference to the necessity of renewables and the imperative of decarbonisation, is well-known beyond the petrochemical industry. Indeed, the literature on green extractivism and related work in political ecology reveal the darker side of sustainability and innovation and the mobilisation of arguments and rhetoric with striking similarities to petrochemical incumbents (de Leeuw & Vogl, 2024; Kalt et al., 2023). In these regards, sustainability also plays a legitimising function, closing down or framing out questions of ownership and sovereignty, how and with what consequences extraction is pursued to serve whose interests, and most importantly, what alternatives are possible. Positioning petrochemicals as an answer to, instead of at odds with, lowering emissions similarly helps obscure questions of justice and political economy (Papers III and IV). And as opposed to questions of toxicity and environmental injustice, climate change is global rather than regional or local, and so incumbents get to 'share the blame' while taking the credit for renewable rollout.

Keeping the legacy of deceit and denial in mind, the strategies of petrochemical incumbents also take on a particular form in relation to energy transitions and

climate change. Instead of hiding the impacts of their products in terms of health hazards and toxicity, incumbents boast of and inflate the climate benefits of their products, and different forms of 'creative accounting' are widespread (Papers I and III). And instead of weaponising uncertainty to play down toxic risks, incumbents overplay certainty, leaving aside the crucial assumptions that make their estimates possible. These assumptions include the selective use of system boundaries and measures of performance (Papers I and III). Linde, for example, explains that the 'avoided emissions' from their products, which include energy efficiency gains from the use of jet engine coatings, are much higher than their greenhouse gas emissions, while industry climate targets make selective use of baselines, system boundaries and renewable energy certificates to set targets that imply limited disruptions to existing operations (Papers I and III). And in the vision of circular carbon, such issues will remain as new accounting questions related to offsetting, claims of recyclable content and the climate impact of carbon capture and use arise (Paper IV). Across various forms of manoeuvring, the wider shift from denial to delay in climate discourse also plays out in relation to petrochemicals, where instead of funding climate denialists as has historically been the case, delay discourse now permeates incumbents' rhetoric and their employment of institutional power (Paper III).

The relationship between energy and chemicals takes on a new form in the light of transitions. Whereas previous transitions from coal to oil to fossil gas as feedstock have been driven by mainly economic and geographic factors of cost, availability and demand for chemicals and synthetics, the shift to renewable-based feedstock and direct and indirect electrification will increase costs (Paper I). And although production costs are likely to fall as low-carbon production technologies mature, price gaps will remain given the material advantages of fossil-based feedstock. At the same time, previous transitions have occurred in the hands of new actors and the development of oil and gas-oriented niches to fuel new growth without stranding old assets, and oil and coal continue to be used as feedstock for chemicals on an enormous scale alongside the growth of natural gas liquids for non-energy purposes. This time around, undoing fossil fuel dependence must happen by replacing and phasing out existing energy and petrochemical infrastructure in the hands of incumbents in the very same industry (Paper V). This predicament complicates the penetration of alternative technologies and means that the political economy of petrochemical transitions cannot be reduced to yet another shift that will play out alongside a renewable energy transition. As

the circular carbon imaginary clearly illustrates, its incumbent proponents insist—and are set to continue to insist—on petrochemical transitions that integrate renewables with fossil fuels rather than undo the symbiosis of chemicals and fossil energy (Paper IV). The extent to which they will be successful plays a central role in deciding the magnitude of climate catastrophe.

6 Towards a political economy of petrochemical transitions

In the introduction, I raised the questions of what perspectives arise from understanding fossil fuels not only as energy carriers but as feedstock and what we see when we centre the analysis of the plastics crisis around fossil fuels, growth, distribution and power. In this final chapter, I return to and reflect on those questions in light of the findings mapped out above and point to the points of contention that the political economy of petrochemical transitions revolves around.

6.1 In search of carbonaceous substitutes

6.1.1 Decarbonisation or defossilisation?

An answer to the question of what we see when we understand fossil fuels as feedstock is that renewable energy transitions are not only a matter of decarbonisation but also *defossilisation.* Most often, the imperative of lowering emissions is referred to as decarbonisation, associated with the shift from fossil-based to renewable-based electricity production. Whether invoked to refer to the process of continuously reducing the flow of human-induced carbon emissions or—as implied by the prefix 'de'—moving away from, that is, eliminating carbon emissions, the gist of decarbonisation is to stop further escalating the climate crisis. In terms of fossil fuels as energy, the literal meaning of decarbonisation, doing away with carbon, is accurate in the sense that carbon will be 'removed' from electrified processes: carbon will neither be present in the form of hydrocarbons as energy carriers nor as climate-forcing carbon emissions. For the petrochemical industry, however, the literal interpretation of decarbonisation does not apply.

While the term captures the lowering and possible elimination of climate impacts from chemical production, there is no complete doing away with carbon because carbon needs to be present in the form of carbonaceous feedstock. Just as our bodies require nitrogen to build proteins, synthetics require hydrogen and carbon molecules to create the molecular chains that polymers are made up of. Notwithstanding the 'origin' of carbon molecules, be they biogenic or fossil, the chemical industry cannot do without carbonaceous feedstock (Palm, 2024).

To capture the distinction between eliminating carbon emissions and doing completely away with carbon in production processes, the notion of defossilisation is gaining considerable traction (see, e.g. Lopez et al., 2023; Schneider, 2023). In this perspective, the climate-related goal for the petrochemical industry should not only be to lower greenhouse gas emissions but also to 'avoid the extraction of fossil carbon' by switching to non-fossil feedstock (Schneider, 2023, p. 20). In short, taking the 'petro' out of petrochemicals. The notion of defossilisation therefore captures that the broader issue of fossil fuel phase-out not only requires expanding renewables but also the need to substitute fossil fuels as feedstock. By avoiding the extraction of fossil fuels, the pathway to net zero is less susceptible to spillovers and carbon lock-in (Paper V).

Substituting fossil fuels as feedstock, however, is no easy ask. While building renewables to replace thermal electricity generation is one thing, replacing fossil fuels altogether is another. For example, the International Energy Agency largely assumes decarbonisation without defossilisation in their net zero scenario, maintaining the total supply of oil for non-energy purposes as the world approaches 2050 (Figure 3). Such techno-economic scenarios find support among scholars sceptical of the potential for defossilisation. McCarthy, for one, highlights the dependence on fossil fuels as feedstock as one of the main obstacles to a fossil-free capitalism (2015, p. 2499), and the energy historian Vaclav Smil similarly highlights the use of fossil carbon in energy-intensive processing industries as an enormous challenge for energy transitions (Smil, 2016, 2020). When we refer to the renewable energy transition, what we actually aim for is, in the words of Helen Thompson, an energy revolution (EUI TV, 2023).

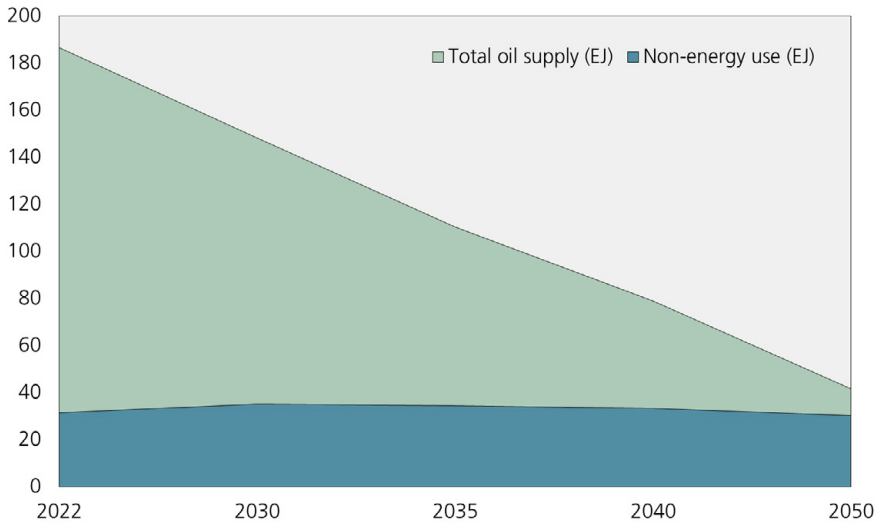


Figure 3. Oil supply in exajules in IEA's Net Zero by 2050 Scenario.
The total oil energy supply and non-energy use of oil are from the Net Zero Scenario in the International Energy Agency's World Energy Outlook (2023c).

6.1.2 The limits of defossilisation

The suggested difficulties of defossilisation are associated with the material properties of fossil fuels—in particular their energy density per volume and weight and their relative ease of transportation—as well as their relative abundance. Moving beyond fossil fuels as feedstock by using alternative sources of carbon requires considerable resources (land, water, energy), carbon capture and use technologies that are largely unproven at scale, and quite possibly massive geographical reconfigurations for easier access to cheap(er) resources (Papers I and IV; see also Gabrielli et al., 2023; Verpoort et al., 2024). The amount of resources that are needed to produce chemicals without fossil fuel feedstock necessarily increase with the scale of production. Maintaining, not to mention expanding, production capacity using alternative feedstocks, which suffer from a cost disadvantage, is therefore a key challenge for petrochemical transitions and, in particular, growth-oriented visions of ecological modernisation. To be sure, there are many policy proposals to 'tilt the playing field' in favour of defossilisation to facilitate such reconfiguration while maintaining growth in line with ecomodernist aims. But doing so is an uphill battle that showcases the limits of

market-oriented transition policy (Hunt & Tilsted, 2024), putting the issue of defossilisation at the heart of the political economy of petrochemical transitions.

Through the lens of defossilisation, the material power of fossil fuels and fossil fuel incumbents takes on a new dimension. In addition to owning and commanding production and finance, it is reliance on the attributes of fossil feedstock that becomes the bedrock of the petrochemical industry's power claims and its employment of institutional and discursive power. If feedstock alternatives with the same material qualities were abundant and available, petrochemical producers would be in a situation more akin to that of fossil fuel extractors and could therefore not operate with the same investment, lobbying, and public relations strategies. And, perhaps more illustratively, petrochemicals would not be the biggest driver of fossil fuel demand growth. To be sure, the reliance on fossil fuels as feedstock has many precursors and cannot be understood outside of the cultural, political, and economic context. Recognising the role of fossil fuels for non-energy purposes should not lead to thermodynamic reductionism or acceptance of the position that reconfiguring chemical production is a Gordian knot whose complexity cannot be untangled. Instead, it gives us an entry point to understand another phase of renewable energy transitions, namely that of replacing and phasing out non-energy fossil fuel use.

Reminiscent of how the IEA assumes decarbonisation without defossilisation, defossilisation is in principle possible without decarbonisation. Considering alternative sources of feedstock, one possibility is increasing recycling. But the conversion of plastics to new plastics, chemicals, or fuels via so-called chemical recycling routes often requires vast amounts of energy, while limitations and constraints also exist for mechanical recycling (for example, the incompatibility of plastic types and degrading quality) (Cullen, 2017; Singh & Walker, 2024; Uekert et al., 2023). And so, increased recycling through chemical recycling technologies might reduce landfilling or incineration but maintain or even increase greenhouse gas emissions in comparison with scenarios without such recycling processes (Nordic Council of Ministers, 2023). A second possibility for an alternative source of feedstock is captured carbon. But when it comes to carbon capture and utilisation and visions of circular carbon, spillovers or indirect effects that increase greenhouse gas emissions can occur. Hydrogen production, carbon capture, and transportation (in particular the shipping of hydrogen) demand large-scale energy consumption that is likely to negate or crowd out alternative

uses. Moreover, the need for scarce biogenic carbon for renewable feedstock could lock in livestock production or various types of monocultures to supply carbon, not to mention the potential for cannibalisation, redirecting biogenic carbon away from competing end-uses. And if carbon is utilised as feedstock for new chemicals, it will not be geologically stored but instead embedded in products, effectively delaying rather than reducing carbon emissions (for example, plastics are later incinerated) (Schenuit et al., 2023). In short, although decarbonisation appears questionable without defossilisation, all routes of defossilisation come with dilemmas for decarbonisation. The potential lack of overlap between defossilisation and decarbonisation is represented in Figure 4.

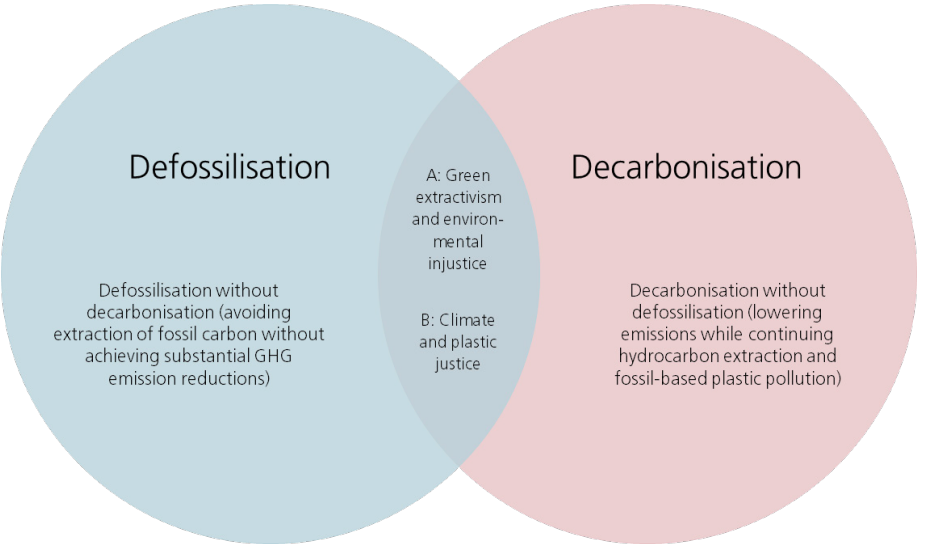


Figure 4. Stylised representation of defosillisation and decarbonisation pathways.
The figure represents the potential difference as well as overlap between decarbonisation and defossilisation, here defined as processes of lowering carbon emissions and the use of fossil carbon, respectively. The two options, A and B, represent the spectrum of possible futures that entail decarbonisation alongside defossilisation.

As critical as defossilisation might be as a transition process, it is subject to many of the same dynamics I have explored in this thesis. Defossilisation is, for example, by no means shielded from trasformismo and the justification of injustices in the name of sustainability. As the notion of defossilisation gets more attention and possibly moves towards mainstream policy discourse, defossilisation can, if not contested and contextualised, propel the circular carbon vision (cf. Paper IV),

serving the dual purpose of maintaining legitimacy in the face of criticisms and justifying expansions, subsidies, and other socio-technical configurations that align with trasformismo. In Figure 4, the dimensionality of defossilisation pertaining to social relations and distributions of power, that is, the distinction between transition and transformation, is captured in the two stylised scenarios, A and B. Pursuing defossilisation along with decarbonisation can, at least in principle, if not in practice, occur within the existing systemic logic (cf. the fourth order of change introduced by Buch-Hansen and Carstensen (2021)) and with a lack of attention to detoxification (pursuing non-toxic production). But in doing so, green extractivism and environmental injustices might be sustained. The need for additional renewable energy for defossilisation increases the scale of mining activities, and toxic impacts and plastic pollution further accumulate as production continues with a different set of feedstocks. Defossilisation, therefore, presents a new but related set of dilemmas and fields of contestation in the struggle for just transitions.

6.2 Essential sustainability?

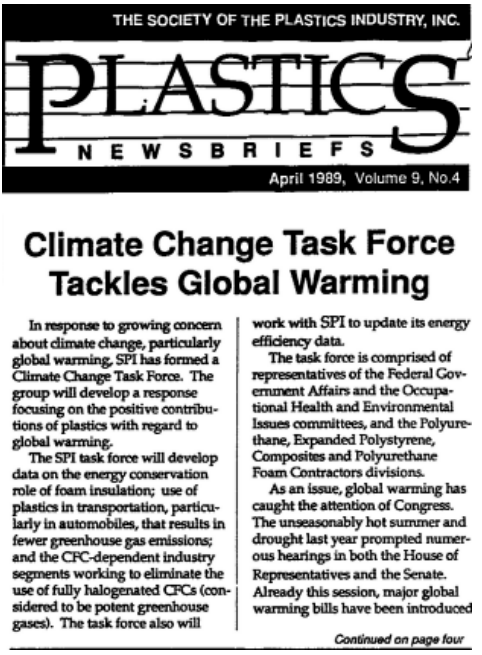
In addition to enquiring into the implications of understanding fossil fuels as feedstock in energy transitions, I also raised the question of what we see when we focus the analysis of plastics and petrochemicals around fossil fuels, growth, distribution, and power. In a sentence, an answer is that the political economy of petrochemical transitions revolves around the rather generic-sounding political questions of who decides what is essential, how and for whom, but in this context in a very concrete way. Because synthetic materials are almost everywhere used for such a variety of purposes, many practices are potentially at stake, and so the issue becomes a matter of which synthetic materials should exist for what purposes.

The power and capacity to define are, in general terms, key tenets of petrochemical transitions. The issue at stake is not only what is sustainable (associated with the widespread tendency towards greenwashing), but also what is essential and what is necessary. As argued most prominently in Paper III (and summarised in Chapter 5), the material, institutional, and discursive power of incumbent firms relies in large part on the power to define petrochemicals as essential and necessary, related to the ability to claim representation of not only

‘capital-in-general’ (Burnham, 1990, p. 181 cited in Newell & Paterson, 1998), but also ‘people-’ or even ‘human-life-in-general’. With limited exceptions, mainstream criticisms of petrochemicals and plastics start by acknowledging that plastics are important and valuable—it is a tribute that is necessary to pay for diplomats, NGOs, researchers, and others who hope to engage in the (re)making of chemical and plastic governance. And in making this concession, appreciating the merits of synthetics and petrochemicals as a hallmark of modernity, the material power of petrochemicals is reinforced. In a material world, being able to multiply materials otherwise restricted by ecosystem services many times over future-proof petrochemicals. Formulated as a question: why are academically informed ‘system-change’ style scenarios maintaining existing levels of petrochemical production and the benchmark or business-as-usual scenario continuous growth? Or why does research on plastic pollution and chemicals invoke developmental justice to legitimise growth and expansion, as documented by Liborion et al. (2023)? The answer to these questions lies in the material power of petrochemicals and the ubiquity of synthetics. Because the circular carbon imaginary is more feasible than restricting modernity from the incumbent perspective—across actors and domains of decision-making—we end with the appearance of no alternative.

In the context of transitions, however, what is sustainable and what is necessary overlap. This overlap has become an increasing focus in the face of transition pressures and a key navigation strategy for incumbents. In 2013, Huber argued that the petrochemical industry in the 21st century is ‘happy’ to be part of the ‘invisible networks of socioecological interchange that make certain lived practices possible’ (Huber, 2013, p. 92). Because of the environmental and health-related consequences of the production, transportation and use of synthetics, any press was—contrary to the saying—not good press for petrochemical incumbents. But in 2024, when petrochemicals and plastics are now subject to multilateral negotiations, it is no longer possible to hide, and the invisibility of petrochemicals is fading. Now, the time has come once again for the petrochemical industry to make their work visible, to position petro-capitalism as a force of good in the world, as the enabler of ‘that thing called progress’, and this time around the notion of progress is tinted in a green, climate-friendly manner. It is therefore that we see the assertion of an interlocked trinity of sustainability, essentiality, and necessity: to affirm that a sustainable future is a future wherein petrochemical producers thrive. When climate change rose on the policy agenda, the US-based

Society of the Plastics Industry established a 'Climate Change Task Force' to produce arguments and statistics to render plastics sustainable. This decision was not part of a transition strategy. Instead, it was a way to position petrochemicals and plastics 'in *response* to growing concern about climate change' [emphasis added]—it was an example of what in Paper III is conceptualised as narrative realignment (see Figure 5). Not only is there no alternative to petrochemicals; there is also no green alternative.



THE SOCIETY OF THE PLASTICS INDUSTRY, INC.

PLASTICS NEWSBRIEFS

April 1989, Volume 9, No.4

Climate Change Task Force Tackles Global Warming

In response to growing concern about climate change, particularly global warming, SPI has formed a Climate Change Task Force. The group will develop a response focusing on the positive contributions of plastics with regard to global warming.

The SPI task force will develop data on the energy conservation role of foam insulation; use of plastics in transportation, particularly in automobiles, that results in fewer greenhouse gas emissions; and the CFC-dependent industry segments working to eliminate the use of fully halogenated CFCs (considered to be potent greenhouse gases). The task force also will work with SPI to update its energy efficiency data.

The task force is comprised of representatives of the Federal Government Affairs and the Occupational Health and Environmental Issues committees, and the Polyurethane, Expanded Polystyrene, Composites and Polyurethane Foam Contractors divisions.

As an issue, global warming has caught the attention of Congress. The unseasonably hot summer and drought last year prompted numerous hearings in both the House of Representatives and the Senate. Already this session, major global warming bills have been introduced

Continued on page four

Figure 5. Newsbrief from April 1989 from the Society of the Plastics Industry (today the Plastic Industry Association).
The newsbrief explains the formation of the 'Climate Change Task Force' and its purpose. The article reads: 'The group will develop a response focusing on the positive contributions of plastics with regard to global warming.' *Source*: Chowkwanyun et al. (2018), discovered in Altman (2024).

The argument that petrochemical transitions are shaped partly by how and the extent to which synthetic materials are accepted as an essential foundation of sustainability—providing the synthetics to which there is no seeming alternative or substitute—is perhaps most clearly illustrated by how this matter is material in the financial sense. When BASF claims that 42 percent of all their petrochemically-derived products are 'Sustainable-Future Solutions', a key

performance indicator introduced by the company in their December 2023 Investor Update, they are telling investors that almost half their output is not subject to transition-related risks (BASF, 2023). And when they point to the strategy of increasing the share of products in this category, they are seeking to 'future-proof' their operations (Mah, 2021). That is, producers are eager to explain to investors that petrochemicals do not constitute fossil capital (with the associated risk of asset stranding) but a different type of capital altogether: a 'synthetic' capital, easily altered and with endless possibilities. Not unlike the role fossil capital played in the past, providing a foundational pillar for expansion, petrochemicals create the conditions for future accumulation in a decarbonising world. To not capitulate to climate change, we are told, we rely on wielding the magic of petrochemicals.

In claiming essentiality, petrochemicals are not much different from other energy-intensive natural resource processing industries. In industries such as cement and steel, incumbents similarly invoke such rhetoric, referencing their output as ubiquitous and essential to justify production and expansion alongside the employment of technical fixes (see, for example, Vogl, 2023). Across these industries, wars of position unfold around what is necessary and whether the output of incumbents falls under that umbrella. Moreover, the most ecologically literate strategy of reduced production and use is uneconomical and seemingly unfeasible when subject to the dynamics of competition and shareholder pressure. But while steel and cement arguably have more homogeneous or carved-out low-carbon production technologies (in the form of hydrogen direct reduction and carbon capture), petrochemicals are less so characterised by the dominance of 'one solution' despite the efforts to push recycling as such. Therefore, the importance of justifying use and maintaining the idea of necessity is even more important to incumbency in the context of petrochemicals and plastics.

It is not that the alleged necessity cannot be challenged in the language of mainstream political-economic logic. For example, calculating the 'disease burden' from plastics in the United States—including direct (where payments are made) and indirect costs (productivity or output loss)—a recent study found the costs of plastics to be $249 billion in 2018 considering only a few chemicals and a limited set of diseases related to those (Trasande et al., 2024). Another paper, leaving out the majority of negative consequences of plastics due to a lack of studies (including all microplastic pollution and health costs in most of the

world), found potential benefits of over a hundred billion dollars (Cordier et al., 2024). But similar to how it is not a lack of studies on the costs of climate change that cause insufficient action on decarbonisation, it is not cost-benefit analyses of the plastic crisis nor further scientific evidence of harms that make incumbents reconsider the future of petrochemicals, nor appeals to power that ensure progressive and interventionist global plastic governance. They will not because the externalisation or shifting of impacts onto those deemed expendable and the reliance on the exploitation 'cheap' nature and labour (Patel & Moore, 2017) underpin the operation of the petrochemical industry. And in claiming to be necessary and essential, incumbents effectively reveal that others are not.

Because of the material power of petrochemical incumbents, the pursuit of just petrochemical transitions should *not* start from the material, as has been the mainstream approach, but from social relations and needs. And so, insofar as the governance and orchestration of petrochemical transitions take as its point of departure the notion that 'plastic is an important material' that 'brings large benefits' or that 'petrochemicals are used for sustainable purposes', it is starting from a disadvantage. Instead, to reject the necessity of petrochemicals in a broad sense, the role of petrochemicals should be decided by starting with human needs and working backwards from there, recognizing petrochemicals as substitutable co-facilitators of material well-being, less fundamental than the underlying human needs of social participation, autonomy, and health (Gough, 2017). The contours of such approaches are already widespread under names such as sufficiency and radical abundance (Bärnthaler & Gough, 2023; Hickel, 2019; Lage et al., 2023). Now, they must come to inform the ethics and dilemmas of petrochemical transitions.

7 Conclusion

> The problem is to see whether in the dialectic "revolution/restoration" it is revolution or restoration which predominates; for it is certain that in the movement of history there is never any turning back, and that restorations *in toto* do not exist.
>
> Gramsci (1971, pp. 219–220)

During the course of writing this thesis project, the links between fossil fuel extraction and the pollution crisis have become increasingly visible in mainstream media and global plastic governance, despite incumbent efforts to scope interventions around waste management. Pushed by the socio-ecological justice movements 'from below' (Dauvergne & Clapp, 2023; Tansel & Tilley, 2024), what started as an issue predominantly concerned with marine litter has developed to become more and more focused on the fossil fuel-chemical-nexus. As the artwork on the cover of this thesis from INC2 testaments, the entire impact pathway of synthetic materials from well to end of life is part of the conversation in the ongoing (and soon to be finalised) plastic treaty negotiations, although it remains marginal in terms of the actual treaty text. The features of this struggle in light of the need for petrochemical transitions are at the core of what this thesis tries to pinpoint, questioning whether it is revolution or restoration that predominates, to use the words of Gramsci quoted above. There is no non-changing status quo, as the concept of trasformismo effectively reveals. And so, what do we see, trying to keep the political economy of petrochemical transitions in plain sight? This can be summarised by answering the research question raised in the introduction, namely, on what basis, to what end, and with what consequences, petrochemical incumbents navigate transition pressures.

Incumbents navigate petrochemical transitions on the basis of material power rooted in the ubiquity of and reliance on synthetics in production and consumption systems. The contestation of this synthetic world is, therefore, a

defining feature of petrochemical transitions. Incumbents employ institutional and discursive power that derives from such entanglements and, when mobilised, take on a particular form in the face of transition pressures to pursue limited transitions that align with the continued growth of petrochemical production and do not address underlying and inherent limitations and contradictions, that is, trasformismo. These dynamics position petrochemical incumbents in a position to maintain fossil-based production even in the phase of decline of fossil fuels for energy purposes, the consequences of which can be the continuation of an extractive fossil-based energy regime. Petrochemical transitions will therefore revolve around the politics of defossilisation—the abandonment of fossil carbon as raw material—a process that comes with another set of dilemmas and potential injustices, alongside the struggle over who decides what materials are essential, how, and for whom. The answer to these questions determines the future of the synthetic world and its injustices.

From a policy perspective, the political economy of petrochemical transitions makes clear that a defossilisation agenda needs to embrace and extend existing supply-side and phase-out policies to include petrochemicals. If the supply of fossil fuels is not addressed and the abundance of cheap feedstock remains intact, petrochemical growth is likely to continue. Transitions away from fossil energy—such as the rise of electric vehicles and the associated decrease in demand for fuels—go a long way in explaining petrochemicals as a diversification strategy. Conversely, if phase-out policies do not address fossil fuels for non-energy purposes, large-scale extraction will continue, with the likely outcome that some or most of it will be burned. And so, if the starting point of this thesis is the outlook that petrochemicals are the future of fossil fuel demand, the ending point is the need to constrain the availability of oil, gas, and coal-based feedstocks, addressing the supply side of petrochemicals. Such measures should not operate on their own but must operate alongside regulation to limit the wasteful use of synthetics to address both production and consumption—a so-called pincher movement so as to cut with 'both arms of the scissors' (Green & Denniss, 2018).

The limitations of the various options for decarbonising petrochemical production and the pollution problems that persist no matter whether plastics are based on renewable feedstock or not, highlight the importance of reducing demand. Addressing supply alongside demand—addressing petrochemicals from both sides so to speak—recognises that the best waste management practice is

reduction (also found in the top layer of the waste hierarchy). Policies and campaigns to enforce reduction must realise the inequalities of plastic use, the global dynamics of (waste) trade in synthetics characterised as plastic waste colonialism and centre the fulfilment of human needs through democratically informed decision-making processes so as to not fall prey to individualist understandings of pollution. In that way, chemicals might come to live up to some of the incumbent promise of enabling renewable energy, but without readily strengthening the fossil fuel-chemical-plastic nexus. To arrive there, though, we must grapple with the synthetic world in which we live and the petrochemicals that sustain it.

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Paper I

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Current Opinion in Chemical Engineering

Mapping GHG emissions and prospects for renewable energy in the chemical industry

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Chemicals is the industrial sector with the highest energy demand, using a substantial share of global fossil energy and emitting increasing amounts of greenhouse gasses following rapid growth over the past 25 years. Emissions associated with energy used have increased with growth in coal dependent regions but are also commonly underestimated in regions with higher shares of renewable energy. Renewable energy is key to reducing greenhouse gas emissions yet remains niche when considering corporate targets and initiatives aiming at emission reductions, which instead favour incremental energy efficiency improvements. These findings point to a risk for continued lock-in to fossil energy in the industry.

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Introduction

The chemical industry is one of the most important industries in terms of greenhouse gas (GHG) emissions [1,2]. It has the highest energy demand of all industrial sectors as it uses fossil fuels – coal, oil, and gas – for energy as well as feedstock for the production of platform petrochemicals [3]. The most central processes in petrochemical value chains (including production of olefins and aromatics through steam cracking as well as ammonia and methanol synthesis) use fossil raw materials and are extremely energy intensive. Production of the platform chemicals used for downstream production of more complex products such as fertilisers and plastics require very high operational temperatures and pressures to manufacture [4,5]. Emissions are generated on production sites through fossil fuel combustion as well as in many of the fundamental processes for producing key chemicals, so called scope 1 emissions, but also in the external production of heat and power used by the industry, so-called scope 2 emissions. Further, before being used in the industry, emissions are generated in the mining, extraction, and processing of fossil fuels and other raw materials, so-called upstream scope 3 emissions. The very high demand for thermal as well as electric energy makes the industry a central demand factor in global energy systems and the industry has through its special relationship with the energy sector played an important role in shaping the modern era of fossil energy use [6]. Addressing chemicals is thus absolutely central for reaching climate goals for global industry [7]. Through complex, interlinked, and globalised downstream value chains the emissions associated with chemicals propagate and diffuse through the modern economy. This generates large challenges in assessing the total contribution to climate change when used and finally discarded, so-called downstream scope 3 emissions. In this paper we aim to show how developments in the global chemical industry in the past decades have impacted energy use and associated GHG emissions in scope 1, scope 2 and upstream scope 3, as well as the prospects for the industry to rapidly reduce its GHG emissions through renewable energy use.

Chemical industry energy use and greenhouse gas emissions

Global chemical production has seen a strong but geographically uneven growth in this millennium. While output in Europe and North America, which were the principal regions for the industry in the 20th century, has remained relatively stable, production has grown rapidly in other regions. Over the last 20 years, production has more than doubled in the Middle East and more than quadrupled in China while also South-East Asia has maintained rapid output growth [8]. The shifting

geography of chemicals production has affected energy and feedstock use in the industry. The expansion in China has made use of domestic coal reserves as feedstock, primarily through gasification in coal-to-ammonia and coal-to-olefin value chains, resulting in coal use being a prime driver for increasing GHG emissions in plastics [9]. European production has largely remained committed to naphtha-based production whereas natural gas (NG) condensates, primarily ethane, has been a cornerstone of the expansion in the Middle East as well as in developments in North America. Globally the industry is estimated to use 8% of gas and 14% of petroleum, and is expected to be a key driver for oil demand growth until 2030 and beyond [3,10,11].

A recent analysis [12] shows how annual global scope 1 emissions from chemicals[1] have grown to reach 1.8 Gt CO_2-eq in 2020, about 4% of total global GHG emissions. Scope 2 emissions are close to scope 1 and estimated upstream scope 3 emissions add another 2 Gt CO_2-eq giving a total estimate of 5.6 Gt CO_2-eq, equivalent to about 10% of global emissions, as shown in Figure 1b. Globally total GHG emissions of the sector have more than doubled since 1995. Figure 1a shows that while emissions have been reduced in Europe and North America through investments in energy efficiency improvements and N_2O abatement technologies, the growth in other regions has been far larger and China now accounts for 2.6 Gt CO_2-eq or 47% of the global emissions from the industry. China saw a substantial increase in the share of GHG emissions, as it accounted for 24% of global GHG emissions in the sector in 1995. GHG emissions also increased in the Middle East region but at slower pace. In contrast, Brazil, Russia and India have decreased their GHG emissions from the sector.

Scope 2 emissions are significant as electricity used by the chemical sector currently is largely fossil-based – in most regions more so than the rest of the regional electricity system. This is due to chemicals production taking place at large sites that share dedicated energy infrastructure based on fossil resources and the parallel demand for electricity and heat leading to the use of on-site cogeneration based on fossil fuels. As seen in Figure 2a considerable differences in fuel use can be observed across regions [13] owing to variations in the relative costs of fuels. Globally, natural gas is the most important fuel for chemical sector power generation with a capacity share of 41% [14]. While the shale gas boom in the US has diffused the use of natural gas as fuel China is abundant in coal which is thus frequently used in local power plants. A common pattern in chemical sector power plants throughout the world is also the use of oil residues which are not further processed into chemical products but serve as inexpensive supplementary fuels [13]. Such practices have been found to reduce the needs for waste treatment but typically lead to higher specific CO_2 emissions. Renewable energy plays a minimal role, with a capacity share of only around 2% [14] but can contribute to lower GHG emissions of the chemical sector energy supply where electricity from the regional electricity grid is consumed. This can for example apply to smaller sites without local generation capacity, to electricity demand that exceeds local supply, or to chemical firms with dedicated Power Purchase Agreements (PPAs).

Current modelling practices of energy supply to chemical sector do not fully capture these characteristics [16]. In life cycle assessment (LCA) the electricity demand of the chemical sector is typically assumed to be the same as the regional or national electricity mix [15], leading to significant underestimation of GHG emissions from chemicals production in regions with a high penetration of renewables in the electricity mix. In some regions, the differences can be minor, but for example switching from the regional average emission data to the emissions of the chemical sector-owned power plants could increase specific global warming impacts of electricity in North America by about +45%, while these impacts in Europe or Latin America could even double (based on estimates calculated with ecoinvent v3.8 cut-off version [15]) as shown in Figure 2b. In light of these differences the proper attribution of energy supply technologies would represent an important step. Furthermore, these differences highlight how far behind the chemical sector is in terms of renewable energy use in comparison to the national averages in some regions.

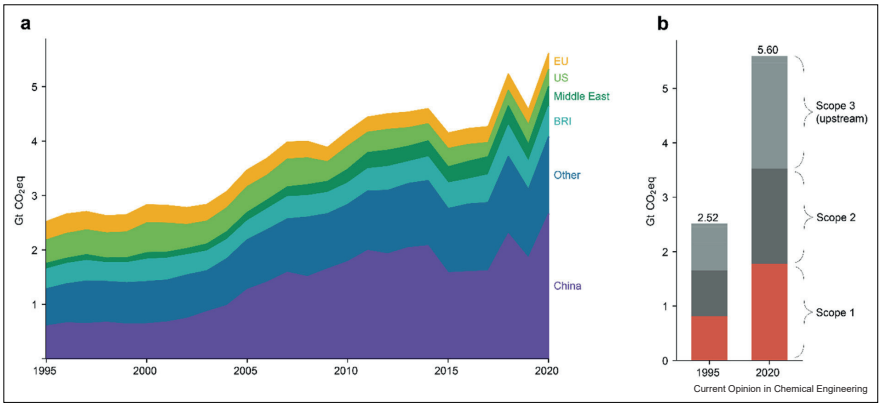
Prospects for renewable energy

Recent scenario analyses have studied the prospects for a transformation of the industry, pointing to various pathways for reaching zero or low GHG emission targets [17–21] and others have focused specifically on the key market segment of plastics [22–24]. Although scopes and assumptions differ these studies underline the necessity of addressing the integrated flows of material and energy through the industry to reach emissions in line with international climate targets. While there is no silver bullet, it is clear that a shift in energy use towards renewable electricity is central to reducing the GHG emissions [20–22].

Reducing GHG emissions from the chemical industry with renewable energy is possible in a number of ways. Renewable electricity can directly substitute electricity used in industrial processes today through high

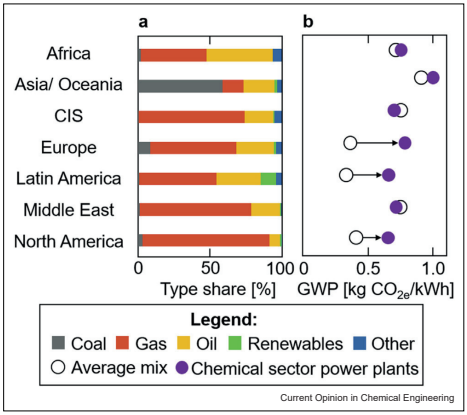
[1] The analysis used data from EXIOBASE covering the sectors Plastics, basic; Reprocessing of secondary plastic into new plastic; N-fertiliser; P- and other fertiliser; Chemicals nec, Manufacture of rubber and plastic products.

Figure 1



GHG emissions from chemicals (a) by country and **(b)** by scope, where scope 1 is direct emission from petrochemicals, scope 2 indirect emissions from utilities and scope 3 (upstream) represents all upstream emissions such as extraction, mining, and transports (but does not include downstream, e.g. incineration). Figure 1a represents total (i.e. scope 1 + scope2 + scope 3) GHG emissions for each country/region. BRI: Brazil, Russia, and India. Based on an analysis of data from EXIOBASE in [12].

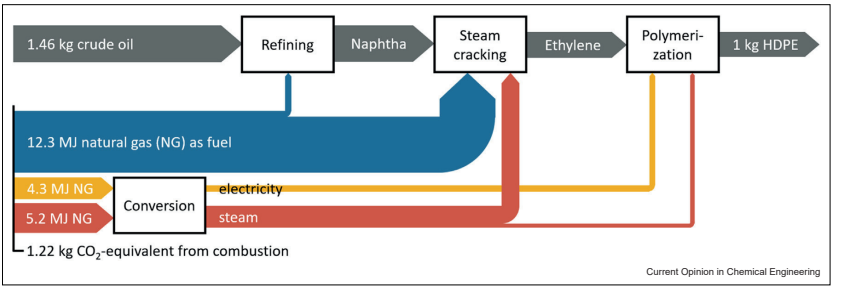
Figure 2



Power generation capacity mix used by chemical companies and the associated carbon footprint of generated power (a) Power plants owned by chemical companies in different regions by capacity share, based on the S&P Global Platts World Electric Power Plant database [14] and **(b)** consequences of switching from average Global Warming Potential (GWP) scores per kWh of electricity to those estimated from chemical sector power plants [15].

temperature heat pumps, radiative heating, or other forms of electrified heat transfer as well as be used to electrify boilers and other applications currently heated with on-site fossil fuel combustion [25]. A cornerstone of direct electrification could be the electrification of steam crackers, which play a central role in the supply chains of many chemicals including the most widely used types of plastics such as polyethylene and polypropylene (as shown in Figure 3). In addition to direct electrification, a large share of the chemical industry's future electricity demand arises from the need for production of green hydrogen by water hydrolysis. This green hydrogen can be used directly in conventional ammonia production, and other chemical synthesis steps [26]. Blue hydrogen – produced from steam reforming of fossil gas but with carbon capture and storage (CCS) – remains a questionable solution due to the very high climate impact of methane emissions that occur throughout the gas value chain and are at high risk of being significantly underestimated [27,28]. While CCS could enable reduction of emissions in the industry, the rapidly decreasing costs for renewable energy indicate that only in a few cases is CCS likely to make a significant long-term contribution [29]and that the additional costs for capture and storage could soon make green hydrogen the more attractive solution compared to blue hydrogen [30]. A third avenue for decarbonisation that necessitates large-scale electrification is through carbon capture and use (CCU) for chemical processing. CCU processes require renewable electricity not only for green hydrogen, but also for the capture of carbon, for example from rich process emission streams or direct air capture. The energy demand for carbon capture processes differs widely depending on the source of the captured carbon [31]. Estimates show

Figure 3



Typical (primary) energy and raw material inputs in the supply chain of high-density polyethylene (HDPE) using NG as fuel. Based on data from [4,32–35].

that a chemical industry completely based on CCU processes would require almost all of the global electricity expected to be available in 2030, although the development of novel processes could reduce this demand [17]. For the CCU pathway to be transformative it is also crucial to ensure that emissions are not only delayed but truly avoided through the use of captured carbon [31]. As both the green hydrogen and CCU pathway demand vast volumes of energy, these alternatives add to the need for the industry to engage in renewable energy deployment.

For an electrification of the industry aligned with international climate targets, certain infrastructural developments are key. Preconditions for electrification include an accelerated deployment of new renewable electricity generation capacity and upgrading of transmission grids to transfer power to chemical clusters. Further, more flexible operations of power-intensive processes as well as distributed storage capacity for both energy and chemical intermediates will be needed to make up for fluctuations in the energy supply at different temporal scales [36]. An expansion of renewable energy supply in regions with significant renewable energy resources could be an opportunity for investments in new chemical production facilities in these regions, potentially shifting the geography of the industry again. However, due to the massive investment costs for chemical infrastructure, the complex interlinkages of the chemical supply chains, the international competition in terms of costs, and high path dependency and historical lock-in in the industry we expect such relocations to be unlikely in the near term.

Despite the importance of renewable energy to decarbonise the chemical industry, current corporate commitments to renewable energy appear both scant and inadequate. This is evident from a review of company disclosures to CDP (formerly Carbon Disclosure Project), the leading platform for voluntary corporate GHG emission disclosures, through which more than 13 000 companies disclosed information in 2021.[2] In total, 113 companies reporting to CDP identified their primary activity as chemicals production[3] in 2020 (with disclosures remaining inconsistent, incomplete, and disparate – for an overview see [12] and references therein). Table 1 shows the 16 companies that reported company-wide "target(s) to increase low-carbon energy consumption or production" [39]. Most of these were related to voluntary corporate climate governance initiatives such as RE100 (promising commitments to '100% renewable electricity') [40] or the Science-Based Target initiative (scenario-based emission reduction targets) [41]. In line with a wider tendency of corporate commitments to clean energy [42], achieving these targets rely on market-based methods, for example through purchasing renewable energy certificates. In their CDP disclosures, 37 of the 113 companies reported use of market-based products to lower their scope 2 emissions. However, market-based methods are at risk of not leading to actual emission reductions. This is the case for market-based instruments that are nonadditional meaning that they do not lead to extra renewable energy generation [43,44]. To combat that entities claim emission reductions that are not real through market-based instruments, strict requirements for additionality are necessary (as associated with PPAs which are often thought to lead to additional renewable

[2] Founded in the beginning of this millennium, the CDP is a multistakeholder initiative meant to inform private investment decisions and enable accountability, representing institutional investors which according to CDP hold US$130 trillion in assets combined [37,38].

[3] The analysis includes companies listing their primary activity as agricultural chemicals, basic plastics, inorganic base chemicals, nitrogenous fertilisers, non-nitrogenous fertilisers, other base chemicals, speciality chemicals.

Table 1

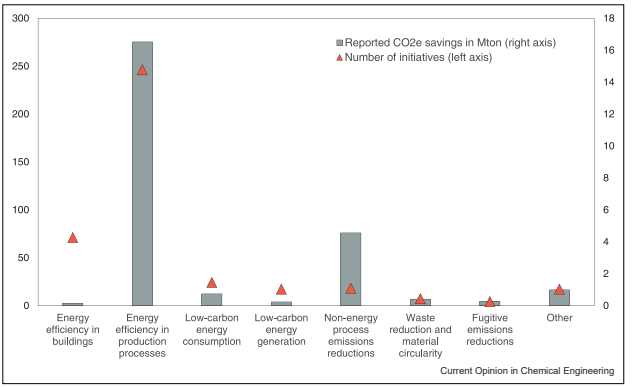
Low-carbon energy targets reported in 2020 CDP disclosures.

Organisation	Country	Target	Use of market-based instruments	Is this target part of an overarching initiative?
Air Liquide	France	10 000 000 MWh from renewables in 2025 (base: 6000 000 MWh in 2015)	Yes	Science-based targets initiative
Denka Company Limited	Japan	153 MWh from renewables in 2030 (base: 114 MWh in 2005)	Not part of target	No
DIC Corporation	Japan	5.7% of total energy consumption from renewables in 2030 (base: 4.1% in 2013)	Under consideration as per 2022 to reach key performance indicators for insurance of green bonds	Not specified
DuPont de Nemours, Inc.	United States of America	60% of total electricity 'sourcing' from renewables in 2030 (base: 2.9% in 2019)	Yes	No
Givaudan SA	Switzerland	100% of all purchased electricity from renewable in 2025 (base: 0% in 2015)	Yes	RE100
Indorama Ventures PCL	Thailand	25% renewable electricity consumption by 2030 (base: 6.86% in 2019)	Yes	Renewable Electricity Buyers Alliance
International Flavors & Fragrances Inc.	United States of America	75% renewable electricity procurement in 2025 (base: 0% in 2010)	Yes	RE100
Johnson Matthey	United Kingdom of Great Britain and Northern Ireland	60% of electricity from renewable sources in 2025 (base: 24% in 2019)	Yes	No
Koninklijke DSM	Netherlands	75% of purchased electricity to be sourced from renewables by 2030 (base: 0% in 2015)	Yes	RE100
LG Chem Ltd	Republic of Korea	100% renewable energy by 2050 (base: 1% in 2019)	Yes	RE100
Linde PLC	United States of America	30 400 001 MWh of low-carbon electricity consumption of in 2028 (base: 15 200 000 MWh in 2018)	Yes	No
Novozymes A/S	Denmark	100% renewable electricity consumption by 2030 (base: 37% in 2018)	Yes	RE100
PPG Industries, Inc.	United States of America	25% of total electricity usage from renewables (base: 16% in 2017)	Yes	Not specified
SABIC	Saudi Arabia	4000 MWh of renewable electricity in 2025; 12 000 MWh in 2030 (base: 0 MWh in 2010)	Not part of target	Not specified
Symrise AG	Germany	100% renewable electricity procurement in 2025 (base: 18.3% in 2018)	Yes	RE100
Toyobo Co., Ltd.	Japan	849 883 kWh renewable energy consumption (base: 1214 119 kWh in 2013)[a]	Not explicit in disclosure	No

Source: Authors' compilation based on CDP and corporate sustainability reports.

Target formulations largely follow wording in CDP disclosures. The use of market-based instruments to achieve set targets has been cross-referenced with corporate sustainability reports.
[a] The stated target of decreased consumption compared to base year corresponds to CDP disclosure. Disclosures are not checked by CDP for consistency and have been shown to contain multiple inconsistencies also with regard to companies in the chemical industry [12].

Figure 4



Self-reported emission reduction initiatives implemented in the reporting year in the chemical industry in 2020 disclosures to CDP. *Note*: The category *other* includes inter alia company policy or behavioural change, transportation, and other initiatives not categorised elsewhere including nonspecified initiatives. Initiatives that were not categorised have been coded using CDP categories to the extent that companies reported sufficient details in their disclosures.
Source: Authors' compilation based on corporate disclosures through CDP.

energy capacity) [43,45].

For substantive emission reductions to take place, it is crucial to follow strategies towards deep decarbonisation [46], rely on proper attribution of energy supply technologies (cf. Figure 2) and commit to reliable PPAs rather than nonadditional market-based instruments. Otherwise, companies risk reporting emission reductions that are not real [45].

Analysing implemented emission reduction initiatives, chemical companies continue to focus on energy efficiency improvements and incremental adjustments while low-carbon energy initiatives remain niche, as shown in Figure 4. While there is no data available on all energy investment in the industry some firms have made large investments in renewables recently, for example both Yara and BASF have acquired large positions in offshore wind farms in the North Sea [47,48]. However, the picture painted by disclosures shows that these initiatives are marginal and not yet part of the strategic core in the industry and even for BASF, the planned investments of up to 1 billion EUR made towards climate targets from 2021 to 2025 [49] represent no more around 4% of the planned capital expenditures [50].

In CDP disclosures, reported GHG emission reductions from improved energy efficiency outweigh all other initiatives. Critically, this approach risks leading to self-enforcing loops furthering integration of existing processes that can deter from pursuing deep decarbonisation [51] and also ignores the central role and potential of renewable energy. In this way, despite delivering relative emission reductions, energy efficiency might result in furthering carbon lock-in unless integrated in comprehensive industrial policy frameworks for deep decarbonisation [46]. Taken together, voluntary corporate disclosures indicate that both company-level targets and initiatives are drastically inadequate considering the scale and scope of zero emissions electricity needed to decarbonise the chemical industry.

Conclusions

In this paper we have shown how GHG emissions have been growing rapidly in the chemical sector on a global scale, more than doubling since 1995. This has been fuelled by rapid growth of production especially in coal dependent regions, far outweighing energy efficiency improvements and abatement of specific GHGs such as N_2O. Emissions from the industry are to a large degree associated with energy intensive production processes but also occur throughout the life cycles of chemical products (downstream and end-of-life emissions were not included here). As emissions remain difficult to estimate due to limited geographic representation in LCA datasets and inconsistencies in voluntary reporting and disclosure there is a dire need to improve these types of data – although that in itself does not mitgate emissions. Despite the centrality of renewable energy in decarbonisation scenarios aligned with international climate targets, corporate commitments to adoption of and investments in renewable energy remain limited. As a

fundament of a transformation of the industry, this needs to change to pursue and achieve a decarbonisation aligned with international climate goals. Renewable energy is central for decarbonising the energy use in existing processes as well as for the transformation pathways relying on green hydrogen and CCU. Just as the industry historically shaped energy system development in the fossil era it could take centre stage in accelerating renewable energy deployment globally – or act as a barrier to the transformation. Taking an aWe conclude that the industry is likely to remain a major emitter and key contributor to global climate change beyond 2050, unless reorientated towards transformative approaches to industrial change that include active engagement in the development, deployment, and adoption of renewable energy.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Fredric Bauer reports financial support was provided by V Kann Rasmussen Foundation. Stephan Pfister reports a relationship with Ecoinvent that includes: board membership.

Data Availability

The authors do not have permission to share data.

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- • of special interest
- •• of outstanding interest

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An analysis showing how the clustered structure typical of the chemical industry must be consideredin climate policy making.

Paper II

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Connected we stand: Lead firm ownership ties in the global petrochemical industry

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ABSTRACT

Using oil, gas, and coal to produce platform chemicals on an enormous scale, the petrochemical industry constitutes a core part of the global energy order. Given demand growth for petrochemicals, the sector is set to become increasingly important to fossil fuel interests. Arguing that internationalised networks help structure the social metabolism and are important for transformative change, this paper sets out to analyse economic ties in the global petrochemical industry. In this paper, we conceptualise such relations and explore how they foster alignment on a global scale. We emphasise the role of internationalised networks in global socio-technical regimes, arguing for the importance of economic ties that establish a financial and juridical relation. On this basis, we theorise that extensive lead firm ties strengthen global regimes and shape socio-technical reconfigurations to align the interests of incumbent actors. Applying this framework, we analyse ownership relations amongst lead firms in the global petrochemical sector. We find a polycentric but global network aligning interests across major producers which we argue helps maintain and reproduce commitments to fossil fuels. The findings illustrate the relevance of pursuing parallel transitions along the petrochemical value chain, including energy, chemicals, and plastics, to break from fossil fuel dependency.

1. Introduction

A substantial share of the social metabolism revolves around the production of synthetic materials, processes of which the petrochemical industry is at the heart. To produce chemicals, the petrochemical industry relies on fossil resources, including coal, oil, and gas, not only as sources of energy but also as feedstock. Despite being the industrial sector with the highest energy demand, petrochemicals have often been overlooked in both research and policy related to the energy and climate nexus (cf. Hanieh, 2021; IEA, 2018; Svensson et al., 2020; Wesseling et al., 2017). This omission is troubling, as the recent decade has seen massive investments into petrochemicals contributing further to escalate an already strong commitment to fossil-based chemical production (Bauer and Fontenit, 2021; VCI, 2021). In addition, several analyses project petrochemicals to be the main driver of oil demand growth in this decade (BP, 2022; IEA, 2018, 2021a). This outlook makes the petrochemical sector key to energy transitions and the struggle over the future of the global social metabolism. The potential for escalating commitments to fossil fuels (Arbuthnott and Dolter, 2013) through petrochemicals highlights the need to assess the relations (financial, economic, and judicial) that underpin the maintenance of and investments in fossil capital.

To understand transition dynamics in industries on a worldwide scale, scholars in the field of sustainability transitions have invoked the concept of global regimes. Conceptualised as dominant institutional rationalities, global regimes are said to have reached validity beyond specific geographies (Fuenfschilling and Binz, 2018). The global regime concept helps theorise change dynamics on a global scale, highlighting how and why industries maintain socio-technical stability. For regime (re-)enforcement and (re-)enactment, Fuenfschilling and Binz (2018) highlight the importance of internationalised networks and their role in diffusing rationalities. In this paper, we seek to unpack such relations to better understand what makes regimes 'stay' (Turnheim and Sovacool, 2020). Focusing on the form and extensiveness of ties amongst actors orchestrating the global energy metabolism, we point to the risk of (re-)enforcement of carbon lock-in (Könnölä et al., 2006; Unruh, 2000) with important implications for the prospects of transformative change on a global scale.

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Starting from a relational perspective, this paper explores the potential role of internationalised producer networks in creating and upholding stable configurations, thereby maintaining the stability of the global regime in the petrochemical industry. Specifically, we conceptualise the importance of internationalised networks around the neo-Gramscian notion of *trasformismo,* arguing that economic ties between central actors in the global regime commit incumbents to pursue strategies of accommodation and absorption. Our empirical analysis explores ownership interlocks across the largest petrochemical producers, assessing economic integration on a global scale. In assessing integration across lead firms in the chemical sector, we argue that extensive economic ties in the sector work to support past and planned investments in fossil capital at a time when the industry as a whole is under pressure. We thereby add to recent research that has begun to unpack networks in the petrochemical industry (Buch-Hansen and Henriksen, 2019; Buch-Hansen and Larsen, 2021; Verbeek and Mah, 2020) and the social metabolism of petrochemicals more generally (such as Bauer and Fontenit, 2021; Hanieh, 2021; Mah, 2021a; Tilsted et al., 2022). While the analysis does not seek to determine direct causal links between the network and specific outcomes, we argue that it is relevant to understand the network structure as conditioning and possibly inhibiting radical industry transformation.

The paper continues as follows: Section 2 introduces the global regime concept and reviews the notion of global networks in the literature that the regime concept draws upon. Section 3 presents the methods and data used, as well as the empirical context, before turning to the empirical analysis. Section 4 discusses the findings and their implications, while section 5 concludes.

2. Global regimes and global networks

From an ecological economics perspective, understanding the economy as a metabolic organism, sustainability transitions extend beyond the techno-economical and involve changing social arrangements and relations of power that shape the provisioning of key societal functions (Røpke, 2019). This multi-faceted understanding of socio-economic systems that drive resource consumption and pollution demands engagement with their technical as well as their political, social, and economic aspects, spanning across scales and geographies (Røpke, 2016).

To understand the relations that connect and shape the social metabolism on a global scale, scholars in the sustainability transitions literature have invoked the notion of global socio-technical regimes. In transition studies, regimes are said to form the 'deep structure' of socio-technical systems that fulfil societal functions (Geels, 2010). Regimes constitute the most strongly institutionalised socio-technical configuration and help explain inertia and stability (Karltorp and Sandén, 2012), as regimes exert more power over actors than so-called niches, i.e., weakly institutionalised configurations (Fuenfschilling, 2019; Miörner et al., 2021). Regimes solidify through the co-evolution of society and technology as formal and informal institutional structures that guide behaviour and shape social practices develop alongside technologies (Fuenfschilling and Binz, 2018). Building on, inter alia, the global value chain (GVC) and the global production network (GPN) literature, the global regime concept then points to institutional rationalities that exist beyond specific territorial contexts.

Bringing together various perspectives, Fuenfschilling and Binz (2018, p. 739) define a global socio-technical regime as the dominant institutional rationality in a socio-technical system, which depicts a structural pattern between actors, institutions and technologies that has reached validity beyond specific territorial contexts, and which is diffused through internationalised networks.

From this definition alone, global regimes appear rather stable. Yet, these institutional rationalities are, following Meyer (1999), only semi-coherent and, following GPN, multi-scalar. As with non-global regimes, they are contested by different actors and constantly renegotiated and re-produced. Moreover, following the GVC literature, actors' abilities to influence the dominant institutional rationality depend on their positions in international networks as well as their capacities to invoke institutional power (Fuenfschilling and Binz, 2018). As cultural-cognitive rationalities, regimes exert mimetic pressures but can also influence behaviour through regulative and normative pressures, and by materializing in technology. Due to the multi-scalar nature of global regimes, spatial variation is bound to arise through interplays across scales and regionally anchored regimes, challenging simplistic notions of technology transfer (Monstadt and Schramm, 2017).

Nuancing the global regime concept, Fuenfschilling and Binz (2018) distinguish between strong and weak global regimes, allowing for varying degrees of institutionalisation and structuration across sectors. Strong and weak regimes differ in terms of the scale and scope of diffusion and their resistance to alternative configurations. As various rationalities co-exist in most socio-technical systems, different institutional logics compete across scales. The regime thus denotes 'the semi-coherent assemblage of elements of various ideal-type rationalities which are most deeply institutionalized (…), while elements of other institutional rationalities are much more fluid, unstable, and thus less influential' (Fuenfschilling and Binz, 2018, p. 739). As institutional rationalities diffuse through and take hold in different regions with otherwise different preconditions (cultural, institutional, material), the strength of the regime increases.

2.1. Conceptual foundations of internationalised networks

Internationalised networks constitute important relational structures in global socio-technical systems. Through connecting actors across places, scales, and sectors, networks make up central, if not foundational, elements of the global political economy (Coe et al., 2008; Dicken et al., 2001). Yet, the conceptualisation of networks in transition studies often remains flat, i.e., it does not distinguish between and specify the importance of different kinds of relations. Regimes were in early work seen as involving multi-actor networks (e.g. finance, research, and producer networks), with regimes being produced and reproduced by networks of various actors and institutions (Geels, 2002; Smith et al., 2005). Therefore, networks are said to be a generic feature of innovation systems (Grillitsch et al., 2019; Musiolik et al., 2012). Later work has described competing socio-technical configurations including both social and technical elements as networked with dominant paradigms constituting stable networks and niche innovations represented as emerging networks (Heiberg et al., 2022; Miörner and Binz, 2021). Neither of these abstractions, however, is particularly helpful in identifying and operationalizing internationalised networks that underpin the global regime, nor do they give emphasis to specific types of networks over others. To further unpack global networks, we therefore now turn to two of the approaches that the global regime concept draws from, namely the GVC and the GPN literatures.

Drawing from social network theory (Borgatti et al., 2018; Cronin, 2016; Robins, 2015, pp. 17–38), we focus on three aspects relevant to transitions. These include i) network conceptualisation, ii) collaboration, and iii) stability. *Conceptualisation* relates to the basic understanding of networks, in what sense the term is evoked, and the context and relations it is meant to describe. *Collaboration* pertains to the form and dynamics of network relations, e.g., the possibility of both collaborative and competitive ties as well as the co-evolution of trust, control, and learning in actor relations (Inkpen and Currall, 2004). Finally, *stability* refers to the role of networks in enabling stability and endurance in the network environment. Although we here delineate between different elements of network conceptualisation, these categories overlap. For example, collaboration in a network relates to how ties are defined. Thus, we do not see the categories above as fundamentally distinct but rather as analytical aids useful for review.

2.1.1. Networks in GVC and GPN

GVCs are, in essence, conceptualised as chain structures tied through dyadic inter-firm links, representing economic activity in a rather parsimonious manner (Bair, 2008; Dallas et al., 2019; Gibbon et al., 2008; Henderson et al., 2002). These relationships and their degree of formalisation within value chains exist on a spectrum, ranging from 'hierarchies' between headquarters and subsidiaries in an MNC to 'markets' with arm-length relations (with 'captive', 'relational' and 'modular' constituting the categories in between) (Gereffi et al., 2005). In line with the attention given to the production, distribution, and consumption of specific products and services in particular industries, the multinational corporations (MNCs) around which production networks are coordinated, i.e., lead firms, are of special importance to GVCs (Dallas et al., 2019; Yeung and Coe, 2015). Following a broadening in the GVC literature towards multipolarity, the importance of actors outside the core inter-firm networks has been flagged, and so has lead firm heterogeneity (Dallas, 2015; Nadvi and Raj-Reichert, 2015). This is closer to the core conceptualisation of production networks in the GPN literature, which are conceptualised as fragmented, complex, and operating across locations at a continuum of scales[1] (Coe et al., 2008; Dicken et al., 2001; Henderson et al., 2002). There is thus attention to extra-firm dynamics, institutions, and regionality in the core conceptualisation[2] (Coe and Yeung, 2015). Recent efforts to further develop the definition of GPNs see them as lead-firm-based configurations (Coe and Yeung, 2019) or as 'chains' of 'multiple, differentiated networks at each stage of a given production network' (Stephenson and Agnew, 2016, p. 559).

Regarding collaboration in GVCs, the aforementioned governance structure as well as the degree and form of power asymmetries shape the nature of relations. Thus, although participation in a given GVC is a way to acquire both knowledge, access, and assets (Taglioni and Winkler, 2016), lead firms typically decide the terms upon which inclusion is negotiated (Dallas et al., 2019; Gibbon and Ponte, 2005; Humphrey and Schmitz, 2002). Although the focus in GVC analysis initially tended to focus on coercive dynamics in relations, the approach now includes unintentional and more subtle dynamics which structure relations such as mimetic pressures through norms, conventions, and worldviews, similar to the regime concept (Dallas et al., 2019; Mondliwa et al., 2021). To add to the notion of inter-firm relations as power struggles, the GPN tradition emphasises dependency and aspects of mutual interest in networks (e.g., in the case of knowledge transfer). In this perspective, specific production networks configured around lead firms are understood as interfirm partnerships that collaborate and coevolve in competition with other networks (Yeung and Coe, 2015).

In terms of stability, a key tenet of GVCs is that the power to influence value chains mainly resides within lead firms (Dallas et al., 2019). Through their structural positions, lead firms have influence over and the ability to shape operations elsewhere in the chain (Gereffi et al., 2005; Ponte and Sturgeon, 2014). Questions of stability in inter-firm relations are, in this sense, matters of GVC governance and the strategizing of various actors, especially lead firms (Gibbon et al., 2008). Power dynamics thus help determine stability in GVCs. The extent to which certain forms of power are more resistant to change remains an open question and is highlighted as a point for future research by Dallas, Ponte and Sturgeon (2019, p. 678), who nevertheless point to the tendency for networks to generate monopoly power through dynamics of path dependency and lock-in. Complementing this perspective, the GPN approach highlights political-economic 'drivers' that actors face to explain change (and thereby stability). These important drivers are different but related to the capitalist dynamics of cost-capability ratios, pressure to develop new markets, and financial discipline (Coe and Yeung, 2015; Yeung and Coe, 2015).

2.1.2. Lead firms in global regimes

Table 1 summarises the GVC and GPN network conceptualisations as presented above, which we use as a starting point to operationalise internationalised networks. While the GPN concept underscores the complexity of the internationalised networks that underpin global regimes, these perspectives help bring clarity by guiding our attention towards particular actors (lead firms) and particular relations (formalised economic ties). As leading incumbents in an industry, we posit that lead firms must, by definition, relate to the global regime, i.e., the globally dominant institutional rationality. At the same time, lead firms are in a position to reach out and relate to both local and global niches and regimes in different industries through various governance arrangements. For example, incumbent petrochemical companies have engaged in the production of bioplastics through joint ventures (Total, 2016; Tullo, 2011) and acquired smaller firms engaged in niche development of new products and processes (e.g. Evonik, 2021). Despite elements of mutual interests and dependency, the more asymmetric and hierarchical the power relation between lead firms and their respective counterparts, the more likely lead firms are to dictate (the form of) change within a given value chain. For example, MNCs have used the sustainability agenda for 'green capital accumulation', operationalizing sustainability in specific ways and squeezing suppliers to ensure new opportunities for accumulating capital (Ponte, 2020). In short, lead firms 'navigate the storm' from a structurally dominant position (van Mossel et al., 2018).

With this focus on lead firms and formalised inter-firm relations in mind, we now home in on the question of how such actors and ties in internationalised networks influence stability in global regimes in the face of transition pressures. To address this issue and put forward a coherent framework, we resort to neo-Gramscian theory and the notion of 'trasformismo'.

2.2. Shaping socio-technical reconfigurations

In recent years, various scholars have pointed to the merits of neo-Gramscian perspectives on transitions (Ford and Newell, 2021; Szabo, 2022; Tilsted et al., 2022). In particular, Ford and Newell (2021) unfold the range of relevant neo-Gramscian concepts and their application to transition studies (and the widely invoked multi-level perspective), highlighting the relevance of trasformismo. Distinguishing between transitions and trasformismo, Newell (2019) defines the latter as

Table 1
Overview of the network conceptualization in the GVC and the GPN literature.

Scholarly tradition	Network definition and conceptualisation	Collaboration	Stability
Global value chains (GVC)	Inter-firm networks focused on dyadic ties between lead firms and suppliers at the industry level.	Nature of collaboration is shaped by power struggles. Lead firms typically decide terms on which suppliers access knowledge and assets through GVCs.	Stability hinges typically on lead firms and the form of GVC governance. No a priori stance on what power dynamics lead to stability.
Global production networks (GPN)	More elastic network concept, emphasising complexity, fragmentation, and multiple scales.	In addition to power, GPN also emphasises dependency and mutual interests.	GPN points to capitalist dynamics to explain the evolution of GPNs.

[1] While distinctions between the GVC and the GPN literatures have become less discernible in later years (cf. Coe and Yeung, 2019; Grabs and Ponte, 2019), the core network conceptualizations differ.

[2] The broad conceptualization of GPNs has also been a point of criticism as 'the elasticity of this view of networks means that it often includes just about everything and lacks analytical boundaries and clarity' (Sunley, 2008, p. 8).

> the ability to accommodate pressures for more radical and disruptive change and to employ combinations of material, institutional and discursive power to ensure that shifts which do occur in socio-technical configurations do not disrupt prevailing social relations and distributions of political power (p. 28).

What trasformismo captures is that stability can take different forms, including that of accommodation. When transition pressures increase, be it at the regime or the niche level (or in combination), the ability of regime actors to absorb these pressures through coordinating and employing multiple forms of power (material, institutional, discursive) critically influences the prospects of change and the degree of stability in the system (Ford and Newell, 2021).

Material, institutional, and discursive power are related but point to different sources of influence and the multiple aspects of maintaining regime stability. Material power arises from controlling production and finance and from promoting and ensuring economic growth, a core objective of states (Ford and Newell, 2021). Institutional power, in turn, builds on this material power and is employed to influence and shape policymaking, both via formal and informal channels. Discursive power, lastly, is employed by actors to build consent around specific projects through story building and narrative work pushing, e.g., discourses of climate delay or certain policy narratives (Lamb et al., 2020; Palm et al., 2022). Regime actors in dominant positions, who hold power in all three dimensions, can seek to outright resist and inhibit change or, in the face of mounting pressure, pursue trasformismo to shape change processes (Ford and Newell, 2021; Newell, 2019). The prospect of change is then decided by not only whether socio-technical reconfiguration does occur but also what form such alterations take. This is not to say that genuine alternatives to the regime—or in neo-Gramscian terms, the historical bloc—are not possible. In transition studies as well as neo-Gramscian theory, regime actors are contested and their dominance remains contingent (Geels, 2014; Levy and Newell, 2002).

The process of accommodation encompasses strategies to foster consent and acquire the acquiescence of important or powerful actors and actor groups so as to shape socio-technical reconfigurations in desired directions (Ford and Newell, 2021; Levy and Newell, 2002). Accommodation happens both in response to niche and landscape pressures. As for landscape pressures, the overwhelming adaptation of growth-oriented and climate and circular economy discourse focusing on technical fixes in the wake of increased policy pressure illustrates such efforts (Mah, 2023; Markusson et al., 2017). In terms of niche pressures, incumbent actors can buy up, own, and occupy niche spaces, including alternative and potentially threatening technologies. By doing so, incumbents can demonstrate green credentials, build a knowledge base of competing configurations, and align niche industry advocacy organisations with the interests of regime actors (Ford and Newell, 2021; Ford, 2020; Haas, 2019). Ford and Newell (2021) also suggest that incumbents, through institutional power, can seek to influence policies that support niches or make compromises and concessions to avoid total reconfiguration and thereby sustain the regime.

By bringing the insights from this section together, we can address the issues of what forms of power and what types of relations that are relevant to foreground. Regarding the former, the neo-Gramscian perspective stresses material power as a foundation that other forms of power build on, which are employed in a coordinated fashion. In a time of mounting socio-ecological crises, these forms of power that enable not only resistance but accommodation, are critical for regime stability. Regarding the types of networks to home in on, we posit that internationalised networks amongst different lead firms warrant particular attention. Because ownership is hierarchical and represents a strong link between firms—as compared to other forms of inter-firm connections and value chain governance—lead firm ownership networks stand out. Such networks embody direct, dyadic forms of power but also reflect other and more diffuse forms of power that operate through mimetic pressures, as is characteristic of regimes. At the same time, lead firm ownership networks do not represent specific value chains[3] but rather concrete internationalised actor networks diffusing and reproducing global regimes. In that sense, we take inspiration from the more multi-faceted network concept found in GPN. The actors in lead firm networks take part in various GVCs (depending on the scope of their activities) and the inequalities that occur within, along, and through value chains (Lang et al., 2022).

Given the advantageous position of lead firms, making them uniquely capable of absorbing both global niche and broader landscape transition pressures, we argue that extensive lead firm networks help maintain global regime stability. Extensive corporate networks do not necessarily entail a non-changing system but might as easily foster trasformismo. Faced with different types of pressures, lead firm networks allow for alignment between incumbents in seeking to accommodate such pressures through different means without disrupting the underlying rationality. Extensive lead firm networks allow for widespread diffusion and can, following our argument above, increase the ability to absorb change pressures. This argument concerning lead firm networks and the ability of incumbent actors to accommodate and absorb pressures is illustrated in Fig. 1, which depicts an ideal-typical representation of trasformismo in a global regime with integrated lead firm networks facing external pressures.

In proposing that lead firm ownership networks are particularly worthy of note in relation to processes of change, we stress the importance of material, economic, and juridical relations. Ownership ties between lead firms are materially anchored and backed by judicial obligations. These ties are instances of collaboration and/or hierarchy and represent common commitments. An extensive lead firm ownership network ensures that firms have common material interests. Anchoring common interests in joint commitments to specific projects arguably fosters alignment and accommodation in response to pressures from outside the regime that challenge existing socio-technical configurations, i.e., trasformismo. This is not to say that lead firm ownership networks do not arise in already existing internationalised networks. Instead, in line with the sustainability transitions literature, we see lead firm networks as both an outcome and a facilitator of institutionalisation. Yet once in place, these relations underpin and condition the global regime that seeks to uphold a given socio-technical system.

3. Relations in the global petrochemical industry

3.1. An industry under pressure?

The petrochemical industry is characterized by a set of contradictions. Used across industrial processes for a variety of purposes, petrochemicals ensure the ubiquity of fossil fuels in modern society. While their broad use means that the chemicals are, as is often stressed by industry, needed in sustainability transitions for applications such as carbon fibre for wind turbines (Tilsted et al., 2022), the industry is 'locked-in' to fossil-based production (Janipour et al., 2020, 2022; Tilsted et al., 2023; Wu et al., 2015). Moreover, foreseeing that the 'future of oil is in chemicals' (Tullo, 2019), the industry is booming in terms of production capacity, fuelled especially by expansions in China, the Middle East, and the United States (Amghizar et al., 2017; Bauer et al., 2023b; Bauer and Fontenit, 2021). At the same time, actors across petrochemical value chains are facing increasing external pressures. The industry is criticised for its central role in a range of issues, from environmental justice (Davies, 2019; Davies and Mah, 2020; Ho, 2014), toxicity and health (Davies, 2018; Jephcote and Mah, 2019; Tickner et al., 2021), climate change, and environmental governance (King and Lenox, 2000; Mah, 2021b; Palm et al., 2022). Together, these

[3] To understand specific GVCs, in-depth engagements and case studies are required (see for example Mondliwa et al. (2021) for an application of GVC theory to the case of the South African petrochemical value chain).

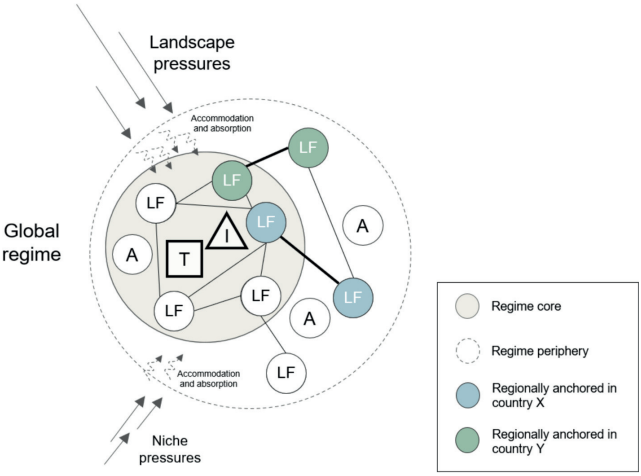

Fig. 1. Ideal typical representation of accommodation of transition pressures in an industry with strong lead firm networks. Own figure inspired by Fuenfschilling and Binz (2018), Miörner and Binz (2021), and Dallas et al. (2019). I – institutions, T – technologies, A – actors, LF – lead firms. Wider edges represent stronger, potentially more asymmetric LF relations.

contradictions portray an industry at a crossroads with mounting transition pressures.

The global chemical regime is, according to Bauer and Fuenfschilling (2019, pp. 175–176), centred around three core characteristics: 1) the historical linkages with energy production and the resulting integration of fuels and chemicals production in large petrochemical clusters as well as a common chemical engineering knowledge base (Rosenberg, 2000); 2) a research and development focus on process improvements due to a molecular similarity in products that rely on economies of scale (Ren, 2009) and are subject to downstream product requirements and cost-orientation; 3) the importance of traditional chemical companies, complemented by specialized engineering firms who develop and license process technologies (Arora and Fosfuri, 2000). Taken together, Bauer and Fuenfschilling (2019) emphasise stability as well as the dominance and permanence of incumbent firms when describing the structure of the industry. Further, they highlight the sector's global nature with global markets for both products and technologies, cumulative innovation patterns, and strong, long-standing MNCs. Over time, the pressure to sustain market development, coupled with a focus on decreasing costs through efficiency gains and scale, has been key to developments in the industry (Aftalion, 2001).

The petrochemical industry is arguably a good example of trasformismo and accommodation of landscape pressures. Over time, environmental discourses have influenced the chemical sector, which has gradually evolved to integrate aspects of 'green chemistry' and 'eco-innovation' (López and Montalvo, 2015). More recently, the marine plastics crisis has faced the industry, threatening its 'social license to operate' (Mah, 2021b, p. 129). Lead firms have responded by embracing the circular economy discourse, which, in a few years during the 2010s, was adopted by all the top firms, forming joint alliances and action groups (Mah, 2022, 2023). The way the circular economy discourse has been adopted by the industry, focusing on large-scale chemical recycling and marine plastic pollution prevention, however, is far from the calls for reducing the use of plastics and capping production made by other actors (Bergmann et al., 2022; Mah, 2021a, 2021b). Drawing on extensive field research and interviews with corporate stakeholders, Mah (2021b) documents how industry-level threats made the industry come together, collaborating to contain pressures and use them to expand new markets.[4] Moreover, climate-related transition narratives are prominent amongst petrochemical majors, positioning the industry as integral to sustainability efforts and a low-carbon future by realigning it with decarbonisation. Building on lobbying efforts and their structural importance, industry actors seek to influence pressures for sector-level reconfigurations (Tilsted et al., 2022).

In line with our argument laid out above, the globalized nature of the petrochemical industry and its engagement in trasformismo-like strategies means that we would expect internationalised lead firm networks. From a coevolutionary perspective, such networks both facilitate and result from alignment, pointing to self-enforcing feedback mechanisms. Strong lead firm networks would thus instill continued collaboration and accommodation going forward. The extent to which these relations are materially anchored in existing fossil-based investments, i.e., through common ownership, bears implications for the prospects of a global-level low-carbon reconfiguration of the petrochemical industry. Petrochemical lead firm networks represent a common commitment to fossil-based infrastructure. With investment horizons of several decades and high upfront investment costs (Wesseling et al., 2017), and with expected profits premised on maintaining and/or upscaling production, lead firms have massive committed emissions given current investment patterns (Bauer et al., 2023a; Bauer and Fontenit, 2021). The alternative, decommissioning or scaling down production, would mean that lead firms' commitments end up as stranded assets. To remain profitable, these corporations will continue to rely on fossil fuels. And where individuals can come and go, infrastructure stays. Thus, the industry is under financial pressure to continuously produce *petro*chemicals on a massive scale in the years to come.

At the same time, the 2020s is a crucial decade for investments in

[4] In 2019, the corporately founded Alliance to End Plastic Waste was established with multiple petrochemical lead firms joining. Setting aside intensive rivalries, working to defend plastic markets and deter responsibility, the alternative to collaboration was 'leaving it to the regulators' (Mah, 2021a, p. 133). This alliance has been reported to be an outcome of coordinated work orchestrated by petrochemical actors (Baker et al., 2022).

fossil-based chemical production infrastructure. According to the International Energy Agency's Net-Zero Emissions by 2050 roadmap, carbon dioxide emissions from the chemicals industry must decrease by 2030 and be halved by 2040 from 2020 levels, while production volumes increase by around 30% (IEA, 2021b). Drastically reducing emissions on a global scale in an industry where 2050 is only one investment cycle away means that this decade constitutes a critical 'window of opportunity' (IEA, 2021c, p. 124). In the IEA net zero scenario, the share of total chemical production carried out via conventional routes is less than 90% by 2030, and all capacity additions feature 'near-zero' technologies (IEA, 2021c, pp. 121–131). But while the IEA scenario emphasises that refurbishments and lifetime extensions of existing industrial assets along conventional routes are not in line with global temperature goals, projections of planned and announced expansions show a 40% production capacity growth in this decade (Global Data, 2021; IEA, 2021c).

3.2. Methods and data

To analyse lead firm networks in the chemical industry, we restrict our analysis to the 52 largest companies globally[5] (see Table 2). These firms vary significantly in global market share, but all play important roles regionally and most can arguably be characterized as lead firms. For example, in their analysis of the petrochemical value chain in South Africa, Mondliwa et al. (2021) characterise Sasol, which is amongst the companies with the lowest chemical sales in our analysis, as a lead firm. Following the above, we see lead firms as connected to the global regime. The list includes major chemical producers, covering MNCs from both the traditional petrochemical strongholds of Western Europe and the United States (e.g., BASF (DE) and Dupont (US)), firms that emerged in the latter half of the 20th century (Mitsubishi Chemical (JP) and Formosa Plastics (TW)), as well as the largest emerging market chemical companies (Sinopec (CH) and Reliance (IN)). Showcasing the relationship between chemicals and fossil fuel extraction, both international oil companies (e.g., ExxonMobil and Chevron Phillips) and national oil companies (e.g., Sinopec and Sasol) are part of the sampled MNCs.

We restrict our analysis to ownership networks, considering instances where business entities are listed as subsidiaries of more than one of the lead firms in the sample. We use the Orbis (Bureau van Dijk) database, which compiles data from a range of sources to present comprehensive information on companies worldwide. This means that the analysis presented below depends on the extensiveness and quality of global company databases (Heemskerk et al., 2018). Extracting the full lists of registered subsidiaries for all 52 firms produced a data set totalling 37,030 observations with 28,455 unique company IDs. This data set includes all subsidiaries of the sampled companies listed in Orbis as active at the time (July 2, 2021), including entities whose ownership shares are unknown and non-majority-owned subsidiaries. Thus, the data reflects the ties formalised in joint ownership of subsidiaries and captured in the database at that moment. The dataset allows for the creation of a network of parent MNCs and their subsidiaries, 1574 of which have interlocking ownership with a varying number of parent companies. Links between MNCs (indicating cross-ownership) were removed to produce a two-mode (or bipartite) network, which was then projected to a one-mode network configuration of only the parent MNCs, in which the edges are constituted and weighted by all instances of joint ownership of a subsidiary.

To visualise the network and calculate descriptive statistics, we use the software Gephi. For the network graph, we include parent companies as nodes, with edges representing instances of joint ownership. We include all subsidiaries with ties to more than a single parent in the dataset. Tie width is scaled by the number of subsidiaries two MNCs have in common. Similarly, nodes are scaled by their eigenvector centrality, capturing the centrality of related nodes. Descriptive network statistics are available in Table 3 and node-specific statistics are available in Appendix A.

3.3. Lead firm ownership networks

3.3.1. An integrated network

The petrochemical lead firm ownership network illustrated in the network graph (Fig. 2) supports the characterisation of the petrochemical industry as globalized (cf. Section 3.1). 284 linkages exist across the network which is 21.4% of the total number of possible ties (see Table 3). Specifically, major petrochemical producers across all continents outside of Oceania with headquarters in 18 different countries are linked through ownership in subsidiaries located in 56 different countries. Outside of three corporations,[6] all of the sampled companies are linked through ownership ties and have one or more subsidiaries in common (as of July 2021). Among the connected companies, no producer has more than three nodes between them and any other companies in the network. The degree count, i.e., the number of actors with which a given company is connected, varies across the network (see Fig. 3). On average, each petrochemical producer has ownership ties to around 11 other producers in the network through common ownership in 76 subsidiaries, illustrating linkages across the largest firms in the industry on a global scale.

Considering the most integrated firms, 27 of the sampled companies have ownership ties to 10 or more of their counterparts. Of these, Saudi Arabian SABIC has the highest degree count of 28. SABIC also has, by a substantial margin, the highest betweenness centrality in the network, meaning that it occupies the most important position in terms of relating other firms to each other through the shortest possible paths (Robins, 2015). For closeness and eigenvector centrality, capturing respectively the average distance to other notes and the centrality of related actors, a range of firms ranks as the most central. This is evident in the network graph, where nodes are scaled by eigenvector centrality, showing a range of centrally placed firms, including large Japanese producers as well as the biggest North American players in the form of ExxonMobil, Dow, and LyondelBassell. Eigenvector centrality is relevant for regime diffusion because it captures to what extent nodes are connected to other central lead firms. Being linked to central actors in the network is likely to mean exposure to dominant rationalities and offers the potential to diffuse rationalities and ways of thinking well beyond immediate and dyadic relations.

In Fig. 2 the varying tie width between nodes, i.e., the number of shared subsidiaries, stands out. While some firms are tied to each other through joint ownership of a single subsidiary, others hold hundreds of subsidiaries in common, as is shown in the edge weight distribution in Fig. 3. An example is the link between ChemChina and Syngenta, reflecting that the Chinese firm acquired the Swiss agrichemical company Syngenta in 2017. Generally, more ties arguably indicate increased collaboration and/or control, as with the hierarchical relationship between ChemChina and Syngenta, although other important factors are also at play. A tie need not entail an equal ownership share, and such variances might reflect power asymmetries or the differing strategic importance of an entity between its owners. Moreover, if two lead firms share ownership in a major plant, that might not result in a high number of shared subsidiaries, despite being of high importance to the respective

[5] We use the Chemical and Engineering News' (C&EN) 2020 Global Top 50 ranked according to chemical sales in 2019 and include the two major Chinese chemical producers ChemChina and SinoChem, which do not disclose chemical sales and are not included in the C&EN Top 50.

[6] These are ChevronPhillips (US), Ecolab (US), and Hanwha (KR) which were ranked respectively 34, 39 and 41 in the C&EN global top 50 for 2020. ChevronPhillips is a joint venture owned by US oil companies Chevron and Phillips 66 and has multiple relevant joint ventures not identified here. For example, the company has recently begun construction of what is set to become the largest ethane cracker in the Middle East together with QatarEnergy (Brelsford, 2024).

Table 2
Sampled companies ranked according to chemical sales.

Company	C&EN description	Headquarters	Ownership	Chemical sales as % of total sales	Chemical sales 2019 (M USD)
BASF	Diversified	Germany	Public	100.0	66,401
Sinopec	Petrochemicals	China	State-owned (China)	14.7	61,596
Dow	Diversified	US	Public	100.0	42,951
SABIC	Petrochemicals	Saudi Arabia	State-owned (Saudi Arabia)	92.4	34,420
INEOS	Diversified	UK	Private	100.0	32,009
Formosa Plastics	Petrochemicals	Taiwan	Public	66.7	31,425
ExxonMobil	Petrochemicals	US	Public	10.7	27,416
Mitsubishi Chemical	Diversified	Japan	Public	83.3	27,353
LyondellBasell	Petrochemicals	US	Public	78.1	27,128
Linde	Industrial gases	UK	Public	90.1	25,429
LG Chem	Diversified	South Korea	Public	100.0	24,554
Air Liquide	Industrial gases	France	Public	98.5	24,171
PetroChina	Petrochemicals	China	State-owned (China)	6.2	22,733
DuPont	Speciality chemicals	US	Public	100.0	21,512
Reliance Industries	Petrochemicals	India	Public	22.0	20,640
Toray Industries	Diversified	Japan	Public	85.4	17,344
Sumitomo Chemical	Diversified	Japan	Public	76.3	15,231
Evonik Industries	Speciality chemicals	Germany	Public	100.0	14,674
Shin Etsu Chemical	Diversified	Japan	Public	100.0	14,158
Covestro	Diversified	Germany	Public	100.0	13,895
Braskem	Petrochemicals	Brazil	Hybrid	100.0	13,267
Lotte Chemical	Diversified	South Korea	Public	100.0	12,973
Yara	Fertilizer	Norway	Hybrid (a)	100.0	12,858
Solvay	Speciality chemicals	Belgium	Public	100.0	12,568
Mitsui Chemicals	Diversified	Japan	Public	100.0	12,282
Hengli Petrochemical	Petrochemicals	China	Private majority	81.2	11,839
Bayer	Agricultural chemicals	Germany	Public	23.6	11,482
Indorama Ventures	Petrochemicals	Thailand	Private	100.0	11,362
Syngenta	Agricultural chemicals	Switzerland	State-owned (China) (b)	78.0	10,588
DSM	Speciality chemicals	Netherlands	Public	100.0	10,086
Asahi Kasei	Speciality chemicals	Japan	Public	50.8	10,027
Wanhua Chemical	Diversified	China	Public	100.0	9851
Arkema	Speciality chemicals	France	Public	100.0	9782
Chevron Phillips Chemical	Petrochemicals	US	Public	100.0	9333
Eastman Chemical	Speciality chemicals	US	Public	100.0	9273
Borealis	Petrochemicals	Austria	Hybrid (Austria & UAE)	100.0	9071
Air Products & Chemicals	Industrial gases	US	Public	100.0	8919
Mosaic	Fertilizers	US	Public	100.0	8906
Ecolab	Diversified	US	Public	59.2	8904
Johnson Matthey	Speciality chemicals	UK	Public	47.4	8819
Hanwha Solutions	Speciality chemicals	South Korea	Public	79.0	8569
Umicore	Speciality chemicals	Belgium	Public	41.9	8196
SK Innovation	Diversified	South Korea	Public	19.1	8186
Westlake Chemical	Petrochemicals	US	Private	100.0	8118
Sasol	Diversified	South Africa	Public	56.7	7995
Nutrien	Fertilizer	Canada	Public	38.6	7729
PTT Global Chemical	Diversified	Thailand	Hybrid (Thailand)	57.6	7660
Lanxess	Speciality chemicals	Germany	Public	100.0	7614
Tosoh	Diversified	Japan	Public	100.0	7211
DIC	Diversified	Japan	Public	100.0	7050
ChemChina	Diversified	China	State-owned (China)	–	–
SinoChem	Diversified	China	State-owned (China)	–	–

Source: Chemical sales data from the Chemical & Engineering News global top 50 for 2020. See Tullo (2020) for details. *Notes:* Hybrid ownership refers to arrangements with non-majority but significant state ownership. *a*) The largest shareholder of Yara is the Norwegian government (36.2%) *b)* Ownership through ChemChina which acquired Syngenta Group in 2020.

Table 3
Descriptive network statistics.

Network	# Nodes	#Edges	Density	Average degree	Weighted average degree	Diameter
One-mode	52	284	0.214	10.9	76.2	4

Note: Density – share of all possible ties that exist in the network, average degree – average number of ties per node, weighted average degree – average number of common subsidiaries per node, diameter – maximum distance between any two nodes in the connected network.

firms. These two aspects are not well captured in the graph (financial data is not available for many of the subsidiaries through ORBIS), but they are relevant to contextualise specific relations within the network.

3.3.2. Network clusters

To capture poly-centricity and identify strongly interconnected clusters in the network, we use an algorithm for community detection, represented by different node colours in Fig. 2 (Blondel et al., 2008). We identify five clusters in the network, which differ in terms of how strongly they are linked to the rest of the network. A noteworthy cluster is the pink cluster in the upper middle part of Fig. 2, showing strong ownership ties between all Japanese firms in the sample, as well as some other firms mainly from the Republic of Korea. The strong ownership linkages amongst Japanese firms can be attributed to the form and extensiveness of corporate networks in Japan and the institutional logic

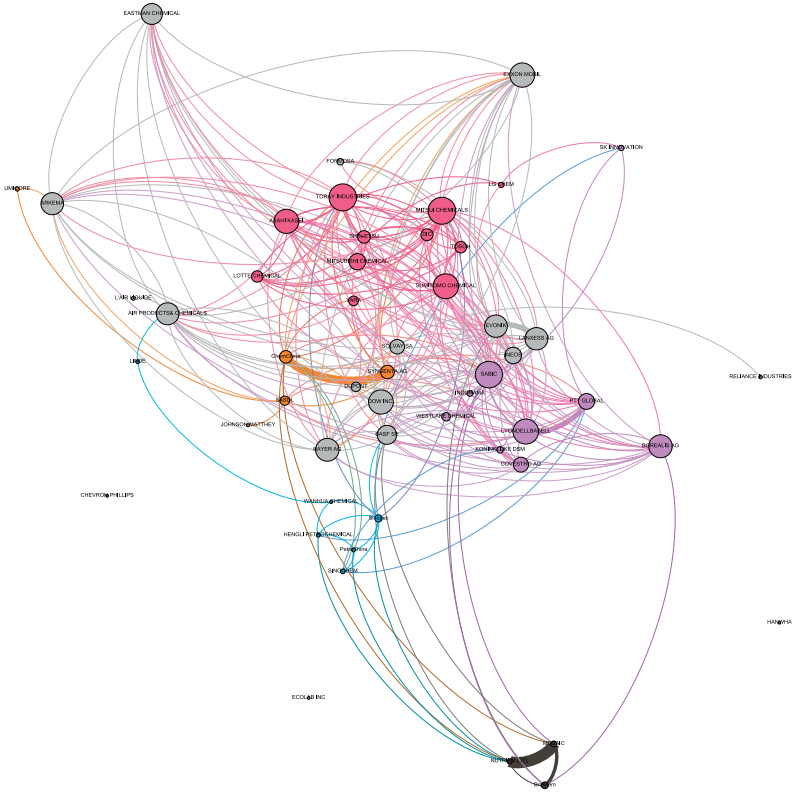

Fig. 2. One-mode ownership network graph. *Note*: Nodes (MNCs) are scaled by eigenvector centrality, while edges (instances of common ownership) are scaled by the number of subsidies in which two MNCs share ownership. Colours represent internally strongly connected communities.

governing them (Bhappu, 2000; Morck and Nakamura, 2005). Close collaboration amongst Japanese chemical companies also has historical precedence, most noticeable in the form of a cartel of Japanese chemical firms orchestrated by the Japanese government in the 1970s (Aftalion, 2001). Despite such regionality, the cluster also includes four of the most centrally positioned lead firms in the network, measured by degree count as well as closeness and eigenvector centrality, and is therefore far from isolated from the rest of the network. This integration across scales aligns with the pressure to pursue new markets emphasised by the GPN literature. A recent McKinsey report on the Japanese chemical industry stresses a need for further mergers, acquisitions, and adaptations to global markets to ensure growth (Kakimoto et al., 2023).

While the Chinese producers are hugely important in terms of production capacity (Bauer et al., 2023b), the Chinese cluster in blue appears rather peripheral in the ownership network. The companies in this cluster do not have extensive ties to other actors in the network, despite their substantial and increasing share of global production capacity and status as some of the largest producers worldwide (cf. Bauer et al., 2022). Although several links to other MNCs exist (for example, BASF (DE), PTT Global (THA) and the Japanese cluster), the Chinese firms do not appear amongst the 20 most central actors in the network. In terms of corporate board and spatial interlocks, Verbeek and Mah (2020) find a similar picture using data from 2018 when assessing relations between 14 lead firms in the petrochemical industry, although Sinopec is the only Chinese firm included in their analysis. Despite this relative isolation in terms of shared subsidiaries, they also find that publicly announced joint ventures between Sinopec and other lead firms are common. All of these joint ventures, though, are located in China (Verbeek and Mah, 2020), reflecting the Chinese industrial policy strategy, which for many years required foreign firms to collaborate with national firms to enter the market[7] (Howell, 2018). It was through joint ventures with oil and gas majors that petrochemical production capacity skyrocketed in the new millennium because this approach was politically acceptable, enabling expansion while limiting dependence on foreign actors (Tobin, 2019).

While our findings illustrate spatial variation in global regimes in terms of the Chinese focus on self-sufficiency and nationally consolidated corporate networks (Tobin, 2019), this relative isolation does not mean that the ties that do exist cannot strengthen the prospects of trasformismo. Considering betweenness centrality, Sinopec and

[7] This also reflects that our data and approach do not capture all joint ventures located in China.

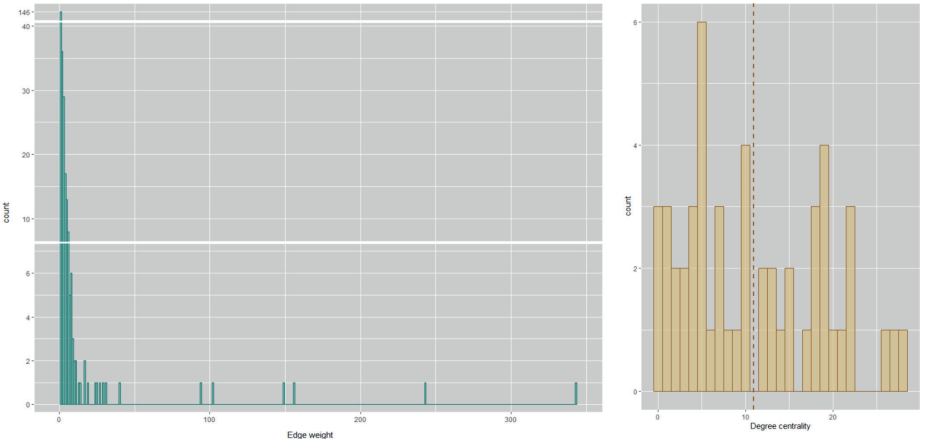

Fig. 3. Network statistics of edge weights and degree centrality in one mode parent x parent network. *Left panel:* Edge weight distribution. Breaks in the vertical axis were added using ggbreak (Xu et al., 2021). *Right panel:* Degree centrality distribution. The dashed line represents the average degree centrality of 10.9.

ChemChina are amongst the ten most central actors, playing a relatively important role in connecting other nodes in the network. Such relations can push actors faced with transition pressures to maintain commitments to fossil feedstock. For example, in the wake of the Russian invasion of Ukraine and increasing gas prices, BASF, the world's biggest chemical company, publicly threatened to "permanently" cut European production while investing in China, building on, and strengthening its existing ties to Chinese producers (Burger, 2022). As such, instead of decreasing fossil-based production in the face of increasing costs, BASF seeks ways in which it can expand its commitments through its existing production network.

4. Reproduction or reconfiguration?

The ownership network mapped above consists mostly of dyadic relations where two lead firms in the network have ownership shares in the same entity (this is the case for 1479 out of 1579 ties). These represent common commitments that we argue underpin investments in fossil-based infrastructure and support trasformismo (see Section 2.2). In this section, we discuss our findings in relation to this argument and consider mechanisms of alignment and accommodation with implications for the prospects for and forms of low-carbon reconfiguration in the petrochemical industry.

4.1. Mechanisms of alignment

The ownership network shows that shared commitments exist between actors working across the fossil fuel value chain. For example, LyondellBasell, the major US-headquartered integrated plastics, chemicals, and refining company, has ties to PTT Global (THA) and SABIC (SAU), both owned by national oil companies, while collaborating with Covestro (DE), a major polymer firm. Similarly, the vertically integrated oil major ExxonMobil (US) notorious for its climate delay and denial efforts (Supran et al., 2023; Supran and Oreskes, 2020, 2021), has ownership interlocks with more downstream, materials-focused firms such as Arkema (FR), Asahi Kasei (JP), and Toray Industries (JP). Ownership interlocks across firms working in related but, in terms of climate mitigation, often thought of as distinct industries, locks in a commitment to a fossil-based global regime across actors in the value chain from extraction to polymer production, signalling to other industry actors that they commercially and financially devoted, regardless of transition pressures. The network, in that sense, is not only conditioning trasformismo but also an outcome of the existing global regime. The network showcases existing common commitments to fossil-based production, i.e. examples of sites and entities in which actors hold a shared interest in maintaining production at the most profitable capacity until the end of the assets' lifespan. Extensive ownership ties thereby form the basis for promoting fossil-oriented socio-technical reconfigurations and remaining in control of niche, renewable-based technologies, in contrast to alternative pathways focusing on demand change.

In addition to dyadic relationships, the ownership network also illustrates more collective relations and alternative sites of regime diffusion. In the sample, 18 subsidiaries have four or more owners. These include firms managing shared infrastructure, such as gas pipelines, as well as shared think tanks and interest organisations. The most well-connected common-owned entities are policy-oriented and count, e.g., the Singapore Chemical Council (15 ties) and the German BKV ('think tank of the plastics industry') (BKV, 2024a) (7 ties). As for the former, Singapore is a long-standing petrochemical hub for refining, transport, and logistics (Breul and Revilla Diez, 2018; Yun and Jin, 2009) and one of the locations where many lead firms are present (Verbeek and Mah, 2020). The Singapore Chemical Council is the 'official industry association' and represents the integrated fossil-based energy and chemicals cluster with more than 170 companies (SCIC, 2024). With member companies of different sizes involved in activities along the value chain, from refining to so-called specialty chemicals, the council constitutes a site for local diffusion of the global petrochemical regime. BKV is also supported by lead firms in the network as well as other important industry actors.[8] Think tanks are important political actors whose 'coordinative discourses' influence political processes in and around crises (Hernando et al., 2018; Zimmerman and Stone, 2018). The think tank is thus an example of regime actors joining forces to disseminate policy-relevant knowledge and, by extension, regime alignment.

[8] Including SABIC, INEOS, BASF, Dow, Covestro, LyondellBasell and Evonik in addition to other important industry actors such as PlasticsEurope (BKV, 2024b).

4.2. Mechanisms of accommodation

In terms of the global regime accommodating transition pressures, the outstanding centrality of SABIC (SAU) in the network is remarkable. With the firm's central location in the global regime and economic direct connections to a host of other actors in the regime, SABIC is in a position to seek alignment around socio-technical reconfiguration and pursue trasformismo. SABIC was acquired in 2020 by the national oil company Saudi Aramco, the largest oil producer in the world (SABIC, 2020), and is ultimately owned by the Saudi state. As part of a broader diversification strategy, the consolidation of Saudi Aramco and SABIC encapsulates the belief that petrochemicals will be the future of oil (Tullo, 2019). With new refineries that directly convert crude oil to petrochemicals (Reuters, 2022), the 'preferred technology' for reorienting production from fuels to chemicals (Wu, 2023), the company represents the epitome of an oil-oriented reconfiguration of the industry. In a recent joint venture with Aramco that also includes Chevron as a technology provider, SABIC announced that it was commercializing its crude-to-chemicals technology, seeking to scale up these processes and aiming to convert up to 80% of crude oil into chemicals (Aramco, 2024). In another project, Aramco, together with Dow, is running the largest integrated crude, petrochemical, and plastics complex ever built in a single phase, Sadara, on the basis of massive support from public financial institutions in both Europe and the United States (Skovgaard et al., 2023). The centrality of SABIC therefore signals the continued stability of the global regime in the form of common commitments to expanding fossil-based chemical production.

The centrality of SABIC is also noteworthy in relation to accommodation strategies and the absorption of both landscape and niche pressures. In a coordinated effort with Aramco and Saudi-based actors, SABIC promotes a vision of a future built around 'circular carbon' (Palm et al., 2024). The notion of circular carbon is an effort to reframe commitments to fossil-friendly reconfigurations focusing on carbon capture for utilization and blue hydrogen, allowing for continued oil extraction and petrochemical growth (Shehri et al., 2022). Moreover, the vision of circular carbon is, albeit in different variations, also pushed by European and North American-based actors such as industry organisations and large producers to promote visions of the future that align with growth-oriented strategies (Buck, 2022; Palm et al., 2024). In terms of competing technologies, SABIC has entered partnerships with other lead firms pursuing the development of niche technologies, including electrified steam crackers (BASF et al., 2021). These niche technologies, however, still revolve around the processing of oil and gas and do not fundamentally challenge the dependence on fossil feedstocks. The fact that SABIC, with its state-backed long-term commitment to a fossil-based chemical future, has pursued accommodation of both landscape and niche pressures in tandem with other actors in the network while occupying the most central position, illustrates relations that underpin processes of trasformismo.

In opposition to our claim of stability by accommodation and absorption facilitated in and through networks, a well-connected network could arguably also be a vantage point for accelerating sustainability transitions through network diffusion. SABIC, for example, is after all engaging in the development of low-carbon niche technologies with partners in the network. Our point is not that the ownership networks make anything but outright resistance unlikely. Rather, we emphasise here the notion of stability through change. Aligning material interests across otherwise competing actors, ownership relations are part of the structure that can strengthen prospects of trasformismo in the face of disruptive change. For example, regardless of origin petrochemical majors use similar arguments and narratives to position themselves as transition enablers (Tilsted et al., 2022). With calls to cap global production and increased attention to the supply side of the plastics crisis (Bergmann et al., 2022), the risks of capital stranding in time of massive expansion—as well as decreased prospects of proliferation through new 'green' markets—constitute real threats to the petrochemical industry (Mah, 2021b). With varying strength across regions and sites, social movements and forces of 'biojustice environmentalism from below' (Dauvergne and Clapp, 2023), engage in the struggle to shut down petrochemical expansions (Mah, 2023). In this environment, lead firm networks engaging in niche activity work to fend off disruption and strong ownership networks ensure that actors remain materially and juridically committed to fossil-aligned production and solutions.

Regarding capacity additions, Chinese developments are key. A continuation of coal-to-chemicals-based expansions will lead to massive increases in emissions (Cabernard et al., 2021; Li and Hu, 2017; Zhang et al., 2019). In terms of our results, the relative isolation of Chinese producers and the national orientation towards self-sufficiency could indicate less inter-firm pressure to commit to existing assets. Still, all major Chinese producers are state-owned (and in the case of Sinopec and PetroChina, not mainly petrochemical producers), and national priorities are arguably more decisive for petrochemical infrastructure development. At the same time, Chinese large-scale protests against toxic expansions that flourished for years since 2007 have subsided under strengthened societal control (Lee and Ho, 2014; Mah, 2023). Given national dependence on petrochemical production, underpinning domestic economic growth, the prospects for the Chinese cluster to facilitate a sharp break with trasformismo-style tactics appear limited. The possibilities for Chinese re-orientation towards low-carbon chemical production require engagement questions of state control, ownership, and national fossil fuel interests (Babić and Dixon, 2022; Nahm and Urpelainen, 2021).

5. Concluding discussion and outlook

In this paper, we have argued that integrated, materially anchored global networks in petrochemicals work to accommodate and adopt pressures, thereby underpinning efforts of trasformismo. Starting from the simple observation that ownership signals control and commitment related to direct, dyadic forms of power, the present paper has shown one way of analysing the key role that internationalised networks have for global regimes. Our findings show a truly global yet non-homogenous polycentric network. The lead firm ownership network not only displays economic integration between different corporations; it is also an abstraction that relates to the global petrochemical infrastructure. Many of the subsidiaries in the sample are corporations that are engaged in various manufacturing and distributive activities key to the metabolic organism through which fossil fuels come to play a role in countless aspects of modern life.

Because decisions in the ongoing decade are crucial for the prospects of reaching global temperature goals, the extent to which the global petrochemical regime is currently aligned around pursuing a future for oil in chemicals and fending off disruptive pressures is critical. In our view, the ownership network mapped in this paper constitutes a clear obstacle to low-carbon reorientation. Control and ownership of fossil capital suggest the opportunity for the phase-down and eventually phase-out of assets that are not aligned with ecological limits but also imply a dependency on rents from those very assets. With ownership ties that integrate lead firms along the petrochemical value chain and connect to a fossil fuel-chemicals-plastics nexus, common commitments to existing assets and the centrality of fossil fuel companies, a structure that underpins trasformismo towards fossil-based reconfiguration is in place.

Governing the parallel transitions that are needed across sectors involves economy-wide structural transformation with implications that extend far beyond a given focal sector (Andersen and Gulbrandsen, 2020). Because petrochemicals occupy a central position in the fossil energy order and due to the integrated nature of synthetic materials, chemicals, and fossil fuels, there is a stark need for further assessing cross-industry collaboration and the links, integration, and spill-overs along the petrochemical value chain. Many forms of connections between these lead firms exist and the analysis of these parallel connections—which would form a multi-plex network of the same group of

actors—could unpack different forms and mechanisms for isomorphism and alignment with regime rationalities. Relevant network layers could be technology licensing, corporate board interlocks (Buch-Hansen and Larsen, 2021; Verbeek and Mah, 2020), and shared infrastructure (such as pipelines), which directly relate to material system development and decision-making in the network. Looking beyond petrochemical majors, future research could gain from mapping the networks of experts and professionals (Christensen, 2020; Christensen et al., 2020; McCann and Ward, 2010) that (re)produce the global petrochemical regime, including the think tanks and interests organisations also emphasised in this paper. And research related to global financial networks (Coe et al., 2014), and global wealth chains (Seabrooke and Wigan, 2014, 2017), including how they are entangled with global networks of chemical production (Bair et al., 2023), could allow for a better understanding of the financialised nature of fossil-based petrochemicals expansion. Finally, engagement with pressures and counter-pressures and how they vary across regions is crucial to understanding where and how de-escalation to fossil lock-in can arise.

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CRediT authorship contribution statement

Joachim Peter Tilsted: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Fredric Bauer:** Funding acquisition, Investigation, Methodology, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A. Descriptive statistics lead firm network (listed by degree count)

Company	*Degree*	*Weighted degree*	*Betweenness*	*Closeness*	*Harmonic closeness*	*Eigenvector centrality*
SABIC	28	128	144.77	0.68	0.78	0.98
Mitsui Chemicals	27	236	93.11	0.69	0.78	1.00
Toray Industries	26	133	71.06	0.68	0.77	1.00
Sumitomo Chemical	22	69	27.11	0.62	0.72	0.92
Asahi Kasei	22	128	39.85	0.61	0.71	0.89
LyondellBasell	22	243	33.51	0.62	0.72	0.92
Exxon Mobil	21	28	27.57	0.62	0.71	0.89
Dow Inc.	20	67	16.50	0.61	0.70	0.89
Borealis Ag	19	29	17.12	0.58	0.68	0.84
Evonik	19	196	41.69	0.59	0.68	0.81
BASF SE	19	66	59.36	0.59	0.68	0.67
Air Products & Chemicals	19	28	98.53	0.59	0.68	0.80
Bayer Ag	18	34	8.80	0.59	0.67	0.83
Lanxess Ag	18	189	15.69	0.57	0.67	0.81
Arkema	18	21	43.17	0.57	0.67	0.80
PTT Global	17	184	85.17	0.58	0.66	0.54
Mitsubishi Chemical	15	65	18.78	0.55	0.63	0.56
Eastman Chemical	15	15	1.07	0.55	0.63	0.75
INEOS	14	50	16.28	0.55	0.63	0.57
Solvay Sa	13	37	53.12	0.53	0.61	0.49
ChemChina	13	268	52.23	0.54	0.61	0.41
Syngenta Ag	12	276	17.12	0.55	0.61	0.45
Covestro Ag	12	29	11.55	0.52	0.60	0.50
Shin-Etsu	10	100	1.40	0.51	0.58	0.41
Tosoh	10	57	4.83	0.49	0.56	0.36
Dic	10	129	1.86	0.49	0.57	0.38
Lotte Chemical	10	35	5.33	0.48	0.56	0.36
Sinopec	9	22	57.99	0.51	0.57	0.18
Sasol	8	16	59.53	0.49	0.55	0.27
Nutrien Ltd.	7	351	12.55	0.42	0.49	0.10
Yara	7	24	1.81	0.49	0.54	0.29
Dupont	7	33	3.69	0.47	0.53	0.28
Westlake Chemical	6	38	2.55	0.46	0.51	0.24
Mosaic	5	440	2.18	0.47	0.51	0.14
Braskem	5	99	4.52	0.45	0.50	0.17
Hengli Petrochemical	5	13	13.21	0.41	0.47	0.05
Petrochina	5	12	2.68	0.39	0.45	0.05
Sinochem	5	7	9.31	0.44	0.49	0.08
Koninklijke Dsm	5	19	7.31	0.47	0.51	0.15
Formosa	4	5	1.37	0.44	0.48	0.16

(*continued on next page*)

(*continued*)

Company	*Degree*	*Weighted degree*	*Betweenness*	*Closeness*	*Harmonic closeness*	*Eigenvector centrality*
LG Chem	4	8	1.86	0.42	0.47	0.11
SK Innovation	4	4	7.28	0.47	0.51	0.11
Wanhua Chemical	3	11	5.95	0.36	0.40	0.02
Indorama	3	9	0.44	0.44	0.48	0.12
Umicore	2	2	0.00	0.38	0.42	0.06
Linde	2	2	7.19	0.40	0.43	0.05
L'air Liquide	1	2	0.00	0.37	0.40	0.05
Johnson Matthey	1	2	0.00	0.33	0.36	0.02
Reliance Industries	1	1	0.00	0.35	0.38	0.03
Hanwha	0	0	0.00	0.00	0.00	0.00
Chevron Phillips	0	0	0.00	0.00	0.00	0.00
Ecolab Inc	0	0	0.00	0.00	0.00	0.00

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Paper III

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Original research article

Petrochemical transition narratives: Selling fossil fuel solutions in a decarbonizing world

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ABSTRACT

Being integral to the fossil-based energy order and as a key driver of multiple and intersecting ecological crises, the petrochemical industry faces increasing pressures to transform. This paper examines how major petrochemical companies navigate these pressures. Drawing from literatures on discursive power, narratives, and neoGramscian political economy, we introduce the concept of narrative realignment as a nuanced iteration of corporate discursive power that reframes problems of and solutions to green transitions. Specifically, we identify and explore common transition-related narratives, analysing climate and sustainability communications from the largest producers in the petrochemical sector. We argue that these strategic narratives portray the petrochemical industry as key to a successful transition and fend off criticisms by reducing them to misunderstandings. This framing works to reduce pressures for deep mitigation while repositioning the industry as part of the solution. Building on these findings, we demonstrate how petrochemical transition narratives relate to but also diverge from the position of fossil fuel extractors. Despite relying on fossil feedstock and being solidly placed in the fossil economy, petrochemical majors increasingly focus on repositioning themselves proactively as transition enablers. The argument illustrates the work of downstream actors to legitimize the existing energy order.

1. Introduction

In view of climate emergency and global efforts to accelerate a transition to cleaner energy, fossil fuel-dependent industries face increasing pressure to transform. Energy and emission intensive sectors, which have historically been protected from climate policy, need to decarbonize [1]. In this context, incumbent firms seek to shape opportunity structures through active participation in public discourse [2–4]. This includes strategies of accommodation and resistance aimed at absorbing pressures and preventing disruption of institutionalized socio-technical configurations that benefit existing business models and vested interests. For example, it is by now well established that the oil and gas majors have spread misinformation and systematically used public relation activities to delay a transition away from fossil fuels [5–9]. Moreover, recent analyses document that, despite lofty pledges, fossil-based energy companies are not pursuing transformative change. Rather, their strategies remain limited to hedging against or resisting a green energy transition [10,11]. Yet while much of the academic literature on fossil fuel incumbents focuses on their shared corporate interests and strategies, relatively little attention has been paid to distinctions between different industry sectors. The critical political economy scholarship, exploring the role of corporate actors in the orchestration and (re)structuring of the global energy order (e.g., [12–15]), has mainly focused on fossil fuel incumbents. Given the structural importance of the energy intensive processing industries in the fossil energy order, however, the political economy of decarbonization in these sectors is an important area for research. This paper examines how petrochemical incumbents navigate and shape the transition through proactive forms of discursive power, which threaten to undermine global climate action in subtle yet significant ways.

The petrochemical industry is the largest industrial energy consumer [16,17] but has long been "a key blindspot" [16] in climate and energy

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policy debates. Relying on fossil fuels as sources of both feedstock and energy, the petrochemical industry produces a wide variety of products that permeate modern society [18]. Global production of chemicals and the associated use of fossil energy[1] have grown rapidly over the past century [16,19] despite environmental concerns. The decade 2010–2019 alone saw global chemical sales increase by approximately 7.5 % per year [20]. A key driver is the seemingly never-ending use of plastics, which alongside fertilizers constitute the most important product categories [18]. Plastics are used for a wide-range of purposes – as packaging for all types of goods, fibres for textiles, as structural components in cars and vehicles, and for pipes and cables in buildings and infrastructure [21]. Not surprisingly, GHG emissions from plastic production have sky-rocketed, not least because expansion has primarily occurred in coal-dependent regions such as China [22,23].

Since its emergence in the early-to-mid twentieth century, the petrochemical industry has been closely connected to the fossil fuel energy regime.[2] Initially primarily reliant on coal, petrochemical production shifted towards petroleum in the post-war era while recent decades have seen another shift towards natural gas and natural gas liquids [26]. The dependence on fossil fuels for chemical production is not set to change any time soon. Banking on predictions that the "future of oil is in chemicals" [27], leading firms in the industry have invested massively in new fossil-based production in recent years [28]. Projections indicate that global production capacity is expected to increase by 40 % from 2020 to 2030, primarily in the Middle East, United States and Asia [29]. Once operational, these facilities can continue operations for decades – well beyond 2050 – with limited opportunities for retrofits and modifications. Accordingly, chemicals have been identified as the single most important segment for new oil demand this decade [16,30,31], demonstrating the undeniable importance of petrochemicals in climate change and energy debates.

At the same time that the sector is continuously expanding production, it is increasingly being called into question. Due to its role in the climate, toxic pollution, and plastic crises, policymakers, civil society, and academics have made calls for more stringent regulation and caps to production [32–34]. Accordingly, the petrochemical industry is subject to multiple environmental pressures and conflicts [35,36]. Corporate actors' historical response to ecological concerns has been to accommodate emerging pressures without disrupting the industry [37]. Innovation efforts have concentrated on efficiency improvements and process intensification [38], and economic motivations have dominated conflicting commitments towards lower-carbon, technology-led reorientation [39]. Moreover, many major industry players (especially the vertically integrated oil, gas, and chemical corporations) have adopted deceptive tactics of climate-change denial, while maintaining a corporate sustainability discourse that plastics and petrochemicals play an important role in green technological solutions [40,41]. In relation to toxicity and plastics, the industry has a track record of "deceit and denial" [42] of toxic risks, deflecting and co-opting criticisms and objections [35,37,41].

Recent theoretical contributions to the political economy of transitions demonstrate the relevance of neo-Gramscian perspectives and the concept of "trasformismo" in theorizing how corporate incumbents (re) produce favourable social and economic structures [43–45]. Building on this theorization in relation to the rather contradictory situation of petrochemical incumbents, we introduce the concept of narrative realignment. Narrative realignment describes the strategic use of specific storylines that work to affiliate current activities and plans with calls for change through reframing problems and solutions. In this way, we focus on the employment of discursive power to not only accommodate transition pressures and resist change, but also to position industry proactively as a vital "provider" of solutions [46]. We do so mainly by analysing dominant strategic transition-related narratives employed by petrochemical incumbents, examining the puzzle of how the petrochemical sector seeks to retain its status through an energy transition despite being a fossil-based industry. These narratives are important because they reveal forms of discursive power that have material consequences in shaping industrial decarbonization pathways. By examining sustainability reports from the ten largest transnational firms in the sector triangulated with other data, we identify three strategic narratives namely *realizers of sustainability*, *breakthrough technology pioneers* and *already well underway* and explore their implications.

Engaging with a neo-Gramscian perspective, we argue that incumbent firms in the petrochemical industry advance the three identified narratives to accommodate disruptive pressures and position themselves as transition enablers that are key to successfully achieving decarbonization and circularity. By forwarding the notion that petrochemical production – competently guided by industry – (will) help achieve sustainability both now and in the future alongside the idea that modern life is owed to the wonders of chemicals, industry actors frame themselves as the essential foundation for any desirable future. In the words of the American Fuel and Petrochemical Manufacturers, petrochemicals are "the building blocks that make modern life possible" [47]. By taking this approach, petrochemical incumbents differ from their upstream fossil fuel counterparts, as fossil fuel extraction is surrendered to eventually decrease on a global scale through an energy transition. In making this argument, the paper contributes to an emerging literature on the political economy of petrochemicals and decarbonization in the energy-intensive industries [26,28,35,36]. The paper also contributes to the use of narrative analysis and the role of discursive strategies in shaping decarbonization in the petrochemical industry. More broadly, the notion of narrative realignment helps shed light on subtle, diverse, and evolving corporate tactics of trasformismo by describing how pressures for change are reframed as to align with existing developments.

The paper proceeds as follows. First, we elaborate on the concept of trasformismo, expanding on the role and use of discourses and narratives and introducing the concept of narrative realignment. We then describe the methods, materials, and analytical approach. Third, we analyse key recurring storylines that petrochemical majors invoke, mapping strategic narratives around transition pressures and the discursive strategy they constitute. We end with a discussion relating to non-discursive aspects of trasformismo and the position of fossil fuel majors.

2. Shaping transition pathways

2.1. Trasformismo and stability through change

To analyse the political economy of transitions, recent contributions have highlighted the relevance of neo-Gramscian analysis and, in particular, the notion of "trasformismo" [43–45]. Defining it as a capacity, Newell [44] refers to trasformismo as

> the ability to accommodate pressures for more radical and disruptive change and to employ combinations of material, institutional and discursive power to ensure that shifts which do occur in socio-technical configurations do not disrupt prevailing social relations and distributions of political power.

This definition highlights the tension between different orders of change, i.e., incremental vis-à-vis transformative change, as associated with disparate ecopolitical projects [48]. In a more recent definition, Ford and Newell [43] define trasformismo as a process "by which

[1] According to the International Energy Agency, chemicals derived from oil and gas account for around 90 % of feedstock demand in chemical production today [16].

[2] This "special relationship" [24] is not only material (through the integrated nature of petroleum refining and petrochemicals production) but also organizational (through vertically integrated companies) and institutional (through the shared knowledge base of chemical engineering that underlies oil refining, gas processing, and petrochemical production) [19,25].

potentially counter-hegemonic ideas and activities are neutralised by being brought within hegemonic frameworks." Trasformismo is thus not about impeding change as such but rather that change, through a process of co-optation, takes forms that align with the interests of dominant incumbents [44,49]. It thus differs from resistance by focusing on adaptation and absorption rather than on inhibition [43,50]. This is not to say that incumbents do not seek to inhibit change but rather to point out that strategies for maintaining incumbency differ. When dominant actors are under pressure, trasformismo is arguably particularly relevant [50].

Trasformismo is akin to another Gramscian concept, namely the notion of passive revolution. The difference is that, while trasformismo is about aligning counter-hegemonic ideas and activities with the hegemonic framework (thereby neutralising them), passive revolution refers to adopting reformist change to withstand opposing pressures [51]. Passive revolution thus entails incremental change but not necessarily co-optation and is in this sense a broader concept. Accordingly, trasformismo has been understood as a strategy of passive revolution [43,49]. In this paper, we follow this line of thinking and understand trasformismo to involve accommodating ideas of change through adopting for instance new discursive strategies (while such actions are not required for passive revolution). Still, we see both as forms of accommodation [12] – a process of ensuring stability through change – which arguably brings the two concepts very close to each other [43].

From a Gramscian perspective, strategies of accommodation take place within "wars of position" [52] where both hegemonic and counter-hegemonic actors and movements seek to gain influence. This process of social contestation is "endlessly unfolding" [53] and while hegemony[3] might appear stable it is hardly absolute. Like dominant groups, counter-hegemonic movements can build coalitions, win support, gain influence and challenge the "social licence to operate" of incumbent firms [43,54]. In response, incumbents can seek to accommodate criticisms through strategies of trasformismo and/or passive revolution, which thus take form in opposition to counter-movements. For example, petrochemical companies adopted circular economy strategies to respond to the marine plastic crisis when their position on plastics was challenged [35]. The historical moment thus bears great importance for the potential for change [44,55].

That emerging ideas can be adopted to the advantage of business interest resonates with the concept of green capital accumulation, which describes how lead firms utilize the sustainability agenda to enhance profitability [56]. This phenomenon goes beyond managing brand reputation, improving information, and externalising risk by recognising sustainability management as a key capitalist dynamic. Green capital accumulation relates to trasformismo in that it is enabled through "specific operationalisations" of sustainability [56]. Similarly, Mah [35] describes the acceleration into new plastics markets under the guise of circular economy discourse as "proliferation". Common to both the ideas of green capital accumulation and proliferation is that corporate incumbents do not only accommodate potential change pressures – they also seek to utilize them to their benefit to strengthen their (dominant) position. But how do corporate actors engage in such processes?

Trasformismo points to the wide-ranging and multiple sources of influence that incumbents can draw upon, including material, institutional, and discursive forms of power. Material power stems from economic importance and the role of a given (set of) actor(s) in securing economic growth by means of command over finance and production [43]. State dependence on growth for, e.g., legitimacy, employment, and revenue creates reliance upon the actors that structure that process, granting them material power [14]. An industry that is structurally important in enabling capital accumulation, as in the case of energy, can thus claim to represent interests beyond that sector, i.e., those of "capital-in-general", and is thereby advantageously positioned [14,43]. For example, concerns about international competitiveness and carbon leakage have led to persistent watering down of the stringency of production-based climate policies [57]. Institutional power, in turn, builds on material power and relates to the role of business in formal and informal political processes. Institutional power is exercised through both taking official part in decision-making as well as through lobbying and network relations [43]. Finally, discursive power captures how incumbents seek to build consent around "hegemonic projects" through shaping public and political discourse [43]. This form of power is exercised through a variety of public relation activities including direct (e.g., advertising, social media) and indirect forms of engagement (e.g., through media and civil society organizations). Seeking to elaborate on discursive power, the following draws on a range of literature extending well beyond explicitly neo-Gramscian contributions.

2.2. Discursive strategies and narrative realignment

In efforts to invoke discursive power, corporate incumbents decide on certain discursive strategies. Discursive strategies can be built around multiple arguments that relate to different discourses that fit well together [5]. Depending on what incumbents perceive as threats, such strategies are subject to change over time [4,43] while not necessarily neatly orchestrated among actors; they also arise out of "pragmatic, incidental alliances that shape up around specific story-lines" [58]. Coalitions (including non-business actors) can be built around agreed upon storylines as with the British pro-gas coalition analysed by Lowes et al. [59]. In this paper, we distinguish between the overall discursive strategy of corporate incumbents and specific strategic narratives invoked by industry actors. We draw upon Hajer's [60] definition of discourses as an "ensemble of ideas, concepts, notions and categorizations that are produced, and transformed in a particular set of practices and through which meaning is given to physical and social realities". In relation to discourses, narratives act both as "building blocks" out of which larger discourses are constructed and as "indicators" used to identify them. Narratives connect actors, through their statements, to broader discourses, while also providing a site that reveals their elementary components [61]. We here understand narratives as a particular account of a given predicament (for example the carbon-intensity of petrochemicals) pre-empting a certain solution to this problem framing [62].

Discourse can play a critical role in facilitating and breaking path dependency and lock-in [65]. In that regard, Buschmann and Oels highlight discursive carbon lock-in, defining it as "institutionalized mechanisms of discursive reproduction includ[ing] mechanisms of reproduction related to a mental map (or discourse) based on increasing returns" [65]. In other words, a discursive lock in happens when a discourse is institutionalized and becomes self-reinforcing. Breaking discursive lock-in therefore requires disrupting the processes that reproduce the dominant discourse. By constraining choice options, the struggle for discursive hegemony is a critical aspect of industry transformation. For instance, in mapping the "possibility space" and functioning as a narrative for focusing capital, hegemonic visions help decide future trajectories [66]. Emphasising discourse, however, does not preclude other dimensions of change. Reminiscent of how trasformismo stresses material and institutional power as well as discursive power, discursive lock-in underlines and reinforces other forms of lock-in (technological, institutional, and behavioural) [65].

Historically, the domains of climate and energy policy have been influenced by discourses of climate denial. Both think tanks [67] and specific key scientists [68] have worked to establish contrarian discourse and have successfully influenced the confidence of the scientific community in relation to climate change [69]. However, discursive strategies go beyond the efforts to spread and sustain denial of humanly

[3] Hegemony is here understood as "the persistence of social and economic structures that systematically advantage certain groups" [12] including for example privileged access, tax breaks, subsidies and legal frameworks that benefit incumbent actors [43].

induced climate change. In this vein, Lamb et al. [70] created a typology of "discourses of climate delay" and grouped various discourses into four categories namely "push non-transformative solutions", "emphasise the downsides", "surrender" and "redirect responsibility". Discourses of delay are more difficult to "call out" in that they build on legitimate concerns and as such have compelling elements to them. However, when they misrepresent, redirect responsibility and downplay the need for action, they function as mechanisms of delay [70].

To bring together the above lines of argument and advance existing analysis, we introduce the idea of narrative realignment, which refers to discursively bringing practises and activities of incumbents (back) into line with transition pressures and calls for system-level change. This entails advancing specific narratives in which problem-framings necessitate solutions enabled by incumbents, typically in reference to progressive forms of change. The notion of narrative realignment captures how narratives are set up in a way that "twist" or reorient identified problems so that the solution entails dependency upon incumbents. Thus, industry action is part of and often integral to the solution. For example, insofar as actors and industries are criticised for lack of action, corporate actors help outsiders "understand" how incumbents are in fact addressing grand sustainability challenges. To the extent that industries are critiqued for unsustainable production, the use and essentialness of their products and output to sustainability are emphasised. Narrative realignment operates in this sense as a strategy of trasformismo but on a discursive scale. It is not an instance of co-optation of grander counter-hegemonic narratives. Instead, it aligns current practises, operations, and plans with potentially disruptive discourses that – at least in their formation – emerged as disruptive to business as usual (such as decarbonization, energy transition and circular economy). Narrative realignment thus resonates with discourses of climate delay in that it facilitates misrepresentation, redirects responsibility, and downplay calls for action, relying on "particular interpretations" of sustainability [56]. To the extent that specific "twists" are employed and shared across the industry, they can facilitate discursive lock-in, as actors mirror discursive practises seeking to align their existing operations with calls for change and ease regulatory, investor and civil society pressures.

The relevance and novelty of the concept of narrative realignment lies in nuancing and expanding our understanding of how discursive power is employed under trasformismo. The phrase helps unpack the function of and dynamics behind certain narratives and the way they are constructed and employed in response to change pressures which is particularly relevant in relation to transitions. Placed within a neo-Gramscian conceptualisation of wider processes of change and dimensions of power, we see this theoretical contribution as a way of nuancing theory to respond to the complexities of social and economic phenomena. These ideas follows Stuart Hall's interpretation of Gramscian theory as an evolving practice that is responsive to context, in which the "process of theorising" is "the sign of a living body of thought, capable still of engaging and grasping something of the truth about new historical realities" [71]. Homing in on (but not being limited to) the discursive scale, the concept of narrative realignment should thus be understood in relation to other neo-Gramscian concepts, although in principle it could be linked to other frameworks as well. For example, while we focus on the purpose and implications on industry narratives, institutionalist approaches could help conceptualise how and why these narratives might spread [72].

We start from the understanding that discursive struggles play an important role in shaping transition pathways. To accommodate pressures for change, incumbents can employ discursive power, relying on strategies that align with tactics of trasformismo. In practise, accommodation happens through a variety of activities including pushing certain storylines and narratives that bring potentially counter-hegemonic ideas and activities in line with the practises of incumbents. If successful, such dynamics can lead to or maintain discursive carbon lock-in, underpinning other forms of lock-in and maintaining prevailing distributions of power. One way to bring engage in trasformismo is through narrative realignment, which help reframe calls for change, associating them with current and future activities and practises of incumbents. Discursive power is employed happens in a war of position in which both subordinate and dominant groups take part. Social contestation is here constantly unfolding, involving multiple sources of power, and the strategies of incumbents should be understood in relation to counter-hegemonic resistance. We focus here on the exercise of discursive power and explore how it plays into material and institutional dimensions of power in the petrochemical industry.

3. Methods and materials

3.1. Data material

To study narrative realignment in the petrochemical industry, we analyse publicly available statements and arguments on sustainability published by petrochemical majors. Specifically, our empirical analysis focuses on the ten largest firms in the sector as measured by reported chemical sales (Table 1). The industry is and has been dominated by a rather small number of large multi-national firms [73] which hold important positions in and carry the potential to influence the global petrochemical regime [74,75]. Limiting our focus to the largest producers is relevant given our theoretical framework and its attention to dominant actors, which we take these firms to be among. In that regard, the firms we analyse capture the variety and changing dynamics in the sector. Until the turn of the millennium, the dominating firms were primarily enterprises that emerged either in the early days of the industry in Europe (e.g., BASF, Linde), or with the advent of the petroleum-based era in the US (e.g., ExxonMobil, Dow, LyondellBasell). In recent decades, global competition in the industry has increased with the rapid growth of especially state-owned and state supported firms from Asia (e.g., Sinopec, Formosa, Mitsubishi) and the Middle East (e.g., Sabic) [26]. Several of these firms are vertically integrated across petroleum extraction/refining (downstream) and petrochemicals (e.g., ExxonMobile, INEOS, Sabic), whiles other are more chemicals-focused companies (BASF, Linde, Formosa). Certainly, the sales growth and yearly investments of the top ten are substantial (Table 1), and not surprisingly, the firms we analyse are responsible for immense volumes of GHG emissions (even given that inconsistencies and incompleteness of emission disclosure are prominent in the industry, especially for indirect scope 3 emissions[4] [23]). For example, if the nine companies that have a net zero pledge (Table 1) genuinely realised that goal across scopes for their reported emissions, it would approximately be equivalent of abating the current annual emissions from all international transport [78].

Through web search we found the most recently available sustainability reports (as of September–October 2021) from the companies above, which we complemented with data from the companies' websites. This totalled 11 reports (two from Formosa[5] and one for each other company) and 10 website sections on sustainability (each with a varying number of subsections). For triangulation, we also made use of corporate responses to CDP (formerly the Carbon Disclosure Project), the leading global platform on voluntary corporate environmental disclosures whose questionnaire includes several open questions that allows for longer comments. Observations and field notes were also made at four industry conferences in the period 2019–2021.

The relevance of sustainability reports as core documents used to

[4] Scope 1 refers to direct emissions from sources that are owned or controlled, scope 2 to GHG emissions associated with purchased electricity, and scope 3 refers to indirect emissions outside of scope 2 [76]. In the case of petrochemicals, scope 3 includes emissions from e.g. oil and gas extraction or incineration of plastic, which are associated with substantial climate impact [77].

[5] One from Formosa Petrochemical Corporation and one from Formosa Plastics Corporation.

Table 1
Overview of petrochemical producers analyzed for this paper ranked by chemical sales.

Company	HQ	2019 sales (m USD)	Avg. sales growth 2010–2019	2019 emissions disclosed through CDP (Mt CO2eq)			Net zero target
				Scope 1	Scope 2	Scope 3	
BASF	Germany (private)	66.4	4.8 %	17.3	3.6	99.7	2050
Sinopec	China (state)	61.6	9.1 %	170.1	45	NA	2050
Dow	USA (private)	43.0	0.7 %	27.5	5.1	91.4	2050
Sabic	Saudi Arabia (state)	34.4	5.8 %	37.4	17.5	107.6	2050
INEOS	UK (private)	32.0	6.1 %	NA	NA	NA	2050
Formosa	Taiwan (private)	31.4	2.3 %	36.4	8.4	136.7	No net zero target identified
ExxonMobil	USA (private)	27.4	1.5 %	NA	NA	NA	2050
Mitsubishi Chemical	Japan (private)	27.4	8.2 %	8.5	8.2	51.8	2050
LyondellBasell Industries	USA (private)	27.1	4.4 %	14.6	8.6	31.3	2050
Linde	UK (private)	25.4	13.0 %	16.5	19.9	13.7	2050

Sources: Chemical & Engineering News [79], CDP disclosure data and company sustainability reports. *Note*: Net zero targets differ widely in scope and how "carbon neutrality" is accounted for (see also Section 4.1), NA – not available through CDP due to lack of disclosure. The GHG emission figures for Formosa count responses to CDP questionnaires from Formosa Chemicals & Fibre Corporation, Formosa Petrochemical, Formosa Plastics Corp, and Formosa Taffeta Co.

identify narratives is that these reports are linked to companies' strategies for stakeholder engagement [80]. Because sustainability reports are central tools of maintaining legitimacy and are used strategically as part of positive image creation [81], they are suitable for our purposes. In the words of Megura and Gunderson [82], these reports constitute a "window into [the] ideal green self-image" of corporations. The relevance of sustainability reporting relates to its historical emergence as a response from corporate actors that have increasingly come under pressure to put environmental concerns more firmly on the agenda [81]. Moreover, sustainability reports are directed towards stakeholders like investors whose decisions can have direct financial consequences for companies [82]. These reports convey a comprehensive and detailed one-way form of communication under the control of a given firm as compared to shorter statements on interactive social media where claims of sustainability can be questioned and potentially backfire [83].

3.2. Analytical approach

To identify and construct the narratives we used both an inductive and iterative approach. First, guided by the notion of narratives described in Section 2.2, we coded the data according to key problem definitions and solutions on decarbonization that are used by the industry. From this coding, we could identify recurring arguments, concepts, and rhetorical commonalities. We used these elements to construct idealised narratives and then revisited the empirical material to see whether these narratives were representative of the main arguments and central statements. If key arguments were not represented in the narratives, we modified them to better represent the main statements and logics. We consolidated the number of narratives to a few that were used (though to differing extents) by most companies. This process was repeated until three ideal type narratives emerged that were mutually exclusive and collectively exhausted our body of data. We then drew on participant observations and field notes from industry conferences and CDP disclosures to triangulate and qualify this material and confirm the relevance of the identified narratives. To guide the analysis, we focused on the key issue of climate change. Because of the range and geography of other socio-ecological concerns related to the industry,[6] we made this choice in order to be able to compare narratives more directly across companies as well as juxtapose the findings with the rhetoric employed by fossil fuel incumbents. Still, in light of the interdependence and entanglement of the different issues, we considered all of the material including sections not focused on climate change. The findings therefore point to domains other than GHG emissions to the extent that similarities in rhetoric were evident.

[6] Including local air and water pollution, occupational health and safety, diffusion of Polyfluoroalkyl Substances, plastic pollution, nutrient (mis)management, and so forth.

4. Transition-related narratives in the petrochemical industry

4.1. Realizers of sustainability

The "realizers of sustainability" narrative highlights what are seen as inherently positive aspects of petrochemicals and downstream products. Prominently, the narrative challenges the negative framing of plastics as problematic, instead stressing the supposed benefits. In this framing, the problem is lack of acknowledgement of the merits of petrochemicals for green purposes. To the proponents of this narrative, the focus on negative issues (plastic pollution, emissions from production, reliance on fossil feedstock, etc.) disregard benefits such as reduced food waste, reduced vehicle weight, or that plastic production is less carbon intensive than substitutes, e.g., metal or glass for packaging [84]. The solution is thus to recognise the advantages of petrochemicals particularly in achieving emission reductions. Arguments aligning with this narrative are typically made by selectively pointing further down the value chain, asserting for instance that petrochemicals enable emission reductions in other industries. Proponents often account for "avoided emissions" that arise from product applications (such as improvements in energy efficiency). Dow, for example, includes "product benefits" in their 2050 target of being "carbon neutral" [85]. In a broader perspective, proponents frequently also reference the use of petrochemicals for other purposes that purportedly relate to sustainability such as fertilizer (food security), wind turbine blades (renewable energy) and pharmaceuticals (health).

Illustrative examples:

- "In 2020, a subset of Linde applications enabled more than twice the GHG benefit than was emitted in all [of Linde's] global operations." [86]
- "We offer our customers solutions that help prevent greenhouse gas emissions and improve energy and resource efficiency." [87]
- "While ExxonMobil agrees there is no place for plastic waste in the environment, the environmental benefits of plastic are clear." [88]

To reinforce this narrative, proponents often reference life cycle assessment studies that promote the embedded emissions benefits of plastics compared to alternatives [84,89]. For example, a report sponsored by the American Chemistry Council [90] finds that emissions related to plastic packaging could increase significantly if all plastic packaging in the US was replaced by alternative materials. Claiming benefits by referencing a benchmark with higher emissions is a relative rather than absolute assessment, meaning that the chosen benchmark

matters a great deal to this line of reasoning (for example, one could imagine "reduced use" reference scenario). Moreover, this argument does not say anything about whether the unit of analysis performs "well enough" given ecological limits [91], a tendency that is mirrored in corporate sustainability reporting more generally [92]. Quantifying "avoided emissions" requires consistency, or else it results in incoherence [93]. For example, in the quote above, Linde makes it accounting in reference to a hypothetical scenario in which customers do not apply Linde products, seemingly assuming that no relevant substitutes exist. In attributing these reductions to Linde, double counting occurs when their customers report lower direct emissions. Use of "creative accounting" is not unique but rather a widespread tendency in the industry, especially in relation to life cycle assessment [41].

Looking beyond method-oriented critiques, the narrative arguably ignores how accounting is constructed and its political and normative elements [94–98]. The "realizers of sustainability" narrative presents criticisms of the industry as an information-type problem (which corporate actors try to alleviate). Relating to discourses of climate delay, the practise of flagging ostensibly "objective" assessments of avoided emissions as way to alleviate pressure resonates with "whataboutism" [70]. Whataboutism also redirects responsibility, often by deploying and cherry-picking seemingly favourable statistics. While whataboutism typically reorients the focus to blame others, however, petrochemical producers also selectively redirect focus towards themselves in claiming sustainability achievements.

4.2. Breakthrough technology pioneers

According to the strategic narrative "breakthrough technology pioneers", future low-carbon technologies pave the road towards decarbonization; technologies that the petrochemical sector will play an essential role in developing and deploying. The role of industry in ensuring these developments is framed so as to naturally follow from its track record of innovation and technological breakthroughs. In essence, the problem in this narrative is greenhouse gas emissions and plastic waste arising from petrochemical production. While acknowledging sustainability issues, the industry at the same time avoids taking responsibility, passing the blame to consumers for littering and low rates of recycling and highlighting the value of plastics as sustainable materials [41]. The solution lies in changing production processes through innovation by increasing efficiency and pioneering break-through technologies. Rather than being facilitators of carbon lock-in, the petrochemical sector is thought of as playing pivotal role in developing and scaling up what are presented as key technologies. These key technologies include carbon capture (utilization) and storage (CCS/CCUS), hydrogen (both feedstock and power generation) and electrifying the steam cracking process [99]. In addition, several companies promote chemical recycling (also known as advanced recycling, which involves breaking plastics down into their component molecules) as a means to increase circularity and, by extension, emissions reductions, although the ecological desirability of these approaches remain contested [35,100–102]. Many environmental activists, for example, argue that chemical recycling is simply another word for "incineration" [103,104]. Similar for these various means of decarbonization and increasing circularity is that, although their development may take time once they reach maturity (the narrative suggests), they will result in massive emissions reductions. Thus, the existing petrochemical infrastructure, and the expansions of (and further investments in) high-carbon complexes that continue production of virgin plastic are cast as non-problematic. Similarly, the narratives sustain the notion that existing demand patterns are locked-in and that transformative lifestyle changes are not needed. In other words, production volumes of petrochemicals and plastics should not be problematized, we just need to produce plastics with "green" technologies.

Illustrative examples:

- "(…) we are pioneering nearly carbon-free production processes, especially for emission-intensive basic chemicals". [105]
- "Dow delivers breakthrough sustainable chemistry innovations that advance the well-being of humanity." [106]
- "Leveraging our expertise in research and development and molecule management, we are developing options for integrating advanced recycling solutions at our petrochemical facilities." [88]

This narrative is also found in other heavy industries that rely on development and deployment of "key technologies" to decarbonize [107] and, more generally, it aligns with the discourse of "technological optimism" [70]. Although such thinking can be found in several variations, the underlying focus is a steadfast belief in technological progress frequently backed by unsupported claims that lead to other forms of delay (e.g., regulation as damaging or breakthroughs as certain). Especially relevant for the case at hand is the continuous and repeated promotion of technological "myths" that are not manifested within the assured timeframe [108]. Among the sampled companies, most have indicated an interest in low-carbon technologies, but there have not been significant leaps towards realisation. Financing and deployment are still niche, and in several cases, have been so for several decades already [23,109]. Consequently, these technologies may well represent an essential part of the paths to decarbonization, but without significant investment, commitment, and technological development they run the risk of not materialising this potential. Seeing the timeline for uptake of new production processes and limited options for retrofitting, there is a serious lack in investment and commitments if the companies hope to achieve net-zero targets via such pathways. Such criticism is pertinent given that recent research highlights the industry as a facilitator of (an accelerating) carbon lock-in [28,110], questioning the premise of the narrative, namely that industry are pioneers of low-carbon technology.

4.3. Already well underway

In the narrative "already well underway", the climate actions of petrochemical majors are portrayed as ambitious, bold, and inspiring. Therefore, it is important to showcase the commitment and efforts of the industry to stave off critics who misconstrue or have not realised how well individual companies are *actually* doing in terms of their sustainability efforts. The problem in this narrative is that the world is unaware or lack understanding of ongoing initiatives and previous successes. The solution is thus to promote the "many" cases of concrete action and companies' continual progress, including demonstrating (for example) that companies have paid attention to climate change for years, are investing in research and development (R&D) and decarbonization projects, or are retrofitting existing plants. These efforts are often framed as part of a journey or path towards "carbon neutrality" with the company in question as the protagonists. The narrative also extents to plastic waste management and the notion that companies are well on their way to achieving circularity.

Illustrative examples:

- "[The blue hydrogen plant] builds on the significant CO_2 reductions we've already made." [111]
- "The new photovoltaic plant will deliver an 80kt annual reduction in indirect CO_2 emissions and reinforces our support for and contribution to wider climate change initiatives." [112]
- "(…) we are taking [concrete steps], such as the establishment of the Circular Economy Department and the implementation of initiatives to tackle the issues of waste plastic and climate change." [113]

A feature of this narrative is that companies are framed as the drivers of change. Here, corporate action cannot be attributed to outside pressures – rather, these actions are a natural part of the corporate DNA. This feature is manifested when, for instance, corporations re-label an action that they would have undertaken in any case (due e.g. to economic

factors, new legislation or court rulings), as actions that illustrate their climate ambition. To illustrate, LyondellBasell promotes reduced flaring as part of their climate ambition. However, in October 2021, LyondellBasell agreed to cut flaring as part of a US court settlement [114]. In fact, their target of 0.08 Mt. CO2 from reduced flaring matches the reductions they were forced to comply with under the court settlement. Looking beyond examples of re-labelling, the industry has ignored or fought against climate change action for decades [115] and is still lobbying opportunistically to facilitate accumulation and shape or hinder regulation [116]. From this perspective, petrochemical majors are only reluctantly engaging in decarbonization and other sustainability efforts to please stakeholders following massive pressure from multiple actors [35].

The "already well underway" narrative resonates with the delay discourse "all talk little action" identified by Lamb et al. [70], pointing to advancements that downplay the need for further action or more stringent regulatory measures [117]. Such discourse can be supported by setting seemingly ambitious but voluntary targets (cf. the adoption of net zero targets referenced in Section 3) and by promoting specific statistics without contextualising them, since doing so could entail undermining claims of sustainability [94]. Many loopholes exist both in terms of methods for setting and meeting targets, which demands scepticism and scrutiny [118]. Although companies should arguably be credited for committing to action, if the cumulative effect of corporate projects have a relatively small effect on overall emissions, this narrative divert attention and downplay the necessity for structural change. Similarly, "green" R&D spending should be related to overall capital expenditures into fossil-based infrastructure that further carbon lock-in. Certainly, all of these companies have recently announced substantial investments into expanding fossil-based production facilities [28]. Insofar as "green" spending is used to signal a new direction but remains dwarfed by "brown" investments [119], such commitments help legitimize the carbon lock-in that current investment patterns facilitate.

4.4. Narrative realignment in the petrochemical industry

Fig. 1 and Table 2 illustrate and present an overview of the strategic transition-related narratives employed by the sampled petrochemical majors. These various ideal type storylines are not independent, but rather, they relate to and mutually reinforce each other. Together, they constitute a discursive strategy, portraying the petrochemical industry as of unquestionable societal importance, promoting the idea that stringent regulation is not needed, and implying that criticisms against the industry are based on misunderstandings. Across narratives, the industry is portrayed as a transition enabler (rather than an originator of carbon lock-in) facilitating a transition free of contestation which, however difficult, is pleasingly under control. Not only are incumbents realising sustainability now – they are also key for future pathways, fulfilling this role in a constantly improving manner.

Despite reinforcing each other, the different strategic narratives are arguably not entirely internally consistent. For example, if industry actors are indeed "well underway" on a journey towards low-carbon production, there should be little need to appreciate that they enable "avoided" emissions elsewhere. Additionally, the "realizers of sustainability" narrative proudly points to the need for petrochemicals to produce renewables, lending support to the need for an energy transition. Yet the narratives do not necessarily entail abandoning the current energy order, instead lending themselves to continuous extraction, refining and cracking of hydrocarbons on massive scales. Lastly, the "breakthrough technology pioneers" narrative acknowledges problems while passing blame onto consumers. As for the benefits of plastics, though, "realizers of sustainability" take full responsibility. In effect, these apparent contradictions work to consolidate the narratives and fend off storylines that run counter by covering potential blind spots. By invoking these narratives, proponents can dismiss criticisms that target inadequate or lack of action as these have not considered how the industry enables emission reductions; similarly, criticizing the industry for being fossil-based and enhancing carbon lock-in does not appreciate the role of petrochemicals in energy transitions. Strategic ambiguity remains around the framing of the agency of incumbent actors. Across narratives, firms are the main protagonists, downplaying the importance of, e.g., other actors in the global innovation system [120]. Yet the premise that current demand trends are completely fixed goes unquestioned. Taken together, these narratives narrow down climate futures and frames an incumbent-led, technology-oriented transition as the only game in town. As put rather bluntly by the industry organization Petrochemicals Europe: "We build the future!"[7] [122].

The three strategic narratives entail narrative realignment albeit in different ways (see Table 2). Common to all narratives, however, is that they bring ideas and practices of decarbonization in line with existing strategies and current industrial developments within the sector. Narrative realignment is essential to "realizers of sustainability" in that the narrative frames existing petrochemical production as climate friendly and thereby important to decarbonization. Moreover, incumbents often highlight the importance of petrochemicals in enabling transitions to renewable energy systems (e.g., solvents to manufacture solar panels, chemicals needed to produce wind turbine blades, etc.) [73]. In doing so, the industry positions itself as critical to not only decarbonization but also to renewable energy transitions. As such, it aligns fossil-based chemical production with fossil-free energy. The narrative thereby casts current (and increasing) levels of production as legitimate and beneficial implying that the position of petrochemical incumbents in the social order should not be tampered with. Production of and investments into petrochemicals are here not primarily commercially-informed decisions that enrich capital owners but rather sources of sustainability benefits. Thereby, in framing existing and potential new products as sustainable, "realizers of sustainability" point towards options for green capital accumulation.

Encapsulating narrative realignment, the narrative of "breakthrough technology pioneers" seeks to align incumbents' investment patterns and R&D focus with decarbonization and a circular economy. In the analyzed material, multiple companies emphasise CCUS, green hydrogen and chemical recycling – key technologies legitimized by the pathways set out by among others the International Energy Agency, in which particularly the two former hold significant potential for decarbonizing the sector [16,109,123]. Understanding the industry to be a pioneer of key technologies implies that production facilities will be decarbonized once low-carbon processes have been developed and rolled out. As such, regulating the industry amounts to misunderstanding the logics of technological innovation. If anything, public support is warranted, since the industry is uniquely positioned to develop key technologies, thereby opening for avenues of green capital accumulation.

Lastly, "already well underway" tries to cast current sustainability efforts in a positive light. Narrative realignment is here evident in how this narrative aligns previous and current actions taken by petrochemical majors with decarbonization. For example, petrochemical majors highlight energy efficiency improvements as part of their decarbonization efforts, signalling that the industry is in control and steadily following a pathway towards decarbonization. Yet energy efficiency measures have been a long-term trend in the industry [19] as these have clear economic benefits (feedstock dominating production costs). Energy efficiency improvements thereby provide a double dividend, both lowering costs and recasting industry efforts as green through lowering emission intensity, thereby fending off pressures for more transformative visions for the industry [36]. At the same time, however,

[7] This bears noticeable resemblance to the rhetoric of the American Fuel and Petrochemical Manufacturers quoted in Section 1, who referred to petrochemicals "the building blocks of modern life", a terminology also used by individual companies such as ExxonMobil [121].

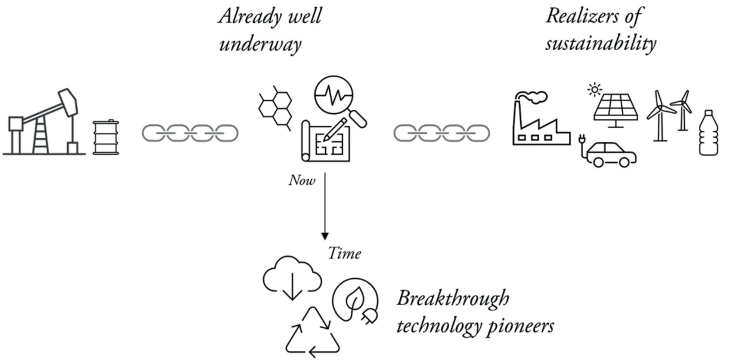

Fig. 1. Schematic representation of strategic transition-related narratives in the petrochemical sector.

Table 2
Overview of the identified narratives.

Strategic narrative	Problem	Solution	Role of industry	Narrative realignment	Resonates with
Realizers of sustainability	Lack of acknowledgement of the role petrochemical products play for various sustainability issues	Acknowledging the benefits of petrochemical products, e.g., emission reductions made possibly by plastics	Delivers tangible and substantial sustainability benefits such as emission reductions. Trying to combat misunderstandings.	Aligns ideas of decarbonization and energy transitions away from fossil fuels with current production patterns of the petrochemical industry.	Whataboutism
Breakthrough technology pioneers	Carbon emissions and plastic pollution from petrochemical production	Innovation facilitated by the industry. Increasing energy efficiency and long-term decarbonization.	Transition enablers and innovative pioneers of new technology.	Aligns decarbonization and circular economy with existing investment and R&D strategy, contending that decarbonization is best facilitated in the hands of industry.	Technological optimism
Already well underway	Unawareness of the existing efforts and transformative success of the petrochemical sector	Promoting the "many" cases of concrete action and initiatives that companies (and the sector at large) are working on in line with previous successes.	In control with high ambition and substantial action.	Aligns decarbonization and circularity with current sustainability efforts in the industry. Elements of passive revolution.	All talk little action

improvements in energy efficiency risk strengthening carbon lock-in by furthering integration of existing production processes [143,144]. This example illustrates a link between narrative realignment and passive revolution in that "already well underway" foregrounds reformist or incremental changes to neutralise criticism while recasting these developments as progressive. By presenting the industry as being on a path towards decarbonization, with key incumbent actors eagerly trotting along, the narrative positions the industry as unproblematic – also from an investor perspective. Thereby, "already well underway" downplays the sector's exposure to climate-related financial risks arising from fossil-based production (e.g., in the form of capital stranding cascades [124]).

On the whole, the three strategic narratives portray the industry as part of the solution rather than as part of the problem. Beyond pre-empting regulation by deflecting or redirecting responsibility and easing pressure, these narratives play into strategies of proliferation and green capital accumulation, framing incumbent actors as integral to decarbonized futures. Dependence on petrochemicals is here both current (as realizers of sustainability) and continuous (as pioneers of breakthrough technology), making transitions possible and driving needed technological innovation. Running against pressures for change, these narratives work to "future-proof" the industry [35] based on narrative realignment, legitimating and thereby reenforcing current patterns of lock-in. In essence, this discursive strategy answers the question posed to industry actors by a senior manager at a global consultancy for companies in the chemical sector: "[How] can you negate or convert threats, and position to capture opportunities?"[8]

5. Perspectives on petrochemical transitions

Seeing the calls to end fossil fuels [125] and cut global plastic production [32] alongside unfolding socio-ecological crises, the petrochemical industry appears to be subject to unprecedented pressure. Yet – at least if their public announcements are to be trusted – industry actors do not seem that worried. In engaging with stakeholders, the discursive strategy presented above seeks to take the disruptive and potentially counter-hegemonic ideas of decarbonization, energy transition, and circular economy, and align them with current petrochemical production and investments patterns. In this section, we discuss this discursive strategy and relate it to other forms of power required for trasformismo. To add perspective, we then consider the unique position of petrochemicals in energy transitions by contrasting the findings above with the rhetoric utilised by oil and gas majors as mapped in recent studies.

[8] Authors' notes, Europe Chemicals and Polymers Conference, September 2021

5.1. Trasformismo and petrochemicals

In the process of trasformismo, the employment of discursive power happens in combination with material and institutional forms of power. As for material power, the dependence on petrochemicals in enabling capital accumulation confers certain advantages to the industry. Not unlike the structurally important energy industries, the petrochemical sector has arguably played a substantial role in facilitating growth in the 20th century [126]. The petrochemical industry provides input to a host of different industrial processes and has many forward-linkages to other sectors [127]. In the words of the industry, "petrochemicals make things happen" [128], which (similar to the energy industries [14]) allows petrochemical incumbents to claim to represent general interests. The ubiquity and apparent entrenchment of chemicals and plastics in modern life thus grant material power, providing a platform from which to stave off disruptive change. As emphasised in the opening keynote by the sustainability manager from the chemicals section of a large vertically integrated company at a petrochemical conference: "Without our industry, essentially everything in modern life [that] society takes for granted would not exist in the form it is today".[9]

The material power of the industry underpins the discursive strategy of incumbents. The basis of the industry's material power, i.e., the widespread use of petrochemicals across industrial processes, also means that a range of petrochemicals are used for sustainability-related purposes (as incumbents are quick to highlight). As we have shown above, such applications enable the realizers of sustainability narrative. More broadly, the notion of petrochemicals as "building blocks" seeks to make visible the structural importance of the sector and render practically all applications of petrochemicals essential by characterising them as prerequisites of "modern life". As long as we desire the comforts of today – it follows – petrochemicals are indispensable. This perspective speaks to wider imaginaries of green growth and ecological modernisation, which take political and economic structures as given and envision economic growth and ecological sustainability as harmonious [94,129]. Conceived as a modified version of today, green growth might entail restructuring, but the essentiality of petrochemicals remains, i.e., things still need to "happen". Resting on the structural importance of petrochemicals, petrochemical companies can thus position themselves as integral to hegemonic visions of the future.

Linkages between different forms of power are also pertinent in relation to institutional power. The petrochemical industry has a long history of trying to influence political decision-making, both through formal and informal forms of participation including lobbying for and against certain policies, contributing millions to political campaigns and as part of the US's climate change counter-movement, funding climate-denial efforts [115,130–132]. A relevant and coordinated form of institutional power is the wielding of influence by industry lobbying groups, which use the three narratives analysed above in their effort to position the industry as integral to combatting climate change, and evoke the sector's economic importance, both to influence policy [39,133]. Invoking these narratives and backed by structurally dependent material power, the employment of institutional power relates to and depends on other forms of power.

In various ways, the issue of scale is central to discursive, material, and institutional power. On a fundamental level, different socio-ecological crises are fuelled by the massive and increasing scale of petrochemical production [41,134]. In the run-up to the UN Environment Assembly resolution initializing the process of negotiating a global plastics treaty, petrochemical producers lobbied to keep the focus on waste management only and thereby disregard the role of production [135,136]. In this ongoing war of position, the industry seeks to convince stakeholders that plastics are part of the solution rather than the root of the problem. As for discursive power, industry actors seek to tone down issues of scale through realigning plastics and sustainability. Yet it is scale that both facilitates growth and underpins the structural importance of the industry and industry actors have sought to ensure continued upscaling by fending off potential limiting threats. The identified strategic narratives should thus be seen in this broader perspective where narrative realignment and discursive efforts are part of a wider set of activities and practises seeking (through the process of trasformismo) to acommodate transition pressures so that they will not disrupt prevailing social and economic relations. For plastic and petrochemicals, reduced production and consumption is clearly a critically important mitigation pathway [110]. Looking forward, the degree to which incumbents will be successful in ensuring trasformismo will help decide whether this pathway will be pursued.

5.2. Petro-chemicals vis-à-vis petro-extraction

Despite relying on fossil feedstock and being solidly placed in the fossil-based energy order (with strong historical, knowledge-based, and economic linkages to oil, gas, and coal, as reflected by the multiple integrated fossil fuel and chemical companies), the petrochemical industry occupies a different position in an energy transition than do extractors of oil, gas, and coal. As explained above, petrochemicals are framed as integral to ecomodernist futures, despite being fossil-based. How does this position differ from that of fossil fuel extractors?

The oil and gas majors do not have the same platform as petrochemical producers. The "fossil fuel saviour" frame identified by Supran and Oreskes [5] builds on discourses of fossil fuel solutionism [70], positioning the fossil fuel industry as an essential part of the solution to climate change and fossil fuels as critical and necessary for meeting energy demand (which is taken as given). However, this holds only for the foreseeable future. To exemplify, fossil gas is portrayed as a "bridge" towards cleaner energy production and an increasing share of renewables is acknowledged to be necessary (at least at some point) [137]. Even if ideas of technological fixes in the form of large-scale negative emission technologies and "cleaner" fuels underpin the fossil fuel solutionism discourse [82], fossil extraction has to eventually decrease or, at the very least, energy production has to change composition. Ultimately, oil and gas firms face an existential threat, and operate with the fundamental options of either not remaining oil and gas firms or not remaining in business [10]. This means that the battleground is set up around the extent and pace of decreased production and the role of negative emission technologies herein. The contrary is the case for petrochemicals, as contextualised in the introduction: increased production is instead the starting point. Insofar as incumbents successfully manage to present themselves as critical to climate mitigation, and insofar as ecological modernisation remains the dominant imaginary, more "building blocks" are called for.

An important aspect of the fossil fuel saviour frame is the "technological shell game" discourse which, relying on strategic ambiguity, spreads doubt around feasibility, costs and implementation of energy alternatives [5]. Given that the potential of renewables appears increasingly evident (as renewables costs go down and deployment unfolds), a clear outside threat has materialised, arguably increasing the resistance from incumbents standing to loose rents [138,139]. Along these lines, the technological shell game discourse has played an obvious function for fossil fuel companies namely that of questioning the validity of renewables. But what alternatives exist to the "building blocks of modern life"? Technological alternatives for petrochemicals (e.g. bio-based feedstocks, carbon capture, and green hydrogen) focus on complementing or improving existing production processes [110], and are framed to emerge from within, with niche technologies being promoted by petrochemical majors (breakthrough technology pioneers).

Despite the above differences, similarities in rhetoric are also apparent across the value chain including discourses of climate delay such as "technological optimism", "whataboutism", "no sticks just

[9] Authors' notes, European Petrochemicals Virtual Conference, November 22, 2021.

carrots", and "all talk, little action" [70]. A prominent example is the tendency to diminish responsibility by taking production growth as a given, "casting itself as a kind of neutral innocent, buffeted by the forces of consumer demand", a manoeuvre used by both the fossil fuel and the tobacco industry [140,141]. Moreover, various civil society actors have worked to lump together petrochemicals, fossil fuels and plastics. For instance, Greenpeace successfully led a campaign for LEGO to end their partnership with the vertically integrated oil, gas, and petrochemicals company Shell, presenting Shell as fundamentally problematic and mobilising action against the use of fossil-based plastics for LEGO products [142]. However, unlike fossil fuel extractors who combat clear substitutes, petrochemical majors are positioned to pursue strategic narratives premised on the inevitability of "modern" society in which chemicals and plastics are ubiquitous.

With the agreed-upon resolution at the UN Environment Assembly (UNEA-5) requiring a global plastics treaty, stepping up international plastic governance across the value chain in spite of counter-efforts by industry lobbyists [32], transition pressures appear to be increasing. The three narratives discussed above that proactively frame industry as imperative to sustainability are likely to come into play as the war of position continues to unfold and hegemony is challenged. What the consequences will be and whether new narratives will emerge as the landscape changes remain open questions.

6. Conclusion

Because of their involvement in various socio-ecological crises and conflicts, petrochemical producers are subject to a multitude of change pressures. In seeking to navigate such pressures, they promote a number of strategic narratives that align current and planned activities with ideas of sustainability, decarbonization and circularity. This promotion happens through efforts of narrative realignment positioning petrochemical industry actors as central to ecomodernist futures as pioneers of technology and enablers of transitions. This position differs from that of fossil fuel extractors in petrochemicals not being a bridge to but rather the fundament for modern sustainable future(s). Instances of narrative realignment constitute examples of the use of discursive power and play into wider processes of trasformismo and wars of position. The processes we have described here are not only a matter of accountability, deflection and avoiding responsibility, but also about positioning and power, seeking to maintain favourable socio-technical configurations and rendering "unlimited" plastic futures more likely [41].

The concept of narrative realignment adds to our understanding of the employment of discursive power by illustrating how its concrete manifestations can mimic and feed into larger-scale processes of trasformismo. In this way, we have sought to illustrate trasformismo "in practice". Mapping narrative realignment is thus one helpful way of tracing efforts of transformismo as the process unfolds whether these efforts will be successful or not. Future research can fruitfully compare the employment of discursive power across energy intensive processing sectors and see how discursive efforts relate to central conflicts about the potential for reduced production and use as part of industry transformation. Which narratives do actors promote across industries, how are they related and what is the role of narrative realignment? For example, to what extent do incumbents push the notion of output from the steel and cement industries as essential and ubiquitous? Future research could also assess dynamics internal to the petrochemicals industry, exploring how, why, and to what extent various narratives travel and become institutionalized on a global scale. Exploring such questions will help shed further light on the material implications for industrial transformations of narratives and discursive forms of power.

With calls to cap the global production of (virgin) plastics in the upcoming global plastic treaty [32,33], the war of position concerning continued upscaling (and locking-in) of the already colossal petrochemical production will likely intensify. Accordingly, efforts of narrative realignment are set to continue as incumbent actors emphasise petrochemicals as necessary and essential and seek, once again, to make plastic "fantastic". If the socio-ecological consequences of continued growth of petrochemical production are to be avoided, these efforts have to be counter-balanced and the crucial role of chemicals in upholding the fossil energy order must be made visible. Yet undoing petrochemicals growth also raises questions around the vast array of processes and products that depend on synthetic petroleum derivatives. The struggle over the future of petrochemicals is thus also a struggle over the future of consumerism. To challenge petrochemical growth while meeting the needs of all therefore requires confronting existing inequalities in material and (embodied) energy consumption in conjunction with the unequal distribution of power and resources upon which these inequalities are predicated.

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CRediT authorship contribution statement

Joachim Peter Tilsted: Conceptualization, Methodology, Investigation, Writing - Original draft preparation, Writing - Reviewing and Editing. **Alice Mah:** Conceptualization, Writing - Reviewing and Editing. **Tobias Dan Nielsen:** Methodology, Investigation, Writing - Reviewing and Editing, Funding acquisition. **Guy Finkill:** Investigation, Writing - Reviewing and Editing. **Fredric Bauer:** Conceptualization, Writing - Reviewing and Editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Paper IV

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Imagining circular carbon: A mitigation (deterrence) strategy for the petrochemical industry

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ABSTRACT

Petrochemical producers both rely upon and generate some of the most problematic substances in the current age of socioecological crisis: fossil fuels and plastics. With mounting calls to cap fossil fuel extraction as well as plastics production, the industry appears to be caught between a rock and a hard place. Nonetheless, betting on continuously increasing global plastic demand, petrochemical production is expanding significantly. This predicament raises the question of how the industry attempts to square increasing petrochemical production with the need to address environmental issues. In recent years, leading actors in and around the industry have promoted notions of carbon circularity as a desirable mitigation strategy. In this paper, we examine this strategy, using discourse analysis to uncover what we refer to as the imaginary of circular carbon. We highlight how the circular carbon imaginary risks delaying climate mitigation by rendering alternative mitigation pathways undesirable. It does so by reconciling increased production, carbon neutrality, and circular economy in a vision of a circular carbon economy, framing the climate crisis as an issue of carbon management. In the circular carbon economy, carbon dioxide, petrochemicals, and plastics all fit as mere flows of carbon. The circular carbon imaginary thereby helps future-proof the petrochemical industry in legitimizing its carbon-intensive practises essential to the fossil world order and the plastic crisis.

1. Introduction

With the highest energy demand of all industrial sectors (IEA, 2018), the petrochemical industry utilizes fossil fuels to produce platform chemicals for a broad range of applications, most prominently plastics and fertilizers (Levi and Cullen, 2018). The processes that underpin this production are enormously energy-intensive and place the petrochemical industry amid the climate, plastics, and pollution crises (Tickner et al., 2021). Firmly rooted in the fossil energy order (Newell, 2019), the production of petrochemicals and plastics has expanded significantly (Bauer et al., 2023b), and – largely due to increases in the use of plastics in packaging and construction – leading actors do not expect growth to stop any time soon (BP, 2022; IEA, 2018; OECD, 2022). This outlook makes the petrochemical industry the biggest driver of oil demand growth in this decade (BP, 2022; IEA, 2021) and massive investments have been placed into fossil-based chemical infrastructure (Bauer and Fontenit, 2021; Skovgaard et al., 2023; Tilsted et al., 2023).

Against the backdrop of unceasing fossil-based growth, petrochemical producers have faced mounting pressures (Tilsted et al., 2022). While plastic governance for years focused mainly on downstream waste management (Nielsen et al., 2020), traces of policy narratives that focus on the fossil origin of plastics have emerged (Palm et al., 2022). Social movements and civil society actors now stress the links between petrochemicals and climate change (BreakFree From Plastic, 2023; Von Wong, 2023), and advocacy organizations and think tanks advance the argument that "plastics demand won't rescue the oil sector" since fossil-based investments will become stranded assets (Bond, 2020; Gray, 2020). In relation to the ongoing multilateral environmental negotiation towards an international legally binding instrument to end plastic pollution a group of 60 countries rallied behind a call for "restraining plastic consumption and production", stressing the role of plastic production in causing climate change (Tabuchi, 2022; UNEP, 2023). Similarly, scholars in Science have called for a cap on global plastic production (Bergmann et al., 2022). Alongside these developments – and the increased attention to framing emission reductions around net zero (Hale et al., 2022) – the petrochemical industry has advocated a new approach to climate action, namely the notion of *circular carbon*. Departing from the need to provide carbon-based feedstock for the

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continued production of chemicals, this imaginary has emerged as an overall solution frame for the petrochemical industry. Built around the collection, capture, and utilization of diversified flows of carbon to produce chemicals, the mitigation prospects of circular carbon are deeply technology dependent.

Scholars exploring the political economy and ecology of net zero have theorized the reliance on various forms of carbon capture and related technologies through the concept of mitigation deterrence. Highlighting the risks of such reliance, this literature maps how and why promises of technological fixes – most prominently in the form of carbon dioxide removal and negative emission technologies – can serve to deter from other forms of climate action (Carton et al., 2023; Markusson et al., 2022; McLaren, 2016a). Drawing on a cultural political economy lens, the scholarship on mitigation deterrence emphasises how technologies and approaches to climate action must be understood in relation to political and economic institutions, innovation regimes, as well as the social imaginaries that mediate material interests (Markusson et al., 2018). Up until now, the research on mitigation deterrence has mainly focused on carbon dioxide removal, lending less attention to the prospects of utilising captured carbon dioxide (although noting the links between carbon capture and enhanced oil recovery) (Carton et al., 2023; Markusson et al., 2018). A noteworthy exception is Buck (2022), who discusses how circular carbon imaginaries guided by fossil fuel industry can, amongst other things, be read as a delay tactic. Focusing the empirical analysis on the fossil fuel industry in the United States, Buck analysed circular carbon as "an update to CCUS [carbon capture, utilization and storage] discourse" (2022, p. 1089).

In this paper, we reorient the focus on circular carbon from a discourse for and by fossil fuel companies and take a broader perspective by concentrating the empirical analysis on the fossil fuel-petrochemicals-plastics nexus. This nexus is underpinned by material, institutional, organisational and economic ties, with global production networks and entangled industrial clusters, vertically integrated companies and a shared knowledge base (Mah, 2023; Tilsted et al., 2023). Interested in the expectations and futures that circular carbon strategies promote, we explore how frames associated with circular carbon risk delaying climate mitigation. We see the circular carbon imaginary as an operationalisation of the ideas of net zero and climate neutrality for the production of carbon-reliant synthetic materials that fit growth-oriented business models. This imaginary is very much in the making. Running up against environmentalist claims that net zero for chemical and plastics production are a "false narrative" and a "myth" (CIEL and GAIA, 2021), circular carbon is most strongly advocated by large upstream chemical actors (e.g. Cefic, 2022a), but elements of it are also gaining ground elsewhere, such as by downstream consumer brands (Unilever, 2022), renowned academic journals (Meys et al., 2021; Shehri et al., 2022), and in high-level political conversations (G20, 2020). Accordingly, the main empirical material was identified through a targeted literature search and conference participation. While we recognise that the circular carbon imaginary is not yet institutionalised, its prominence in the petrochemical and plastics industry warrants critical scrutiny.

In the following, we outline our analytical process and theoretical framing of imaginaries within a cultural political economy, and how we use that to understand its role in mitigation deterrence. In the two subsequent sections, we analyse the core components and promises of the circular carbon imaginary and how it promotes mitigation deterrence. The conclusion offers a summary, outlook, and policy recommendations.

2. A cultural political economy perspective on mitigation deterrence

2.1. Mitigation deterrence: Definitions and variants

The concept of mitigation deterrence refers to the "prospect of reduced or delayed mitigation resulting from the introduction or consideration of another climate intervention" (Markusson et al., 2018, p.1). Research on mitigation deterrence has explored how and why promises of carbon dioxide removal and negative emission technologies can undermine climate action, illuminating the risks associated with pursuing technologies that promise to substitute for other means of reducing emissions (Carton et al., 2023; Markusson et al., 2022; McLaren, 2020, 2016a; McLaren et al., 2021). Such delay in emission reductions is facilitated through a variety of social, political, and economic mechanisms, including imaginaries. Together, these mechanisms – fuelled by economic interests and relying on particular discursive frames – push for certain solutions rather than others (Markusson et al., 2018; McLaren et al., 2021).

To theorize the mechanisms through which deterrence operate, Markusson et al. (2018) introduced a framework on the cultural political economy of mitigation deterrence. In this cultural political economy lens, technologies co-evolve alongside political and innovation regimes,[2] emphasising how technologies are advantaged and promoted if they "fit" with prevailing political and economic institutions (Markusson et al., 2022, p. 2). When faced with a crisis, the capitalist system tends to respond by shifting problems across time and place – a so-called spatio-temporal fix (Harvey, 2012). Spatio-temporal fixes help defer crises and maintain legitimacy, aligning with the dominant interests and the political and innovation regimes of capitalist societies. Negative emission technologies, for example, work as mitigation deterrence because they fit the "dominant techno-economic framing" as well as established market-oriented climate policy in the form of emission trading that rely on fungibility, i.e., establishing equivalence between different forms of carbon (Carton et al., 2021; Markusson et al., 2022). They constitute a technical fix – a sub-set of the spatio-temporal fix (Markusson et al., 2017). In the case of fossil capital, carbon capture and storage and negative emission technologies work as a spatio-temporal fix to maintain legitimacy in the face of climate change through promising future removal of carbon without necessitating short-term material realisation (Carton, 2019; Markusson et al., 2018). What follows is therefore the risk of mitigation deterrence from pursuing negative emission technologies (Markusson et al., 2022).

Mitigation deterrence can take different forms. In an attempt to quantify the potential scale of mitigation deterrence in relation to negative emission technologies, McLaren (2020) distinguished between three different types. The first (type 1), substitution and failure, describes a situation in which policies and climate plans rely on various techniques that then fail to materialize at the imagined scale due to lack of technical or commercial viability. It might also be that the effectiveness is lower than planned (accounting for the full life-cycle emissions of deployment and operation). A defining feature for type 1 mitigation deterrence is that it has been promised, i.e., formally substitutes for alternative climate interventions. The second type of mitigation deterrence (type 2), rebounds, designate the indirect (and often inadvertent) effects from technological applications and deployment. McLaren (2020) highlights examples such as enhanced oil recovery, methane leakage, and indirect land use change. The final type of mitigation deterrence (type 3), mitigation foregone, denotes a situation in which the immaterial promise of future climate interventions limits mitigation. Type 3 is distinguished from type 1 in that the anticipation of a given technique or approach lowers mitigation without being formally planned or modelled as a climate intervention. As noted above, technical fixes help maintain the legitimacy of fossil capital, arguably making it more difficult to increase mitigation. Re-analysing the type 1–3 typology, Markusson et al. (2022), (pp. 5–6), propose how framing effects

[2] Political regimes here refer to "a specific set of actors that dominate society economically and politically, but crucially also a set of institutions embodying their hegemonic ideals and rationality" (Markusson et al., 2017) while innovation regimes denote "the environment in which new technology is generated" (Markusson et al., 2022).

play into the mechanisms through mitigation deterrence can occur, namely certainty, rationality, substitutability, and boundedness. Underpinned by overplayed notions of certainty (implied by modelling and scenarios), assumptions of rational planning and coordination obscure the scrappy and contested nature of actual deployment. Presenting alternative options along the same limited dimensions (e.g., amount of greenhouse gases, costs, number of resources), in turn, gives the impression of direct substitutability and boundedness, framing out the political and cultural dimensions of the proposed interventions. Such framing effects play a critical role in the mechanisms through which mitigation deterrence occurs and how climate action is governed as part of and fitting with dominant social imaginaries (Markusson et al., 2022, 2018).

2.2. Imaginaries as promoters of mitigation deterrence

The fit between dominant material interests and imaginaries is an explanatory factor in understanding how imaginaries can contribute to mitigation deterrence in either type outlined above. While we acknowledge that contestation around imaginaries is embedded in institutional practices and norms, and that such dynamics are needed to explain how and why certain frames are more successful than others, our focus here will be on the discursive aspects of the circular carbon imaginary and how the framings and ideas that are central to it promote mitigation deterrence.

Our understanding of imaginaries takes its starting point in Jessop's (2010), p.344 definition:

[Imaginaries are] semiotic systems that frame individual subjects' lived experience of an inordinately complex world and/or inform collective calculation about that world. They comprise a specific configuration of genres, discourses and styles and thereby constitute the semiotic moment of a network of social practices in a given social field, institutional order, or a wider social formation.

In this conceptualisation, imaginaries are the semiotic counterpart to institutions in the making of the social-economic order. The importance of imaginaries is that they reduce the complexity of the social and economic order by making sense of it through different means, including all kinds of representations (discursive and not), distinctive ways of acting (genres) and being (identities) (Jessop, 2010). Complexity reduction does not happen through semiosis alone, but in a dialectic between *the cultural* and *the social*. What imaginaries do is that they highlight what particular actors regard as significant, foregrounding certain solutions and futures and excluding or downplaying others (Jessop, 2010; Markusson et al., 2018). As such, imaginaries are efficacious, shaping the development of socio-technical systems, for example by encouraging technocratic responses and framing out justice (McLaren, 2016b) or by promising perpetual energy consumption growth, rendering ideals of sufficiency or efficiency redundant, as in the hydrogen economy imaginary (Hultman, 2009). Be it explicit or implicit, the foregrounding and backgrounding of different issues come with certain ideas of social order and power relations (Jessop, 2010). Given a materialist perspective, in which profitable growth is a key driver of capitalist societies, social imaginaries develop as part of political economy regimes. Imaginaries can support and embody political regimes to establish hegemony while their inherent ambiguities are open for contestation and re-formulation, as they are part of a complex, unstable and dynamic social structure (Jessop, 2010). To maintain hegemony and sedimentation they also require continuous maintenance (Markusson et al., 2018), and can be claimed to be always in the making, never finalized.

3. Data collection and analysis

To trace the imaginary of circular carbon, we analysed communications from up- and downstream chemical actors and industry associations, as well as observations at industry conferences. The analysis includes sources of different genres (e.g., position papers, reports, PR material, legal text, speeches, and pictures) to include many kinds of representations of the imaginary. A list of actor types and actors included is shown in Table 1 and a full list of the empirical material is provided in the Appendix. Besides attending several web conferences and presentations, participant observation was conducted at the plastics industry world fair K2022 in Düsseldorf (Germany) in 2022. The observation departed from the industry organisation Plastics Europe's 7-day long show entitled "Plastics shape the future" which consisted of keynotes, panel discussions and a plastics experiments show. Besides representatives from Plastics Europe, it mostly included upstream chemical producers such as Covestro, Neste, SABIC, and BASF, the latter two being amongst the largest and most influential petrochemical companies in the world (Bauer et al., 2023a; Tilsted and Bauer, 2023). SABIC and BASF are also both involved in fossil fuel extraction and production—BASF holds majority ownership in the oil and gas company Wintershall DEA[3] (BASF, 2023) and SABIC is owned by state-owned Saudi Aramco, the largest oil producer in the world. During the fair, extensive notes and photos were taken, and most of the talks have been watched again via publicly available recordings. To triangulate our empirical material, we identified additional sources that provide insight into how actors in and around the chemical and plastics industries portray a decarbonised future through a targeted literature search.

To identify the defining features of the circular carbon imaginary, our analysis was guided by questions on expectations, promises, and imagined solutions. More specifically, we focused on what is centered on as important, what risks and problems are discussed (van Lente, 2000), and what actors, networks, and collaborations are highlighted (Brown, 2003). Not only the content but also the type of arguments used were noted, such as if they were of a rational or emotional kind (Guice, 1999), and how they connect to other discourses or societal goals (van Lente, 2000). From this analysis, we uncovered commonalities across the material from which the imaginary emerged. All authors participated in this process, which was iterative in nature and featured regular discussions on how findings from different pieces of material related to each other. The analyses and subsequent discussions were informed by ex-ante ideas of the imaginary based on previous (research) experience. These were then refined when tested against the empirical analysis. In this process, we triangulated our material and the identified imaginary with the sources we found through our targeted literature search. To confirm the relevance of our findings and to capture discrepancies and variations across different manifestations of the imaginary, we revisited the empirical material before engaging in further discussions..

4. The circular carbon imaginary

The circular carbon imaginary makes use of many different technical

Table 1
Overview of actors included in the analysis.

Actor type	Actors
Business organisations and coalitions	Cefic, Plastics Europe, Renewable Carbon Initiative
Governance/policy	European Commission, Kingdom of Saudi Arabia
Think tanks/consultancy/research	Nova Institute, King Abdullah Petroleum Studies and Research Center
Upstream chemical producers	Covestro, BASF, SABIC, Neste
Consumer-facing companies	Unilever, Ikea

[3] BASF has recently sought to sell off Wintershall DEA (Burger, 2023), which is a joint venture renowned for strong ties to Gazprom and the Nordstream gas pipelines. Following the Russian invasion of Ukraine, however, Wintershall has exited Russia (Waldersee et al., 2023).

Table 2
Concepts and ideas central to the circular carbon imaginary with a basic explanation of their use and meanings.

Concepts and ideas	Basic explanation
Carbon Capture and Storage (CCS)	Different processes and ways in which carbon dioxide emissions are collected and processed to be stored long-term so as not to leak into the atmosphere.
Carbon Capture and Utilisation (CCU)	Refers to similar processes as CCS but instead of storing the carbon dioxide, it is used to produce carbon-containing products, such as fuels, chemicals, and plastic.
(Carbon) feedstocks	Different sources from which carbon can be taken and be put into use.
Chemical recycling	Recycling when molecular structures are being changed, using chemical reactions, rather than only relying on mechanical recycling in which the molecular structure of the materials are being maintained.
Molecular circularity	The focus of circularity is put on how different molecules (here notably carbon) are being used and re-used, rather than materials or fuels.
Direct Air Capture (DAC)	While CCS and CCU most often refers to processes in which carbon dioxide is captured from point sources, such as industrial facilities and power plants, DAC refers to processes in which carbon dioxide is instead captured from the air.
Carbon farming	Agricultural methods that increase the soil's uptake and storage of carbon.
Negative emissions	Processes by which more carbon is used and stored than released to the atmosphere. The storage is most often assumed to be long-term, but not always.
Carbon flows	Different ways in which carbon is reacting with other molecules, thus being transformed into different types of molecules, structures, and materials. Also refers to different ways in which carbon is sourced, used, emitted, and captured.

terms and concepts. While most of them are discussed in detail below, a summary explanation of the meanings, in lay terms, of the most central concepts is presented here.

4.1. Circular and diversified carbon flows

In the circular carbon imaginary, carbon is quintessential. It is "the atom of life, of our societies and economies" (European Commission, 2021b, p.1). Circular carbon so extends the notion of circularity to a molecular level: "Circularity can extend material boundaries [and] drive higher level of molecular circularity within [the chemical system]" (Systemiq, 2022, p.59). The imaginary entails visions of carbon flows as part of an effectively closed-loop system in which carbon from different sources is continuously circulated. The cyclical nature of carbon in the environment is represented as replicable by human-made systems and technologies where carbon flows through several spheres where it can be sourced or stored depending on the purpose. Technologies that relate to these flows are chemical recycling, carbon capture and utilisation with the subsequent production of hydrogen as well as carbon capture and storage. Negative emission technologies such as direct air capture, carbon farming and bio-energy carbon capture and storage are also included. It is imagined that increasing the loops and circles of the production system has the potential to create a chemical industry delinked from fossil carbon emissions. In making use of different carbon flows, spheres and technologies, the circular carbon imaginary presents carbon circularity as a core organising principle for a climate neutral society. The current lack of circularity of carbon and plastics is thus implicitly seen as damaging the industry's legitimacy and challenging the prospects of the sector.

Three different sources of carbon are typically referenced in the imaginary; solid (plastic) waste, biomass, and point-source or atmospheric carbon dioxide (see Cefic's representation in Fig. 1). Solid and plastic waste can be recycled via both mechanical and chemical routes. The imaginary envisions that an extensive increase in recycling can turn waste and pollution into carbon-based resources. However, recycling cannot do it all. There is still a need for "[fresh carbon] to feed the growth of the chemical industry and to compensate for inevitable recycling losses", as noted by a Shell researcher in an academic paper on circular carbon (Lange, 2021, p. 4358). In the short term, an expansion of the biogenic carbon feedstock is expected, but in the longer term, additional sourcing of carbon would be provided from industrial point sources or the atmosphere (via direct air capture). Such circularity principles with diversified carbon sources are presented as the solution to scarcity and biodiversity issues common to the bioeconomy. The circular carbon economy is thus framed as a part of implementing the circular economy while reducing emissions; circular carbon is "*required* for [the petrochemical industry] to continue serving humanity while responding to the challenges [associated with the energy transition, reducing greenhouse gas emissions and waste streams]" (Lange, 2021, p. 4359, own emphasis). Some actors build directly on circular economy discourse. The Saudi Arabian climate policy, called "Circular Carbon Economy" (Shehri et al., 2022), references principles at the heart of many conceptualisations of the circular economy such as *reduce*, *reuse*, and *recycle* (while adding *remove*).[4] However, these terms take a new and specific meaning in reference to carbon and greenhouse gases in what is labelled the "4 R" taxonomy (Kingdom of Saudi Arabia, 2021). Naturalising negative emissions, *recycle* includes converting carbon dioxide emissions into new and different products while *remove* somewhat ambiguously refers to the removal of emissions from the system through either carbon storage or re-utilisation for other purposes (Kingdom of Saudi Arabia, 2021).

(Re)classifying carbon sources is characteristic of the different iterations of mitigation strategies tied to the circular carbon imaginary. Beyond the distinction between biogenic and fossil (European Commission, 2021b), carbon is divided into living, durable and fugitive (McDonough, 2016), renewable and fossil (Renewable Carbon Initiative, 2022), and gaseous and solid carbon (Systemiq, 2022). In general, carbon is depicted as flowing through several interlinked spheres where it can be sourced or stored depending on the purpose. While there is some difference between genres and actors here, one attempt at distinguishing the undesired carbon from the desired carbon is to label it according to where it has been sourced. In Unilever's climate action plan, the terms *recycled* and *renewable* carbon are used to distinguish between carbon from the technosphere and the biosphere (Unilever, 2022). These different sources are given colours and put together into a carbon rainbow to illustrate the diverse flows of carbon imagined (see Fig. 2). In versions of the imaginary where fossil carbon is included as one of many carbon sources, such as the Saudi Arabian state-backed King Abdullah Petroleum Studies and Research Center (KARPSARC, 2020), they break with the common dichotomy between biogenic and fossil carbon. Instead, *living* carbon flows in the biological cycle, such as cultivated or grown biomass. *Durable* carbon on the other hand is solid carbon in the form of plastics, coal, limestone, fibre, and wood, hence clustering biogenic and fossil carbon under the same umbrella. *Fugitive* carbon is that carbon which "has ended up somewhere unwanted", referencing carbon dioxide from burning fossil fuels and plastic in the ocean (McDonough, 2016, p.351).

4.2. Framing the climate crisis as carbon mismanagement

The circular carbon imaginary centres around managed circular carbon flows. Assuming the manageability of such flows and the feasibility of closing them and ensuring circularity provides actors with a malleable discursive solution for a host of problems including climate change and biodiversity loss (European Commission, 2021c). As such, the circular carbon imaginary is able to promise to provide for a

[4] These terms are associated with the waste hierarchy and included in, e.g., the European waste framework directive.

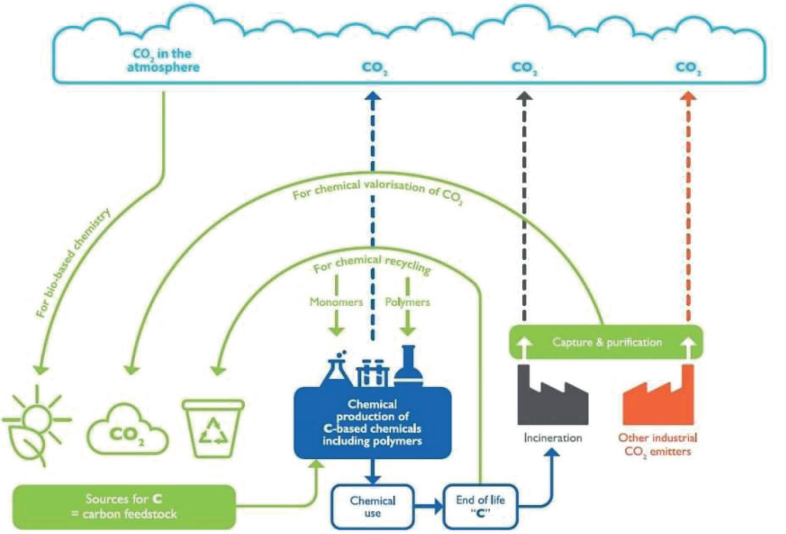

Fig. 1. Cefic's "Circular Carbon" emphasises different sources of carbon feedstock namely "nature", "plastic waste", and "industry". Source: Cefic (2023).

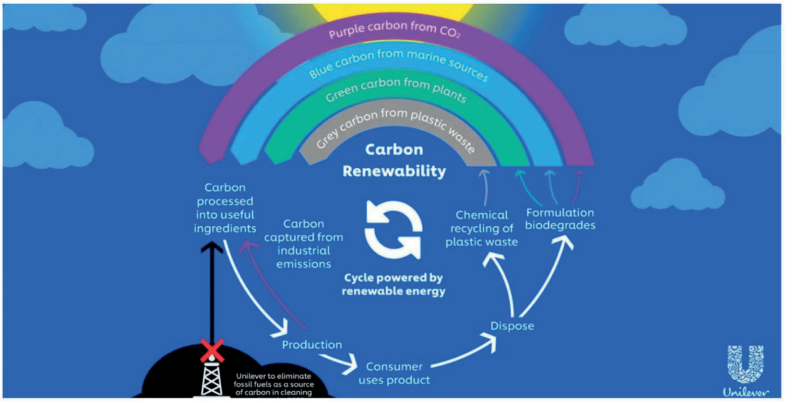

Fig. 2. Unilever's "Carbon Rainbow", portraying different stages of a chemical system based on various forms of circular carbon. Source: Unilever (2022).

presumed lasting and increasing need for carbon feedstock for the production of chemicals and synthetic materials. By promising to properly manage carbon, the circular carbon economy even appears to provide a more reliable carbon source than the current linear, fossil-based system. This is emphasised in different ways through statements that are premised on the desirability of certain lifestyles. In their promotion of circular carbon cleaning and laundry products, Unilever associate a clean home with a desirable home and a sustainable planet and future (Unilever, 2022) while Neste promotes circular carbon as enabling continued flying through sustainable fuels (Neste, 2021). This appearance undermines claims that question the sustainability and desirability of such behaviour and consumption patterns and promotes a society in which demands, wants, and needs cannot, and will not, be changed. Thus, industrial and technological changes are instead required, suggesting the appropriateness of circular carbon.

Using the term 'decarbonisation' to denote a mitigation strategy is problematised and explicitly discussed in several framings. Since carbon is the basic building block of most chemicals, decarbonisation strategies

typically include different forms of recycling, electrification and material efficiency (Kloo et al., Under review), but cannot include removing carbon from the process. Some actors understand decarbonisation as removing carbon from a system regardless of its origin or environmental impact. Therefore, decarbonisation is portrayed as a risky discourse for the chemical industry since it supposedly obscures our dependence on carbon in modern society. The Renewable Carbon Initiative suggests a reframing of carbon neutrality and how it is to be achieved. They suggest that such a process should be called *defossilization* – emphasising diminishing dependence on fossil fuels but with a maintained dependence on carbon: "CO_2 is not at the core of the climate problem [instead] additional [fossil carbon is the] core issue" (2022, p. 4). Given this reframing, carbon becomes essential to solving the climate crisis and is no longer seen as a problem. The problem is instead the mismanagement and potential misconstruction of carbon. Consequently, they argue for better management of the carbon flows in today's society where "carbon is and will remain at the very heart" of the industry (Cefic, 2022b, p.1). Carbon neutrality, facilitated through the circular carbon economy, is thereby cast as a logical response – as proper management.

The imaginary depoliticises climate action by rendering different forms of carbon equivalent (Carton et al., 2021) and by positioning them all as feedstock, thus turning carbon flows into a management issue. Rather than pushing for the restructuring of material and end-use flows, the circular carbon economy builds on ideas of expanding extraction from the geosphere to other spheres, especially the atmosphere, and connecting these spheres through the circular movements of carbon. This form of carbon centrism turns the appropriate response to socio-ecological crises into an accounting exercise based on the equivalence of different carbon flows. This perspective not only sidelines other socio-ecological consequences of fossil fuel extraction and the production of chemicals, such as the consequences for the health of humans and non-humans (Carney Almroth et al., 2022), but instils a notion of control (Stirling, 2019) and thereby comfort in suggesting that all we are really confronted with is the need to end the mismanagement of carbon.

4.3. Fitting different innovation and political regimes

The malleability of the circular carbon imaginary allows for different representations of where energy is sourced from and whether there is a need for a final phasing out of fossil feedstock. Across think tanks, research institutes, official state communication and major companies, Saudi Arabian-based actors mention or emphasise the need for carbon capture and storage in a circular carbon economy (Aramco, 2023; KARPSARC, 2020; Kingdom of Saudi Arabia, 2021; SABIC, 2022) and there is a strong orientation towards the continued exploration and utilization of fossil fuels (G20, 2020). For other actors, typically the ones focusing on the European political context or with core businesses other than fossil fuel extraction, carbon capture and storage is not to be associated with circular carbon (Renewable Carbon Initiative, 2022). To these actors, carbon capture and utilization constitute the main and desired form of carbon capture, promising a way to *escape* unsustainable fossil carbon. However, the storage of carbon dioxide is not completely absent in the European context. The European Commission acknowledges carbon dioxide storage as relevant to "restoring sustainable carbon cycles" (European Commission, 2021a).

The versions of the circular carbon economy that are promoted by different actors are tied to their respective material interests and how they aim to future-proof their position in the energy-chemicals-plastics value chain. In the context of European policy, Cefic centres competitiveness concerns in their communication to the European Commission (compared to other larger and fast-growing markets such as Asia and the US) (Cefic, 2019), positioning a decreasing European share of a global chemicals market as a threat. This framing ties into the long-standing strategy of invoking arguments related to international competitiveness to water down climate policy (Sato et al., 2022; Wood et al., 2020). Furthermore, a larger role is given to biomass, nature-based solutions, and escaping reliance on imported fossil feedstock. This fits the European political and innovation regimes better with their orientation towards biotechnological innovation since the 2000 s (Bauer, 2018; Levidow et al., 2012).

In contrast, actors in the Saudi Arabian context connect the imaginary to wider efforts of keeping the world "hooked on oil" (Tabuchi, 2022). This includes lobbying, think tank operations, research funding, and diplomatic efforts. As one of the largest oil exporters in the world, the Saudi Arabian state is highly dependent on oil. More than 40% of GDP comes from oil rents (Van de Graaf and Verbruggen, 2015), and they have integrated ownership of fossil fuel, chemical and plastic producers (Bauer et al., 2023a). Associated actors therefore do not promote a version of the circular carbon imaginary that explicitly denounces fossil fuels as energy carriers and feedstocks. This fit is explicitly recognised. As underlined by Saudi-affiliated researchers in the prominent academic journal Climate Policy: "Targeting emissions from fossil fuels rather than fossil fuel use itself, [circular carbon economy] offers an approach which can potentially align the interests of fossil fuel producers with more climate-friendly futures" (Shehri et al., 2022, p.14). In line with Saudi Arabia's Circular Carbon Economy (CCE) National Program (see Section 4.1), this quote suggests a differentiation between emissions from fossil fuels and fossil fuel use. The inevitable carbon dioxide emissions caused by burning fossil fuels are to be seen as a resource for the carbon-based materials and chemicals needed in a low-carbon future. Using fossil fuels thereby becomes a way to provide necessary carbon feedstock, and not a climate destructive activity. This mitigation strategy is also actively promoted in the context of UNFCCC and G20, with the Saudi government explicitly stating a strategic ambition to "accelerate global adoption of the CCE program" (Alissa, 2022).

Illustrating a fit with the innovation regime, actors speaking to the Saudi Arabian context have framed circular carbon around existing technological capacities. More specifically, the Saudi Arabian Nationally Determined Contribution under the UNFCCC frames circular carbon as having its genesis in the Saudi Arabian petrochemical industry. Describing utilization of by-products from oil production as making use of "waste gases" (Kingdom of Saudi Arabia, 2021, p. 10), circular carbon is presented as a continuation of rather than a break from the development of the Saudi oil economy – as a natural extension of creating products from unutilized streams and flows in integrated petrochemical clusters. The circular carbon economy thereby builds on the chemical engineering knowledge base shared by the petroleum and chemical industries (Bennett, 2007; Rosenberg, 2000). The notion of continuation casts the Saudi hydrocarbon business as capable, willing, and in control of lowering mismanaged carbon, asking the rhetorical question: if the challenge of fugitive carbon is a management issue, who better manages carbon, than the ones with a historical track record of successfully doing so?

5. A circular distraction. The circular carbon imaginary as a promoter of mitigation deterrence

5.1. Framing out short-term and low-risk mitigation pathways

The circular carbon imaginary promotes mitigation deterrence by framing out near-term mitigation strategies that focus on reducing total material use. In contrast to reducing use, the circular carbon imaginary is underpinned by expectations of increased plastics and chemical production. Even when the circular carbon imaginary is represented as an expansion of the circular economy, key aspects such as prevention and reduction or reuse of materials are not included. Various industry actors

justify the prospect of increasing production through an appeal to the desirability and inevitability of "modern" life in which plastics and chemicals play a decisive role[5] (Tilsted et al., 2022) and by invoking notions of distributive social justice. As put by a manager from the leading plastic trade association in Europe: "There is a strong growth of the middle class in the world, that middle class is growing on the benefits that plastics [have] to offer (…). We cannot deprive society from the benefits of plastics" (Plastics Europe, 2022). This form of rhetoric is strikingly similar to how actors in the oil and gas industry have appealed to notions of justice and the existence of energy poverty to uphold the righteousness and sensibility of their position (Lamb et al., 2020; Supran and Oreskes, 2021). In terms of climate mitigation, the application of plastics is in itself presented as a strategy for lowering emissions. To make this argument, various industry actors generalize the overall importance of plastics and chemicals for mitigation on the basis of certain applications. "Plastics is the most carbon efficient material [and] the more plastics that are used in a variety of applications, the lower the carbon footprint will be", the corporate Alliance to End Plastic Waste (2022) posits. Common examples count the use of plastics for mobility, food, and energy purposes, suggesting that plastics lower the climate impact via substituting heavier materials in vehicles, via food packaging that reduces food waste, and via enabling the production and infrastructure of renewable energy (see also Tilsted et al., 2022). Shifting the focus from the climate impact of chemicals and plastics to the benefits they can provide in other parts of society establishes a narrative in which more plastics are needed to lower the societal climate impact. Or as summarised by the Alliance to End Plastic Waste, "demand is there because there are opportunities to do better with plastics" (2022). This narrative – that industry actors help realize emission reductions and decarbonisation – legitimizes existing production processes and thereby renders low-tech or near-term mitigation strategies built around reduced use and material efficiency irrelevant (Tilsted et al., 2022).

Insofar as the circular carbon imaginary successfully reduces and delays low-risk mitigation efforts that do not rely on technological promises and technologies not (yet) deployed at scale, mitigation deterrence can arise. Underexplored low-tech and low-investment options that can be performed without the risk associated with relying on extensive research and innovation include reuse practices, policies, and increased recyclability via substitution to other materials, monomaterials, or fewer materials (Bauer et al., 2022). From a precautionary perspective, civil society actors and environmental movements question why the industry does not explore less energy-intensive pathways that do not rely on high-tech and high-investment options such as carbon capture and utilization and call for a diversified mitigation strategy, or at least a "plan b" (Zero Waste Europe, 2022). They criticise chemical recycling, a dominant technology within the circular carbon imaginary envisioned to "intensify carbon circularity" (Cefic, 2022b), for its high energy and emission intensity and refer to it as an alternative form of incineration (Hamilton, 2022; Singla and Wardle, 2022), instead they call for other visions of circularity inspired by the logic of the waste hierarchy. Plastics Recyclers Europe (2022), for example, advocate two main strategies. First, a design for recycling plastic products where "chemicals and additives that hinder recycling are kicked out". Second, "stop[ing] incineration of plastics" to push the waste stream from energy recovery to material recycling (2022). A circular carbon economy overlooks these options and instead promises technological strategies that provide simplicity and compatibility with current ways of life and industrial organisation in the Global North. When confronted with these underexplored mitigation strategies, the industry pushes the responsibility to enhance recyclability and recycling towards policymakers and consumers. Corporate actors then blame policymakers for not creating policies that are strict or robust enough to enable increased recycling and consumers for not behaving ethically and being educated as to the benefits plastics have to offer: "We as consumers and inhabitants of planet earth have a responsibility. How do we behave? And what products do we favour in the supermarket?" (BASF, 2022).

Mitigation deterrence of types 1 and 3, i.e., material promises that fail to materialize and immaterial promises that delay mitigation (McLaren, 2020), can lead to not only unabated greenhouse gas emissions but also further accumulation of plastics in the environment. This accumulation is tied to the extent to which "circularity" can be achieved. If various forms of recycling do not materialise on the promised scale or if the full scale of losses and leakages of plastics throughout their lifecycle into the environment are not accounted for[6] (Brown et al., 2023; Ryberg et al., 2019), while production volumes keep increasing, plastic pollution is exacerbated. If carbon capture, utilisation and storage technologies are not employed or effective at scale to abate emissions from fossil feedstock and the incineration of plastics, landfilling of plastic products can function as an alternative form of carbon sequestration (Meng et al., 2023). Insofar as the circular carbon imaginary frames out reduced production and use as a pathway for climate neutrality, we can thus talk of deterrence of both climate mitigation and reduction of plastic pollution and an associated trade-off between landfilling and incineration. Because circular carbon is a solution frame that has the potential to encompass both the climate and the plastic crises, promising a double dividend, circular carbon also risks double deterrence.

5.2. Normalising carbon dioxide emissions and largely unproven technologies

Reframing decarbonisation into an operation of carbon management and climate change as a waste management issue normalises the "production" of carbon dioxide. In this framing, releasing carbon dioxide into the atmosphere is analogous to dumping plastics in a landfill – a form of "skyfill".[7] The managerial framing casts emissions of greenhouse gases as part of a bigger system, where they need to be continuously managed as opposed to eliminated. The imaginary establishes equivalence between different sources or flows of carbon – be it from carbon capture and utilization, biomass, or chemical recycling – in a configuration that naturalises carbon dioxide (Buck, 2020). Carbon emissions released into the air have simply ended up in "an unwanted place" (McDonough, 2016), i.e., in an unsustainable carbon cycle (European Commission, 2021b), and negative emission technologies can be thought of in the same overall framework as natural sinks (see also Section 4.1). To handle such mismanagement of carbon, then, the circular carbon economy requires a waste management system, a parallel system instead of the transformation of existing ones (Buck, 2020). And in so doing, the circular carbon imaginary naturalises and normalises largely unproven technologies.

The risks associated with circular carbon become apparent when considering the constraints and trade-offs that each imagined flow of carbon (be it gaseous or solid) is subject to. In terms of carbon captured from the air or point sources, the viability of direct air capture and carbon capture and utilisation technologies is uncertain. If they were to be developed and implemented, they would require enormous amounts of energy and resources (Palm et al., 2016; Realmonte et al., 2019), and the economic costs are likely to be high (Meng et al., 2023). For example, Kätelhön et al. (2019) model the chemicals industry in 2030 and finds that full deployment of carbon capture and utilization would

[5] Underpinned by statements like "plastics is a fantastic material" (BASF, 2022) and "chemistry provides the solutions that we use in the world today" (Cefic, 2019, p.39).

[6] In the material analysed for this paper, most actors avoid the issue of leakage of plastics and energy losses associated with the proposed circular carbon strategies (e.g., Cefic, 2019; Neste, 2021).

[7] Authors' notes, Europe Chemicals and Polymers Conference, September 2021.

require almost all or more than half of the expected world electricity production. The lower estimate, which is to be considered very high, relies on technologies that are the furthest away from commercialisation. These electricity requirements arise from the amount of hydrogen produced via electrolysis that is needed, conditioning emission reductions on large-scale deployment of renewables. But even so, the low technological readiness and varying degree of storage time for chemicals made via carbon capture and utilization give rise to concerns over the greenhouse gas emission reduction potential of this technology[8] (de Kleijne et al., 2022). For carbon sequestration, the constraints and risks are well-mapped in the mitigation deterrence literature (Carton et al., 2023). Concerning solid forms of carbon, bio-based feedstocks are limited and subject to competing claims. As research related to mitigation deterrence has shown, emission pathways relying on large-scale bioenergy with carbon capture and storage imply enormous land use (Dooley et al., 2018) and are associated with unjust appropriation of land (Bluwstein and Cavanagh, 2023). The dominant focus within mainstream approaches to circularity, plastics recycling, is also limited. The laws of thermodynamics dictate degrading material quality (Cullen, 2017) and the complexity of collection and sorting as well as the difficulties of recycling a range of different types of plastics (Bauer et al., 2022) limit the feasibility of this approach, as do socio-economic constraints (Sicotte and Seamon, 2021).

Considering the different flows of carbon in relation to each other with an aim of climate neutrality "sets up an explicit trade-off between bio-based products, recycling, [carbon capture and storage], and demand reduction" (Meng et al., 2023, p. 8). Thus, in theory (or at least in modelling exercises), each suggested flow of carbon in the circular carbon imaginary (be it bio-based, solid, or gaseous) can be substituted by demand reduction, which reduces the need for carbon. However, this suggested substitutability goes in both directions. If it is possible to enhance the circularity of (increasing) carbon flows, there is no need to reduce production and use. To render demand reductions redundant, the imaginary must largely ignore the constraints and risks associated with normalising carbon emissions and circular carbon technologies (such as problem shifting from increased land use or leakage in the form of micro- and nanoplastics). The appeal of circular carbon strategies therefore relies on framing effects similar to those of negative emission technologies (cf. Markusson et al., 2022), namely certainty, rationality, substitutability, and boundedness. Such framing effects imply that the strategies to achieve carbon circularity can be planned in a rational manner with high certainty and no political and social contestation, substituting for demand reductions. At the same time, the waste management framing casts carbon emissions as a public responsibility (Buck, 2020). The circular carbon imaginary thus presents a high-risk technological pathway, that outsources parts of the responsibility for credible, effective, and appropriate flows of carbon as well as the consequences of mismanaged carbon to state and governmental actors.

5.3. The carbon management regime: Changing the system to fit the industry

In encapsulating understandings of how the world works, ideas of social order and power relations are implicit in imaginaries (Jessop, 2010). In the circular carbon imaginary, corporate "carbon managers" are central actors, while governments are given the role of facilitating carbon markets. This social order assigns certain key responsibilities to state and governmental actors. In a world of carbon management, tight control of the integrity of claims will be necessary to avoid double counting, greenwashing, and the like. The delegation of responsibility for carbon flows to private carbon managers evokes ethical concerns over the durability of carbon storage and the credibility of their claims similar to concerns over the integrity of carbon offsets or the safety of permanent nuclear waste storage (Birkholzer et al., 2012; Carton et al., 2021). Implying a future in which carbon flows are guided by market forces, the carbon management framing paves the way for a "new, ethereal frontier of capital accumulation" (Malm and Carton, 2021, p.3). Ultimately, the circular carbon imaginary asks the state to design the world in line with the demands of the petrochemicals sector, so it can reinvent itself as the carbon management industry. From this standpoint, industry actors can claim that they are not only ready for a transition but are indeed well underway (Tilsted et al., 2022).

Promoters of carbon circularity often call for policymakers and regulators to create the conditions for corporate actors. Given the scale of the challenge, industry actors call for policy to enable and support the petrochemical sector's transition. Such policies include direct funding and subsidies for research, development, and demonstration as well as selectively calling for market creation, certification schemes and accommodating infrastructure. For example, concerned with economic competitiveness, the European chemicals industry federation Cefic (2019) emphasizes a need for global net zero standards and market-based frameworks to enable a level playing field on the global scale. Concerning the many classifications of carbon sources, policymakers are encouraged to create comprehensive and supportive framework conditions. Such provisions include redefining non-fossil carbon via certification schemes, allowing companies to selectively market a share of their products as 100 per cent circular-based (the so-called mass-balance approach) and defining and ensuring sustainable biomass (Systemiq, 2022). In terms of infrastructural developments, corporate actors request the construction of facilities for carbon capture, transport, and use as well as the development of renewable energy. If climate policy does not recognise the importance and potential of carbon management, then such policy is portrayed as at risk of being misplaced. Industry actors may be positioned to develop and scale technologies but they are restricted by the willingness of policymakers. Or as expressed by an employee at one of the largest chemical producers in the world: "Now we just need the policy conditions to make it go even faster" (BASF, 2022).

The question of social order relates to how technological promises in the circular carbon imaginary aims at carbon neutrality on a societal level. The circular carbon economy rests on a whole system of interlinked technologies including carbon capture and utilization and direct air capture, which not only need to be technologically mature and operable by themselves but also integrated into a larger system. The risk of either some of these technologies or their systemic integration falling short is largely neglected in the imaginary, as is the energy and labour demand, as well as the necessary infrastructures and institutional innovations necessary to facilitate a circular carbon economy. This is despite actors positing that the circular carbon economy would be the biggest industrial transformation since the industrial revolution. As noted by the Shell researcher also cited earlier in the paper, "the transition from fossil to recycled and renewable carbon as feedstock for chemicals is likely to take most of the 21st century" (Lange, 2021, p. 4372).

Taken together, the circular carbon imaginary suggests that a low-emission chemical industry is possible only in the hands of incumbents if subsidised and supported by public actors in ways that enable capital accumulation while advocating a transition that purportedly links the bio-, geo-, techno- and atmosphere neglecting issues of feasibility and potential risks raised by this proposition. But to address such concerns, the imaginary offers simply one tautological solution: improving carbon management.

[8] The concerns highlighted here should not be considered exhaustive. For instance, there is a risk of hydrogen leakage (which has a significant global warming potential) (Sand et al., 2023), and concerns related to the water footprint of hydrogen (Grubert, 2023). These examples highlighting the possibility of type 2 mitigation deterrence, i.e., indirect rebound effects from pursuing circular carbon strategies.

6. Conclusion

The circular carbon economy is an emergent imaginary competing with other approaches to address the multiple crises that the petrochemicals industry is embedded in. The imaginary adopts diversification as a decarbonisation strategy to justify the continuation of the fossil energy order. It departs from a circular vision but moves the concept to a molecular level by emphasising carbon circularity. By doing so it largely fails to answer the multiple environmental and sustainability issues the current chemical and plastic system is confronted with. Instead, the circular carbon economy is communicated as a mitigation strategy for the petrochemical industry to survive and stay relevant by neglecting uncertainty and relying on technological promises with risk of failure. The imaginary presents a net-zero future with increased petrochemical production where circular carbon flows enable an economy where nothing needs to be lost.

In this paper, we unpack the imaginary and identify three main ways in which the circular carbon imaginary may promote mitigation deterrence. First, the focus on circular carbon shuts out alternative reduction pathways for the sector, in particular those focused on reducing production and throughput. Second, by shifting the frame from fossil fuels to carbon mismanagement, the circular carbon imaginary depoliticises climate action by suggesting control and bracketing crucial risks around feasibility, energy demand and the integrity of carbon removal claims. Finally, by reinventing the petrochemical industry as the carbon management sector, the imaginary really represents a world designed for petrochemicals rather than the other way around. Thus, the circular carbon economy is portrayed as good climate action neglecting the risks of failing to deliver on such a promise.

The circular carbon imaginary so works as a spatio-temporal fix that seeks to future-proof actors along the fossil fuel-chemicals-plastics value chain. In the short and medium term, this fix does not hinge on the large-scale material realisation of a circular carbon economy, allowing for both continued emissions and further accumulation of petrochemicals and plastics. The circular carbon imaginary thereby promotes not only mitigation deterrence but also deters from reduction in plastic use and consumption. In representing a two-fold fix to dual crises, circular carbon goes beyond mitigation deterrence when framed as a legitimate answer to calls for transformative change.

In putting this argument forward, we do not consider the notion of circular carbon as one-sidedly problematic. Neither do we think that all efforts that have been categorized under the umbrella of the circular carbon imaginary are per se undesirable. Rather, we want to stress that the various technologies and interventions associated with circular carbon come with a range of trade-offs, constraints and risks that limit their availability, feasibility, and supply. And to highlight the numerous drawbacks associated with the circular carbon imaginary uncovered in the broader literature on carbon dioxide removal (Anderson and Peters, 2016; Dooley et al., 2018; Fuss et al., 2018). Thus, presenting a circular carbon economy as an all-encompassing solution that can operate without short-term or low-tech pathways is deeply problematic.

When confronted with demands to keep carbon circular, this paper points out several issues that policymakers should be aware of concerning the implicit risks and the highly political nature of the imaginary. The main risks pertaining to the circular carbon imaginary concern the reliance on whole systems of largely unproven technologies, questions over the feasibility of closing carbon cycles, concerns over the integrity and verification of carbon removal claims, as well as adverse side effects associated with the energy provision and infrastructural demand necessary to keep carbon in the loop. While this paper has focussed on the role of representation (discourse) of the imaginary in promoting mitigation deterrence, other aspects of the imaginary and how it is enacted and inculcated in practices such as investment, lobbying, and modelling are yet to be explored. These practices are key components of the institutional work for pursuing an imaginary that is very much in the making. Understanding these practices better would facilitate more informed decision-making on the circular carbon economy.

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Author statement

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us, where Ellen Palm and Joachim Peter Tilsted share the first authorship.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Appendix

Actor	Year	Title	Genre	Reference
BASF	2022	Implementing the change – challenges and opportunities faced by the plastics industry	Panel discussion with members of Reshaping Plastics Report Steering Committee or Expert Panel, including Martin Jung Member of the Steering Board, Plastics Europe and	https://vimeo.com/761463297

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Actor	Year	Title	Genre	Reference
			President Performance Materials, BASF, at Plastics Europe special show "Plastics shape the future" at K2022, 21 October 2022, Dusseldorf (also available online)	
Borealis	2022	Circular Cascade Model	Picture	https://www.borealiseverminds.com/blog/starting-the-future-positive-plastic-revolution
Cefic	2022	Restoring sustainable carbon cycles	Position paper	https://cefic.org/app/uploads/2022/05/Cefic-position-on-Restoring-sustainable-carbon-cycles.pdf (accessed 27 March 2023)
Cefic	2019	Molecule Managers	Report	https://cefic.org/media-corner/newsroom/molecule-managers-cefic-presents-ambitious-european-way-for-the-eu-chemical-industry/ (accessed 27 March 2023)
Cefic	n.d.	Circular Carbon	Picture	https://cefic.org/a-solution-provider-for-sustainability/circular-carbon/
Cisco	n.d.	Cisco's approach	Picture	https://www.cisco.com/c/en/us/about/circular-economy.html
Covestro	2022	Pioneering a Fully Circular Economy – with climate-neutral plastics	Panel discussion including the CEO Markus Steilemann at the indusrty conference K2022, Covestro live, 19 October 2022, Dusseldorf (also available online)	https://www.youtube.com/watch?v=19QuS1CB2JM
Covestro	2022	Circular Plastics and Net zero by 2050. "Blah, blah, blah?" Part 2: Does the plastics industry have a future in Europe?	Panel discussion including Lynette Chung, Covestro Chief Sustainability Officer, at Plastics Europe special show "Plastics shape the future" at K2022, 21 October 2022, Dusseldorf (also available online)	https://vimeo.com/762198324
European Commission	2021	Sustainable carbon cycles	European Commission Communication	https://climate.ec.europa.eu/system/files/2021–12/com_2021_800_en_0.pdf (accessed 27 March 2023)
European Commission	2021	European Green Deal: Commission proposals to remove, recycle and sustainably store carbon	Press release	https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ip_21_6687/IP_21_6687_EN.pdf doi:10.2777/004098 (accessed 27 March 2023)
European Commission	2021	Sustainable carbon cycles	Factsheet	https://ec.europa.eu/commission/presscorner/detail/en/fs_21_6692 (accessed 27 March 2023)
European Commission	2021	Sustainable carbon cycles for a 2050 climate-neutral EU Technical Assessment	Staff working document	https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=SWD:2021:450:FIN (accessed 27 March 2023)
European Commission (Written by COWI - Nova Institute - Utrecht University)	2021	Carbon economy	Independent expert report	doi:10.2777/004098 (accessed 27 March 2023)
G20	2020	Leaders' Declaration	G20 declaration	http://www.g20.utoronto.ca/2020/G20_Riyadh_Summit_Leaders_Declaration_EN.pdf (accessed 27 March 2023)
IEF - International Energy Forum	2020	The Four R's	Picture	https://www.ief.org/_resources/files/news/analysis-reports/march-ief-insight-brief—the-circular-carbon-economy.pdf
Ikea	2022	This is IKEA	Presentation	No URL
IPInside	2018	A New Vision for Carbon Mitigation	Picture	https://www.ipinside.eu/circular-carbon/
KAPSARC	2020	Fugitive, durable and living carbon	Picture	from pdf: Circular carbon economy guide
KAUST	2020	KAUST Circular Carbon Initiative	Picture	https://issuu.com/kaustbeacon/docs/kaust-fall2020/s/11597578
King Abdullah Petroleum Studies and Research Center (KAPSARC)	2020	00 CCE Guide Overview: A guide to the circular carbon economy (CCE)	Report	https://www.cceguide.org/wp-content/uploads/2020/08/00-CCE-Guide-Overview.pdf (accessed 27 March 2023)

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Actor	Year	Title	Genre	Reference
King Abdullah Petroleum Studies and Research Center (KAPSARC) & Institute of Energy Economics (IEEJ), Japan	2021	Toward net-zero emission pathways using the circular carbon economy framework	Agenda for Cop27 side event	https://seors.unfccc.int/applications/seors/attachments/get_attachment?code=JB4R00GML5PPNE1R7E1KJJ1KKQOZTMV (accessed 27 March 2023)
Kingdom of Saudi Arabia	2021	Updated First Nationally Determined Contribution	NDC submitted to UNFCCC	https://unfccc.int/sites/default/files/resource/202203111154-KSA%20NDC%202021.pdf (accessed 27 March 2023)
Kingdom of Saudi Arabia	2022	Fourth National Communication Kingdom of Saudi Arabia	National communication (NC4) submitted to UNFCCC	https://www4.unfccc.int/sites/SubmissionsStaging/NationalReports/Documents/7123846_Saudi%20Arabia-NC4–1-Fourth%20National%20Communication%20NC4%20Kingdom%20of%20Saudi%20Arabia%20March%202022.pdf (accessed 27 March 2023)
Naif B. Alqahtani	n.d.	Circular Carbon Economy: Research & Development	Research poster	https://unfccc.int/sites/default/files/resource/RD%20Poster%20T1%20Saudi%20Arabia.pdf
Neste	2023	Sustainable Aviation Fuel (SAF)	webpage	https://www.neste.com/products/all-products/saf/key-benefits
Neste	2023	Plastics revolutionized	webpage	https://www.neste.com/products/all-products/plastics
Neste	2023	Sustainable air travel today	webpage	https://www.neste.com/products/all-products/saf
Neste	2023	Combating climate crisis	webpage	https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjwsuzHiIH-AhU-RfEDHeAOCJEQFnoECBUQAQ&url=https%3A%2F%2Fwww.neste.com%2Fproducts%2Fall-products%2Fplastics%2Fcombating-climate-crisis&usg=AOvVaw0g15CHtC6kV6CSmB2Y09FY
Noura Alissa (Kingdom of Saudi Arabia Ministry of Energy)	2022	Climate Mitigation Policies & the Needs of the Energy Sector – Case Study: KSA and the Circular Carbon Economy	Presentation	https://unfccc.int/sites/default/files/resource/Noura_MENA-AE00901_Day1_Spice_B_2_Panel-1_02_KSA%20and%20Circular%20Carbon%20Economy.pdf
Nova Institute	2022	The Climate Change Mitigation Star: A Sixfold Challenge	infographic	https://renewable-carbon.eu/graphics (accessed 27 March 2023)
Nova Institute	2021	Comprehensive Concept of Circular Economy	Picture	https://renewable-carbon.eu/publications/wp-content/uploads/2021/08/21–08–04-Comprehensive-Concept-of-Circular-Economy-thumbnail.png
Nova Institute/ Renewable Carbon Initiative	2022	Renewable Carbon as a Guiding Principle for Sustainable Carbon Cycles	Report	https://renewable-carbon.eu/news/renewable-carbon-as-a-guiding-principle-for-sustainable-carbon-cycles/ (accessed 27 March 2023)
Nova Institute/ Renewable Carbon Initiative	2022 (June)	Renewable Carbon as a Guiding Principle for Sustainable Carbon Cycles	Presentation/webinar	No URL
Plastics Europe	2022	Circular Plastics and Net zero by 2050. "Blah, blah, blah?" Part 1: Circularity - opportunity or threat?	Panel discussion, including Benny Mermans, Vice President Plastics Europe and Vice President Sustainability, at Plastics Europe special show "Plastics shape the future" at K2022, 21 October 2022, Dusseldorf (also available online) Chevron Phillips Chemicals	https://vimeo.com/762198324
PPHB	2020	Toward Circular Carbon Economy: REUSE	Picture	https://www.pphb.com/musing-from-the-oilpatch/will-hydrogen-play-a-key-role-in-our-energy-future
SABIC	2023	Sabic reaffirms commitment to the circular carbon economy with a target of one million metric tons of	Press release	https://www.sabic.com/en/news/38517-sabic-reaffirms-commitment-to-the-circular-carbon-economy-with-a-target-of-one-million-metric-tons-of-trucircle-solutions-annually-by-2030

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Actor	Year	Title	Genre	Reference
		Trucircle™ solutions annually by 2030		
SABIC	2022	SABIC reaffirms commitment to carbon neutrality at World Economic Forum in Davos	Press release	https://energynorthern.com/2022/05/25/sabic-reaffirms-commitment-to-carbon-neutrality-at-world-economic-forum-in-davos/
Sunil Kokal (Journal of Petroleum Technology)	2022	Circular Carbon Economy—A Pathway To Reduce Our Carbon Footprint	Picture	https://jpt.spe.org/circular-carbon-economy-a-pathway-to-reduce-our-carbon-footprint
Systemiq	2022	Planet Positive Chemicals	Report	https://www.systemiq.earth/systems/circular-materials/planet-positive-chemicals/#report
The Economist	2021	The Circular Carbon Economy: Managing carbon holistically	Video/Facebook Watch	https://m.facebook.com/EconomistEvents/videos/there-is-a-renewed-resolve-among-manufacturers-to-focus-on-circular-approaches-r/242434024107082/
Unilever	2023	Using our voice for a zero carbon future	webpage	https://www.unilever.com/planet-and-society/climate-action/using-our-voice-for-a-zero-carbon-future/
Unilever	2023	Climate action	webpage	https://www.unilever.com/planet-and-society/climate-action/
Unilever	2021	Unilever Climate Transition Action Plan	Report/Statement Brief	https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjy5Zarh4H-AhW2VvEDHX-tCBUQFnoECAoQAQ&url=https%3A%2F%2Fwww.unilever.com%2FImages%2Funilever-climate-transition-action-plan-19032021_tcm244–560179_en.pdf&usg=AOvVaw0AJQ4OJWq4Bu8kFGozaYOB
William McDonough	2021	circular carbon economy - design for the regenerative biosphere and circular technosphere	Picture	https://mcdonough.com/william-mcdonough-helps-articulate-circular-carbon-economy-framework/
William McDonough	2017	Cradle to Cradle, the Circular Economy, and the New Language of Carbon video	Picture	https://www.buildingcentre.co.uk/news/articles/william-mcdonough-cradle-to-cradle-the-circular-economy-and-the-new-language-of-carbon-video

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Paper V

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Perspective

Ending fossil-based growth: Confronting the political economy of petrochemical plastics

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SUMMARY

The expanding petrochemical industry depends on fossil fuels both as feedstock and a source of energy and is at the heart of the intertwined global crises relating to plastics, climate, and toxic emissions. Addressing these crises requires uprooting the deep-seated lock-ins that sustain petrochemical plastics. This perspective identifies lock-ins that stand in the way of ambitious emission reductions and ending plastic pollution. We emphasize that addressing the growing plastic production and consumption requires confronting the political economy of petrochemicals. We put forward key elements needed to address the dual challenges of moving away from the unsustainable production of plastics and drastically reducing emissions from the petrochemical sector and argue for attention to the links between fossil fuels and plastics, which in turn involves challenging entrenched power structures and vested interests linked to the fossil-based plastics economy. A critical step would be ensuring attention to the production of petrochemicals and related upstream issues in the upcoming global plastics treaty.

INTRODUCTION

Linking together the crises of climate change, plastic pollution, and toxic emissions, the petrochemical industry uses fossil fuels for the production of the molecular building blocks for plastics and other petrochemicals (see Figure 1).[1–3] The production processes have a direct climate impact of around 4% of global greenhouse gas (GHG) emissions,[4] generate 460 Mt of plastics (of which more than 350 Mt end up as plastic waste),[5] and require one-quarter of the Earth's total carrying capacity for their operation.[6] The manufacturing, use, and end-of-life treatment of many petrochemicals are hazardous to humans,[7] ecosystems,[1] and drive biodiversity loss,[8] making petrochemicals a threat to planetary health.[9] As the main product segment for the petrochemical industry, plastics alone are associated with 4.5% of global GHG emissions across their life cycle[2] and have been identified as a principal reason for why the planetary boundary for novel entities is greatly exceeded.[3] Petrochemicals, in short, present an urgent sustainability challenge from the local to the global scale.

Petrochemical production relies on fossil fuels as both feedstock and energy carrier, and the sector therefore has the highest energy demand among the energy-intensive processing industries.[10] The fact that fossil carbon is used not only as fuel but also forms the material basis for petrochemicals also makes a low-carbon reorientation of the industry a unique challenge compared to sectors that use fossil fuels for energy purposes only, such as energy and transport.[11,12] And unlike fossil fuel use for direct energy supply and transportation, petrochemical production is projected to expand significantly, thereby increasing the demand for fossil fuel feedstocks.[13,14] Accordingly, the International Energy Agency points to the prospects of petrochemicals becoming the biggest driver of oil demand growth in this decade.[10,15] To capture opportunities implied by the expectations of increased petrochemical use, leading producers have invested massively in new fossil-based production in recent years.[16]

The growth in petrochemicals is underpinned by a political economy of deep-seated carbon lock-ins and tight connections between the fossil fuel, chemicals, and plastics industries.[16–21] These ties go back to the origin of the industry and are not only material in the form of integrated production facilities but are also institutional, organizational, and economic. Large multinational companies dominating the industry have applied a shared knowledge base to engage in activities ranging from fossil fuel extraction to plastics manufacturing in consolidated global production networks, oftentimes in integrated industrial facilities and clusters,[22–27] and the trend continues to this day. For example, the oil major Saudi Aramco and the chemical giant Dow have, supported by public finance, recently started the joint operation of the Sadara complex, the world's largest petrochemical facility, locking in capital, infrastructure, and organizations in

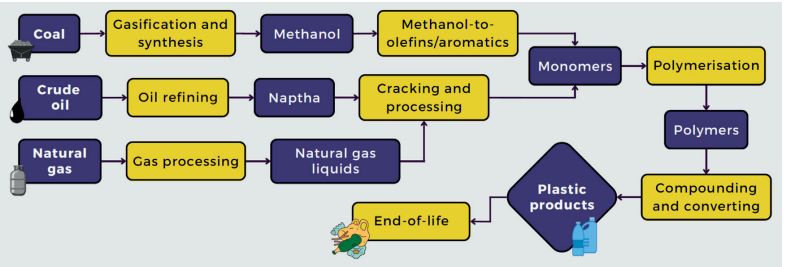

Figure 1. Main production routes from fossil fuels to plastics
Dark blue rectangles represent products/materials and yellow rectangles show processes.

continued fossil dependence for decades.[28] The connections and lock-ins that characterize the petrochemical industry make it of central concern for the global energy transition and the need to phase out fossil fuels.[29–31]

Addressing the full scale of the socio-ecological crises associated with petrochemicals will require significant reductions in virgin petrochemical plastic flows and attention to upstream issues from extraction of fossil fuels to polymer production. In this perspective, we call for and identify possible supply-side interventions to address the overall supply of (virgin) plastics and other petrochemicals as vital complements to plastic pollution reduction strategies focused on waste management and recycling. Limiting supply, however, is not possible without addressing the political economy of petrochemicals and its defining lock-ins, i.e., the technological, institutional, and behavioral phenomena that collectively hinder transformative change. It requires confronting the entrenched power structures and vested interests that support the existing petroleum-chemical-plastic nexus, centering social contestation and struggles for environmental and climate justice in the discussion of petrochemical transitions. Otherwise, effective and just upstream measures that can drive a necessary shift to alternative feedstocks and renewable energy and control the production of (and demand for) primary plastics will not come about.

By exploring the political economy of petrochemicals, mapping out a range of critical lock-ins, and pointing to pathways for transformation and a just transition beyond fossil fuels, this perspective offers a critical intervention coinciding with the negotiations on a new global treaty for plastics and efforts to step up progress toward the Paris Agreement climate goals.

GROWTH OF THE PETROLEUM-CHEMICAL-PLASTIC NEXUS

The chemical industry emerged in Europe in the 19th century, supplying synthetic dyes and other chemicals to the rapidly growing textile industry.[32] In the early 20th century, the German chemical industry was a dominant force, with German firms being the first to commercially produce key chemicals such as ammonia, ethylene, methanol, and vinyl chloride—all from coal.[33] The shift toward oil and gas and the modern petrochemical industry was largely a result of the efforts of the American chemical industry, which saw the growing oil market as a key resource opportunity on which it focused research, development, and education.[34] Supported by strong interventions by the US government, the industry grew rapidly and developed technologies that, in the post-war era, were exported to countries needing to rebuild their industrial infrastructures (Germany, the UK, and Japan), leading to a remarkable shift toward petrochemistry by the early 1960s.[35] Governments all over the world continued supporting the industry as it was a strong contributor to economic growth as demand for its products—not least different plastics—was created, diffused, and inflated. This support took different forms and shapes, from nationalization of parts of the industry after the energy crises of the 1970s, to state-initiated cartels and other forms of subsidies such as tax breaks and access to low-cost investment capital through public financial institutions.[32] Over decades, these developments solidified lock-ins across many domains involving both firms and governments, including research, education, finance, and regulation.[19]

Mirroring expectations of continued economic and population growth, the production of petrochemicals and plastics is projected to expand enormously.[10,14,15] The OECD, for example, expects plastic use to almost triple by 2060 in their recent baseline projection.[13] And growing production implies growing environmental impacts along multiple planetary boundariess.[6,36] Already today, practically all chemical production transgresses planetary boundaries—primarily boundaries related to climate change but also boundaries related to biosphere integrity and ocean acidification.[37] Plastics specifically are central to breaking the planetary boundary of novel entity diffusion in global ecosystems through their widespread pollution,[3] and they also interact with processes impacting multiple other planetary boundaries.[9,38] At the same time, the purported socio-economics benefits of continued growth are being questioned. Recent research points to a global trend of "noxious deindustrialization,"[39] where fenceline communities no longer significantly benefit from the industry in terms of jobs and public services while continuing to be on the receiving end of negative health and environmental impacts, and advocacy organizations and think tanks flag the prospects of stranded assets.[40,41]

Research has explored alternatives to the ongoing growth in global petrochemical production, analyzing the sustainability

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Box 1. The concept of carbon lock-in and different types of lock-in

Path dependence and lock-ins arising from historical choices and events have been recognized in the scholarly literature for a number of decades.[59,60] At the beginning of this millennium, such insights were applied to the specificities of fossil fuel dependence and conceptualized as "carbon lock-in."[61,62] Carbon lock-in captures the idea of how inertia in a range of domains—technology, institutions, and behavior—collectively inhibit systematic transformation. These different forms of lock-in work both separately and interactively, and resistance to change tends to grow as the scale of production increases.

Infrastructural and technological lock-in refers to the lock-ins that arise from the long lifetime of existing physical infrastructure, such as the value loss for capital owners that is associated with the early retirement of fossil assets.[63]

Institutional lock-in concerns the institutional contexts—rules, norms, and constraints—that favor the interests of status quo-oriented actors, emphasizing how events and choices at one point in time are shaped by earlier decisions.[56,64] An example is how subsidies and tax credits for the extraction and processing of fossil fuels propagate through the value chains,[65] benefiting the production of petrochemicals by reducing the total cost for feedstocks and energy.

Lastly, *behavioral lock-in* captures dynamics relating to lifestyles, cultural norms, and associated patterns of consumption. Although historically not a key focus in the lock-in literature, research has emphasized the individual and social mechanisms that lead to the persistence of carbon-intensive behaviors.[56,66] The global diffusion of disposable consumer packaging as well as consumer expectations and marketing related to fast fashion have directly added to the growth in demand for plastics in these domains.

These different types of carbon lock-in can mutually reinforce each other. Lock-in due to existing carbon-intensive infrastructure can, for example, be reinforced through policy and cultural norms. Since its introduction, the lock-in concept has been further expanded with, as with the notion of discursive lock-in, theorizing how discourses establish and legitimize technologies, institutions and behaviors.[67] For example, oil majors have successfully engaged in the discourse on climate change mitigation to individualize responsibility and frame continued use of fossil resources as rational and unavoidable.[68–70]

potential of different types of change to current patterns of production and consumption under various scenarios. These scenarios include carbon capture and utilization or storage, renewable-based feedstocks (i.e., bio- or green hydrogen-based), direct air capture (as source of carbon and to compensate for unabated GHG emissions), improved plastic recycling, and electrification of chemical production processes.[4,36,42,43] Each of these paths, however, comes with a new set of concerns, limiting its feasibility. Particularly, there is a large risk of shifting the burden of environmental impacts to new domains, such as land use change, biodiversity loss, and increasing competition for scarce biomass resources for industrial purposes. For recycling, constraints are also socio-economic and thermodynamic.[44–46] Moreover, these pathways mostly focus on climate change and global boundaries for environmental impact, lending less attention to the consequences of plastic pollution for human and ecological health. Given these concerns, it is for good reason that scenarios that identify pathways toward chemical production within planetary boundaries typically involve a significant reduction of plastic use compared to current demand forecasts.[6,36,47,48]

The centrality of reduced use places issues of growth and distribution at the heart of the discussion on petrochemical plastics. The pursuit of growth, revenue, and profits motivates and structures decisions around investments, lobbying, and public-relations activities[49,50] and shape the actions of industrial and state actors alike.[51,52] While scholars have called for a cap to global plastics production[53] and civil society actors campaign under the slogan of "#turnoffthetap,"[54] incumbents seek to safeguard their investments and ensure future operations and returns, promising sustainable futures mainly through technological solutions.[23] Such promises of technical fixes work both as defences for existing investments, carrying out a system-conserving function, and as attempts to legitimize new avenues for growth in reference to important societal problems.[55] To break carbon lock-in, policy and research must therefore grapple with core issues of political economy, confronting the questions of who benefits and who suffers from which petrochemical futures, challenging the power of vested interests.

KEY LOCK-INS AND BARRIERS

The concept of lock-in captures how "the inertia of technologies, institutions, and behaviors individually and interactively limit the rate of (…) systemic transformations by a path-dependent process"[56] (see Box 1). Lock-ins are, however, not inescapable phenomena that solely occur as unintended side effects of path-dependency, i.e., inevitably shaped and constrained by previous decisions and events; rather, lock-ins are also actively strengthened and deepened through coordinated efforts by actors with interests in so doing.[16,19] The prospects for breaking up existing lock-ins through political interventions thus depend both on the credibility of the long-term direction of an economy-wide transformation away from fossil fuels[57] and the power of short-term interventions to reshape the current investment cycle.[58] This section reviews how different types of lock-ins are found across the petrochemical and plastics value chain.

Infrastructural and technological lock-in

Emblematic for large-scale processing industries such as chemicals and plastics is the reliance on large investments in infrastructure and technology. Such infrastructures include the pipeline systems distributing oil, gas, and their derivatives from extraction sites to oil refineries; steam crackers and downstream processing units; as well as the ports and specialized terminals for the import and export of feedstocks, intermediates, and products like plastics. Petrochemical production facilities are continuously operating assemblages of furnaces, compressors,

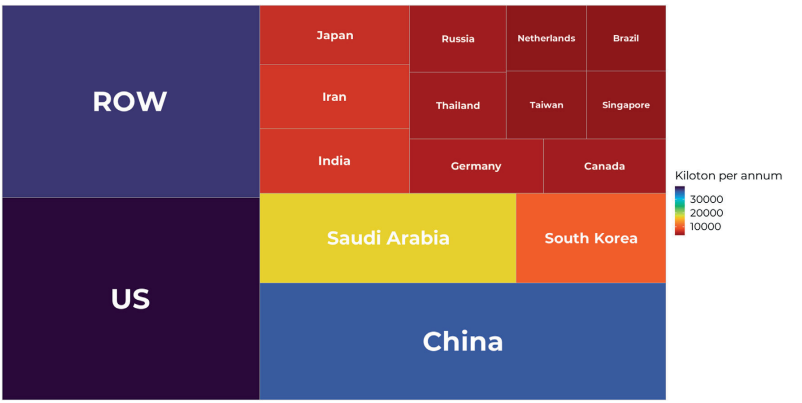

Figure 2. Ethylene production capacity by country in 2020
Source: Data from ICIS Worldwide Ethylene Plant Report 2020[73]

separators, and other units networked in a complex flow of materials often including several different facilities in petrochemical clusters that have grown ever larger over the past decades. Today, such clusters can process many million tonnes of chemicals per year and have become increasingly specialized at using particular fossil feedstocks in production. As production facilities are sensitive to impurities at the level of parts per million, a shift of feedstocks tends to necessitate a significant redesign of existing operations. Taken together, these characteristics mean that petrochemical clusters are subject to a lock-in to fossil-based technologies.[20,21]

Steam crackers—the type of facility that produces ethylene and many other platform chemicals that are subsequently used to produce plastics—are a case in point. Global steam cracker capacity is currently estimated to be around 200 million tons of ethylene per year, with the largest capacities concentrated in just a few countries. The production capacity of USA, China, Saudi Arabia, and South Korea together make up more than half of global ethylene production capacity, as shown in Figure 2. Further, since 2011, global plastic resin production has increased with an annual growth rate of about 3.5%[71] with increases in plastic use outpacing all other commodities.[10] This growth in demand for plastics has spurred a wave of investments in crude-based production in the past decade, focused on maximizing the share of crude oil that is transformed into chemicals and subsequently plastics. In such plants, the share of chemicals exceeds 50% of the yield,[72] breaking with the logic of chemicals simply using a minor, low-value fraction of oil and further contributing to the lock-in to petroleum in the industry.

Investments in existing technologies represent huge sunk costs, which are normally repaid over several decades of operations. These sunk costs mean that where innovation occurs in the petrochemical sector, it typically focuses on incremental process improvements[74] and drop-in solutions rather than transformative change. Opportunities for larger changes in operations and production processes are generally limited to the times when facilities are revamped, which occurs on average every 25 years.[75] In terms of the mid-century climate goals established by COP27, the year 2050 is thus just one investment cycle away in the industry. Steam crackers in China and the Middle East are on average less than 10 years old and will therefore likely continue to operate according to current specifications for many years. In Europe and North America, by contrast, a large share of the petrochemical production facilities are likely to be revamped in the coming decade. Breaking the lock-in will require investments in and focus on implementing near-zero emission technologies and solutions using renewable energy to reduce the use of fossil fuels significantly before 2030, as required to align with scenarios leading to net zero emissions in 2050.[30]

Institutional lock-in

In terms of institutional structures that support carbon lock-in, a key challenge is skewed attention toward the downstream rather than upstream factors driving plastic pollution, which is manifested in the fragmented governance of petrochemicals.[76] In terms of plastics and plastic pollution, governance arrangements have long been focused on "downstream" challenges related to improved waste management and recycling.[77] While there has been a move toward "mid-stream" circular economy strategies focused on the design of products to extend their durability, reuse, repairability, and recyclability,[78] there is still far less policy attention to the "reduce" and "substitute" imperatives of a shift toward greater circularity.[79] Recently, however, as attention to the plastics crisis has become more multi-faceted, instruments regulating price or quantity on the supply side have been gaining attention.[53,54] As for the chemical sector, there is no unified framework at the global level, although several such sectoral frameworks exist. Some international conventions address specific chemicals or groups of chemicals, e.g., the Stockholm Convention addresses persistent organic pollutants.[80] However,

efforts to develop a more comprehensive framework, such as through the Strategic Approach to International Chemicals Management,[81] have been notoriously slow.[82–84] The petrochemical sector has also received little specific attention in the context of efforts to boost climate action. Only in the last year has the chemicals sector come into greater focus in international climate diplomacy with the EU's introduction of carbon border adjustment measures that cover fertilizers and a range of chemicals.[85]

Adding another layer of institutional lock-in, state and domestic industry interests influence developments in the petrochemical industry.[27] Concerns related to job losses, international competitiveness, and cross-border carbon leakage have sheltered the sector from strong energy and climate policies.[86] Coupled with the importance of chemicals to export-oriented growth models, the prioritization of self-sufficiency,[25] and strong state-industry networks,[27] several factors play into the promotion of domestic petrochemical industries by national governments. At the same time, petrochemicals serve as a potential diversification strategy for oil and gas incumbents.[87,88] As traditional sources of demand for oil—and for vehicle fuels in particular—are set to decline, and as demand for plastics continues to rise, chemical manufacturing has increasingly become an attractive option to make up for losses in other markets.[89] For fossil fuel-exporting countries, the prospect of valorizing fossil resources by exporting refined and value-added products instead of raw materials, can be appealing. In a range of Middle Eastern and North African countries in particular, investments in further processing capacity are viewed as a strategy to generate economic growth and development, sustain or increase export revenues, and stimulate employment.[87]

A final key component of the institutional lock-in of carbon-intense industries such as petrochemicals is institutionalized political influence.[56] This influence takes place, particularly through direct access to policymakers, corporatist structures involving industry organizations and trade unions, and public-private co-ownership of carbon-intense companies.[90–93] The geographical concentration of carbon-intense industries plays an important role in this respect: politicians elected in such constituencies often work to promote industry interests and prevent policies detrimental to them.[94] The influence of carbon-intense industries often leads to feedback mechanisms, as they use it to block challengers from low-carbon industries or to obtain preferential treatments such as subsidies, which in turn increases their influence.[95,96] Close ties between carbon-intense industries and policymakers can amount to historical blocs united by shared interests and ideas, which exercise power to maintain their position.[49,97] For example, throughout the 2010s, major UK petrochemical producers worked to increase policymakers' dependence by, amongst other means, facilitating closer ties to key politicians through strategic partnerships. These corporate political strategies were key in opposing and deferring low-carbon reorientation for the industry in times of strengthening climate policy.[98] Likewise, in the early 2010s, a group of emission-intensive companies including petrochemical giants Dow and BASF along with fossil fuel and steel companies lobbied the European Commission to avoid the costs of renewable energy subsidies and increase the production of shale gas.[49] On the opposing side, groups with far less political influence and ties, such as the fenceline communities, who most directly suffer from the toxic consequences of petrochemical production,[99] challenge dominant actors from a marginalized position, sustaining environmental injustices.[100,101]

Behavioral lock-in

Plastics permeate ways of living in the industrialized world: from the packaging around the food and products consumed to the electronics used, the vehicles and infrastructure relied on, and the garments worn. Identifying new applications and creating demand for plastics across practically all domains of consumption was a focused effort of the petrochemical and plastics industries in the late 20th century.[102] Plastics have rapidly diffused into the value chains of all types of products to the degree that they are almost impossible to even trace in trade statistics beyond trade in specific categories of plastic resins and homogeneous products.[103] Through aggressive marketing, customers have been taught to associate plastics with hygiene[104] and freshness[105] and adopt new patterns of consumption made possible by an extensive use of single-use plastics and plastic packaging. In the current era of corporate sustainability communication, petrochemical firms strategically emphasize plastics and other petrochemicals as necessary for the energy transition and other sustainability-related purposes, invoking discourses of delay to fend off against criticisms.[18,23]

The use of plastics is, like most forms of consumption, closely related to affluence. The consumption of plastics thus varies significantly between countries and regions with much higher consumption in richer countries, as shown in Figure 3. While the consumption of plastics is only 16 kg/cap in sub-Saharan Africa it is more than 15 times higher in the US where consumption is 255 kg/cap, according to data from the OECD.[5] Consumption in China, non-OECD Eurasia, and Latin America is closer to the global average, which is about 60 kg/cap. Given relatively low current levels of plastic consumption, global plastic demand would expand considerably, if middle- and low-income countries are to reach consumption levels in the Global North. A similar pattern is evident for plastic waste generation, which closely follows overall consumption patterns. This happens even though lots of long-lived plastics are used for modern infrastructure and buildings, as plastic waste generation is dominated by short-lived products such as packaging and single-use items.[106]

Behavioral norms, practices, and lifestyles that support, enable, and perpetuate very high consumption of plastics proliferate in the Global North.[44] In high-consuming regions, populations have arguably become accustomed to lifestyles built on the disposability of cheap plastic products—from low-cost synthetic clothes and consumer products to packaging and single-use plastics that are used only once before being thrown away. At the same time, systems to properly deal with the generated waste have not been put in place.[107] Although different forms of recycling schemes have been implemented, these have focused on collecting plastic for recycling, primarily plastic packaging, without ensuring that the plastic waste would or even could ever be recycled. For other types of waste that contain large volumes of plastics, such as electronics and apparel, plastic waste has until recently not even been properly considered in extended producer responsibility schemes and other policy instruments.[108] The plastic waste has thus continued to be

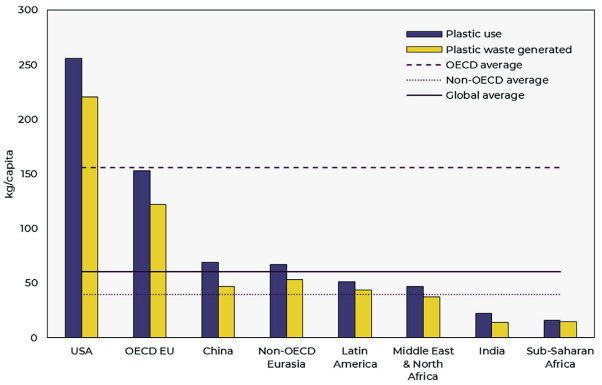

Figure 3. Plastics use and plastic waste generation in 2019 in selected countries and regions
Source: OECD Global Plastics Outlook database.[5]

landfilled, with the risk of toxic additives leaching, incinerated (with high associated GHG emissions), or exported to countries in the Global South already struggling to deal with the plastic waste generated domestically.[109]

NAVIGATING THE POLITICAL ECONOMY OF PETROCHEMICALS

Undoing carbon lock-in and reducing the production and use of plastics and other petrochemicals entail critical issues of what synthetic materials are essential, in what volumes, and how these materials should be distributed. In the following section, we therefore sketch out strategies for potential next steps on a path away from petrochemical plastics, recognizing the political economy in which they will need to be pursued. These steps include adopting ambitious green industrial policies, eliminating subsidies and financial support for investments in fossil fuel-based chemicals and plastics, devising a stronger framework for international governance of the petrochemical industry, and supporting marginalized actors through coalition-building and empowering social movements.

Beyond fossil revenue through green industrial policy

From the perspective of producers of petrochemicals, the growing pressure to move away from petrochemical plastics confronts them with the choice of which political and business strategy to follow: to resist, hedge against or pursue transformative action.[110] These strategies can be followed simultaneously in different dimensions (political, economic) and across geographies.[110,111] As such, engagement by industrial actors in promising projects (e.g., exploring electrification or developing products designed for circularity) does not guarantee pro-climate behavior elsewhere and vice-versa. From the perspective of (state) owners of petrochemical assets, pursuing a path away from petrochemical plastics can ultimately be done by either divesting, redirecting or phasing out carbon-intensive capital.[52] For petrochemicals, divestment means selling off existing and cash-flow positive investments; redirection implies channeling carbon investments into low-carbon production instead (re-investing the capital from divestment), possibly re-purposing existing capital where applicable; and phase-out includes abandoning all re-investments and retiring existing assets, thereby breaking with the logic that plants are never retired once they have been built. In practice, these strategies can be pursued in tandem but differ in effectiveness and feasibility.[52] While divestment may be more achievable when states have smaller shares in carbon assets, the assets that are divested are likely to be purchased by entities that prioritize exploiting them without regard for their climate consequences. Therefore, divestment is not immediately effective on its own.[50,52] Recent research has identified phasing-out as the most impactful strategy for states with stakes in the petrochemical industry if the aim is to lower emissions[52]. However, this strategy seems in many cases to be the least likely option for owners of carbon capital because it involves giving up on revenue and returns on investments,[112] as well as a near-term diversification strategy.

A range of arguments related to urgency, uncertainty, and the ambition to not only reduce but eliminate emissions supports an interventionist approach to climate policy,[113–117] including comprehensive green industrial policy frameworks and strong state interventions that provide clear directionality.[118–121] For the petrochemical industry, the need for directionality, i.e., dedicated interventions that shape the direction of socio-technical transitions,[122] is particularly urgent given the systemic and interwoven nature of the plastic and climate crises. Beyond directionality, a green industrial policy framework must include support for knowledge creation and innovation, carrots and sticks for creating and reshaping markets, efforts to build government capacity for governance and change, attention to international coherence, and sensitivity to socio-economic implications of phase-outs.[118] Efforts to scale up production of new polymers designed to be non-toxic, recyclable, and based on renewable or fully circular sources of carbon[123] illustrates the need for a coherent industrial policy, as it requires both technologically focused support as well as an instruments that push fossil alternatives out of the market, either through direct bans or more market-oriented instruments. More broadly, interventions need to facilitate the immediate and full abatement of emissions of the most powerful GHGs and toxins from plastics productions as well as a moratorium on all plans for expanding the most emissions-intensive routes for plastic production, particularly coal-based routes. Common and stringent international standards for the carbon content of petrochemicals and plastics, as is being attempted for key industrial materials such as steel, iron, and cement,[124] could be important to a fair green transition away from petrochemical plastics.

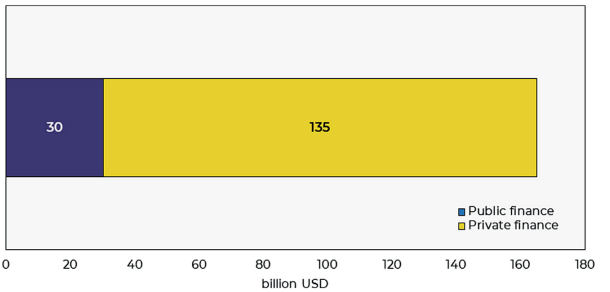

Figure 4. Capital expenditure in large projects (>1bn US$) for plastic production from 2010 to 2020

Private capital accounted for the majority of the funding (134.8 bn US$) while almost a fifth (30.3 bn US$) originated from public financial institutions, together totaling more than 165 bn US$. Based on Skovgaard et al.,[28] data from IJ Global.

If green industrial policy successfully reshapes existing market conditions and establishes security around investments needed for a near-zero chemical industry, it can make resistance ineffective as a business and political strategy. In such an environment, short-term gains through lobbying against regulatory interventions are not as attractive, given that measures that demand serious change have already been put in place. Green industrial policies also strengthens the companies benefitting from environmental regulation, and consequently enhances their lobbying power to act as a counterweight to the anti-regulation lobbying from incumbents.[125,126] Although it is critical to challenge the distribution of benefits and the opportunities for profitable investments (i.e., rents) associated with green industrial policy,[127,128] such strategies represent a vision that goes beyond phase-out and in this sense offers a hopeful path away from petrochemical plastics.

Ending financial flows to expansion of petrochemical plastics

The expansion of petrochemical plastics production capacity over the last decade has been underpinned by a continuation of the financing of large-scale projects (see Figure 4). As such, it is necessary to address and redirect capital flows supporting this expansion. Currently, international and national public financing play important roles in financing the expansion of petrochemicals production, including by leveraging, de-risking or crowding in private finance for large-scale projects. For example, the Sadara petrochemical complex in Saudi Arabia obtained more than $6.5 billion in direct financial support from national and international public financial institutions, including the US Export-Import Bank, leveraging private finance.[28] An important action would therefore be to end all public finance for petrochemical infrastructures that do not align with a low-carbon reorientation of the industry. Public financial institutions are generally well-suited for low-carbon projects as they tend to be less profit-driven and operate with longer time horizons than private finance.[28] However, given institutional lock-in and how domestic public finance is often tied up with national fossil fuel and petrochemical interests, international public finance may play a more catalytic role in driving transformation. To the extent that international public financial institutions are independent of revenues and returns from fossil-based operations, they are not directly bound by material interests that work against established global climate goals.

Breaking the ties between public financial institutions and fossil fuel and petrochemical interests will be essential for undoing the petrochemical lock-in. Due to the strength of institutional lock-in, however, this will not be an easy task. Global fossil fuel subsidies are at roughly the same levels today as immediately after the 2009 G20 commitment to reform such subsidies, despite several other international institutions such as the Sustainable Development Goals having included similar commitments.[129–131] And in the context of climate finance, high-income countries still do not live up to their commitments to provide climate finance agreed in the context of the United Nations Framework Convention on Climate Change (UNFCCC).[132] For petrochemicals, more precise commitments than those concerned with fossil fuel subsidies are probably necessary along with improved monitoring and enforcement of existing safeguards set up to ensure the environmental integrity of international public finance such as export credits and development assistance. Existing commitments regarding public finance for fossil fuels, such as the commitment of 39 public actors adopted in the context of the 26th UN Climate Change Conference of the Parties[133] to end public finance for unabated fossil fuel energy could be strengthened to also include commitments and provisions on petrochemical finance. Strengthened international commitments to end fossil fuel subsidies will in itself impact the economics of petrochemicals to the extent that subsidies for fossil fuel extraction diffuse through the value chain and lower the downstream costs for fuels used in petrochemical production (especially as petrochemical infrastructures are often placed close to fossil fuel extraction sites). For commitments to end public finance for petrochemicals and fossil fuels to deliver real outcomes, however, nations must be held accountable to their commitments, breaking with the tendency of previous international declarations.

Stronger international governance

For actors to abide by international commitments such as those related to finance described above, stronger international governance is needed. Counteracting institutional lock-ins and enabling transformative change of the petrochemical industry on a global scale, demands stronger global governance in both environmental and economic dimensions.[18,76] At present, the ongoing negotiations for a global plastics treaty offers a critical opportunity to strengthen international governance of petrochemicals and has the potential to disrupt lock-ins by addressing primary plastics production concretely and ambitiously through legally binding obligations (see Box 2).

Box 2. The Global Plastics Treaty

In 2022, the United Nations Environment Assembly adopted a resolution to launch negotiations for an international legally binding instrument to end plastic pollution.[134] The resolution follows broad recognition that existing governance frameworks have failed to address the mounting plastics crisis.[135] As governments engage in negotiations for a new instrument to comprehensively address the issue of plastic pollution throughout the full life cycle of plastics, there are growing calls for the treaty to include controls on the production of primary plastics as well as harmful additives used in plastics.[53] A key question is if the treaty will include legally binding controls, which could include measures to restrict or ban not only certain problematic, harmful, or unnecessary plastic products but also the primary plastics from which products are developed. In terms of the linkages between plastics and petrochemicals, the treaty also provides an opportunity to address hazardous and harmful chemicals found in plastics in the form of additives, processing aids, and non-intentionally added substances[136] that restrict the potential for increasing circularity of plastics and are harmful to the environment and public health.[137]

The nature of the legally binding commitments that the treaty could include is the subject of ongoing negotiations. While some countries favor an approach modeled on the Paris Agreement with nationally determined contributions to an overarching target,[138] the High Ambition Coalition on Plastic Pollution, gathering more than 50 countries, has emphasized the need for ambitious legally binding commitments. Notably, the co-chairs of the High Ambition Coalition (Norway and Rwanda), have called for obligations in the treaty to increase transparency and reporting on plastic and chemicals production, to reduce the production and trade of primary plastic polymers, and to eliminate specific polymers, chemicals, and plastic of special concern. Such measures could potentially provide a way to address exports and imports even from countries that do not become parties to the convention to ensure that countries that do not wish to reduce potentially listed polymers, chemicals, and plastic products are nonetheless constrained by the treaty. If efforts to include such provisions are successful, the global plastics treaty could provide a legally binding framework that could help to tackle lock-ins in ways that address both the plastics and climate crises. In so doing, there will be a need to consider how to integrate the principle of *common but differentiated responsibilities and respective capabilities* that underpins many international environmental agreements in the context of legally binding international commitments.[139] Meanwhile, actors with interests in the plastic and petrochemical industries continue to promote positions that limit the ambition of the treaty. Submissions to the treaty process from some governments and industry stakeholders, for example, call for a treaty focused primarily on plastic waste and voluntary actions.[140–143] Through the question of whether to directly address the petrochemical sector, the treaty process has thus become a central site of contestation over the possibility of tackling the plastics and climate crises in tandem.

Meanwhile, and subsequent to the plastics treaty negotiations, global petrochemical governance will continue to have many parts and require a range of different international actors to drive systems change. For instance, to manage and regulate trade in primary plastics, the World Customs Organization will have a role to play in ensuring that governments can properly identify and monitor primary plastics at the border.[144] The International Maritime Organization has a role to play in better regulating the transportation of primary plastics to prevent spillages and losses. At the World Trade Organization, 76 members are engaged in the ongoing Dialogue on Plastics Pollution, governments can provide concrete guidance and build cooperation on trade-related measures that countries can take to regulate trade in primary plastics and contribute to the implementation of the eventual obligations under the global plastics treaty.[145] The need for stronger governance is also recognized in international fora such as the OECD, which outlines the potential for strong global action in one of their scenarios.[13]

Given the strength of lock-ins and the resources of dominant actors, strong global action will not come about without contestation. Industrial actors with interests in petrochemical growth enjoy an advantageous position in international environmental governance[146] and moving away from petrochemical plastics requires challenging not only the fossil fuel dependence of the industry but also the fossil fuel energy order. Breaking lock-in therefore also demands new types of interventions. For example, a Fossil Fuel Non-Proliferation Treaty[29,147] could help structure managed decline of fossil fuel extraction with global justice as a central pillar.[148] Including conventional petrochemical production as part of the scope of such a treaty (e.g., by categorizing such clusters as fossil infrastructure) could help structure the phase-out of long-standing assets in coming decades. To counteract the resistance of major producers, the treaty could be formed as a club arrangement covering particular sources of fossil fuels, and which then expands over time, building momentum and pressure for a multilateral agreement.[149]

Civil society pressures

Transformations to existing systems can emerge from movements struggling for change through ongoing resistance, campaigning, and building alternatives—or reactively when confronted with tangible crisis.[150] Given the power of industrial actors and the privileged position of fossil and petrochemical interests, progressive change relies upon networks of countermovements gaining influence by mobilizing and coordinating various forms of power.[49] In the context of global governance, social movements can play a critical role through a variety of strategies such as influencing the global policy agenda and building narratives around root causes and specific lines of action.[151] Examples of this include the "#turnoffthetap"[54] campaign and the Break Free From Plastics movement's calls to move beyond a focus on plastics waste management and recycling.[152] Other campaigns have focused on facilitating actors through "naming and shaming" banks financing the expansion of petrochemical plastics or exposing financial risks associated with investing in plastics.[153–155] Civil society groups are also

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Figure 5. The path away from petrochemical plastics
Undoing carbon lock-ins and transitioning away from petrochemicals will require policy action at different levels, redirecting financial flows, strengthening governance, and civil engagement and pressure.

using litigation as part of their strategy to steer governments away from the dominant voice of incumbents and to disrupt the status quo. For example, ClientEarth has with 13 civil society organisations pursued legal action to block INEOS' plans to invest 3€ billion in ethylene production in Antwerp, Belgium.[156] Such litigation, although requiring significant legal expertise, innovation, and resources, has the potential to influence developments well beyond specific cases.[157]

To induce progressive change, environmental justice activism from "below" can be effective, with several such examples from around the world.[158] Participatory citizen science and "bearing witness through embodied experience"[158] highlight toxically exposed citizens as active political actors,[159] and concerns about the consequences for health and environmental racism are mobilized in the efforts to stop petrochemical expansion.[160,161] The existence of toxic pollution, however, is no guarantee that data and stories about such pollution from impacted communities "count."[100] Social movements cannot easily match the political access and influence of incumbents and the demands of civil society actors run the risk of being watered down or co-opted. Building coalitions for progressive change and support that empowers social movements is therefore critical to make visible the consequences of petrochemical plastics as well as the lobbying efforts of incumbents, and thereby challenge existing lock-ins. For example, the "Beyond Petrochemicals" campaign backed by Bloomberg Philanthropies is explicitly targeting the expansion of petrochemical plastics in the United States.[162] This campaign focuses specifically on the inequitable toxic impacts on low-income and marginalized communities, i.e., the environmental injustices, which petrochemical expansion exacerbates. Concerns about environmental injustices are also a key reason that groups like Break Free from Plastics and the International Pollutants Elimination Network have engaged in global campaigns on plastics and highlight reputational risks for investments in petrochemical plastics. Narratives focusing on the localized impacts have strong emotive power and help illustrate that visions around petrochemical transitions must go beyond job replacement and speak to wider themes of well-being and participation in a holistic understanding of prosperity.[163]

TOWARD A FUTURE BEYOND PETROCHEMICAL LOCK-IN

Plastics are locked into the fossil fuel dependence of the petrochemical industry, resulting in large emissions of GHGs, other pollutants, and toxins in primary production as well as throughout the life cycle of plastics. A path toward more sustainable value chains and life cycles must be built on both short-term and long-term interventions addressing the production of petrochemical plastics in line with the elements highlighted in the previous section (summarized in Figure 5).

Recent policy initiatives aiming to include energy and emissions-intensive industries in the energy transition, such as the Inflation Reduction Act in the USA and the Net-Zero Industry Act in the EU, signal the potential for large-scale green industrial policy and investments in low- and zero-emission technologies and production processes. So far, however, limited funds have been directed toward incentivizing transformation in the petrochemical and plastics industries. Moreover, initiatives focusing on domestic industry in high-income countries do not address the need for support for transformation in middle- and low-income countries, epitomized by the failure of high-income countries to fulfill climate finance commitments. Taking seriously the need to invest in transformation away from petrochemical plastics on a global scale will require a concerted effort engaging various actors in the financial system including central banks, multilateral development banks, and export credit agencies.

Notwithstanding various efforts to challenge the expansion of fossil-based chemicals, the global plastics treaty has the potential to become a crucial step toward undoing the carbon lock-ins that support the proliferation of petrochemical plastics. To do so, the treaty would need to live up to its declared ambition of addressing the full plastic life cycle, addressing upstream aspects from fossil fuel extraction to petrochemical production, reducing primary plastics production and eliminating harmful plastics and associated chemicals of concern. In this way, the treaty could counteract the fragmentation in the global governance of the petroleum-chemicals-plastic-nexus. Avoiding questions of scale and the supply-side dynamics of petrochemical plastics would leave intact political and economic structures that catalyzed and sustain the plastic crisis, allowing actors with vested interests to stay in the driver's seat. Instead, we must address the carbon lock-ins supported and upheld by the political economy of petrochemicals head-on.

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AUTHOR CONTRIBUTIONS

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DECLARATION OF INTERESTS

The authors declare no competing interests.

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